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Comparative Analysis of The Efficiency of Hybrid and Non-Hybrid Cars: Effect of Weight, Torque and Price

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Abstract--*Fuel serves as the primary energy source for motor vehicles, enabling them to move. Although it has been the primary energy source for several centuries, Fuel has led to various environmental issues. One of its negative impacts is that, when burned, Fuel produces carbon dioxide (CO2), a significant contributor to global climate change. Currently, this petroleum-based energy is facing a crisis. Hybrid vehicles present a solution to address this petroleum energy crisis. Recently, hybrid cars have become popular in the modern automotive industry due to their numerous advantages, especially fuel efficiency and emissions. Hybrid vehicle technology combines conventional engine technology that uses Fuel with electric motor technology. This study provides a comprehensive comparative analysis between hybrid and non-hybrid cars, focusing on fuel efficiency, vehicle weight, torque, and price parameters. The aim is to assess the economic feasibility of hybrid vehicles compared to non-hybrid cars. The methodology used is a quantitative comparative study of several hybrid and non-hybrid car models within the same class. Performance data were systematically collected from reliable sources and analyzed under standard conditions, covering various price segments ranging from 600 million to 1.6 billion rupiahs. Statistical analysis was conducted to compare fuel efficiency, torque, and vehicle weight between the two types of cars and evaluate the economic implications of these differences. The study results indicate that hybrid cars achieve significantly higher fuel efficiency, averaging 18–22 km/l, compared to 10–14 km/l for non-hybrid models ($p < 0.05$). This efficiency increase persists despite increasing torque and vehicle weight, demonstrating that hybrid technology improves performance without sacrificing efficiency. Additionally, cost analysis suggests that although the initial price of hybrid cars is higher, fuel savings can offset the price difference in the long term. This research is expected to serve as a reference for consumers considering cost and energy efficiency when choosing hybrid and non-hybrid cars.*

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1. INTRODUCTION

Fuel is an energy resource greatly needed today, especially petroleum-based fuels [1]. In the transportation sector, the availability of fuel is crucial, as almost 100% of vehicles in Indonesia are powered by energy from fuel (diesel, gasoline, and premium fuel) [2]. Over the past five years, the average annual energy consumption has been 7%, much above the 2.6% global yearly increase rate. Nearly 95% of Indonesia's energy consumption is fulfilled by fossil fuels, with fuel accounting for 50%. [3]. BBM-powered vehicles have become the most significant contributor to air pollution in major Indonesian cities, as their numbers continue to increase significantly yearly [4]. In DKI Jakarta, vehicle emissions contribute around 70% of air pollutants [5]. Systematic, planned, and integrated energy conservation efforts are necessary to increase energy use efficiency, serving as a strategic reserve to meet national energy needs [6].

Related to the above issue, one of the measures that can be taken to reduce the depletion of energy reserves and decrease air pollution is through hybrid vehicle technology [7]. A hybrid vehicle combines an internal combustion engine and an electric motor [8, 9, 10]. A hybrid car uses two types of technologies as its power sources. While conventional vehicles typically rely solely on gasoline engines, hybrid cars have an additional power source: an electric motor powered by a battery. The petrol engine is the primary power source; this one is not used directly; instead, depending on the circumstances, the electric motor from the battery acts as a backup energy source [11, 12]. Hybrid cars are relatively efficient in terms of fuel, increasing their fuel efficiency [13]. Regarding comfort, hybrid vehicles have low vibration and noise levels [14]. Hybrid vehicle technology can serve as a transitional technology before fully electric vehicles, allowing consumers/society to adapt to the electrification of motor vehicles [15].

The gasoline engine and electric motor have distinct characteristics that complement or entirely replace each other. The gasoline engine has low efficiency and high efficiency at high speeds. In contrast, the electric motor has higher efficiency at lower speeds. Conventional vehicles operate at low speeds in traffic jams, significantly increasing fuel efficiency [16]. The gasoline engine in hybrid cars is similar to that of most modern vehicles. However, it is smaller and uses advanced technology to reduce emissions and improve fuel efficiency [17]. This innovation has received positive responses from various groups, including environmentalists, who believe that hybrid vehicles will help reduce pollution from vehicle emissions. Hybrid vehicles can also save fuel by approximately 10%-20% [18]. Hybrid cars show better energy efficiency in urban driving cycles than conventional cars and fuel-cell vehicles [19].

Hybrid cars can reduce greenhouse gas by 60 to 103 g CO_2 per km, compared to 156-163 g CO_2 per km for conventional diesel and gasoline cars [20]. Compared to traditional cars, hybrid vehicles show a notable decrease in CO_2 emissions [21]. Hybrid cars also show a noteworthy reduction in NO_x emissions, mainly due to reduced engine load and less fuel enrichment [22]. By besting energy utilization from the engine and battery, modern energy management techniques, including Dynamic Programming (DP), Fuzzy Logic, and Reinforcement Learning (RL), can improve fuel efficiency and lower emissions [23].

Hybrid and conventional cars significantly differ in torque generated during driving. Hybrid vehicles can fill the “torque hole” during gear shifts by using the electric motor to provide additional torque when the main engine is inactive during shifts, enhancing vehicle smoothness and performance [24][25]. Specific hybrid systems, such as those using hybrid automated manual transmissions (HAMT), are designed to offer higher torque capacity than conventional transmissions. This allows hybrid cars to address torque voids often occurring with traditional transmissions, improving drivability and performance [26]. Hybrid vehicles with dual or multiple planetary gear configurations show significant improvements in acceleration performance compared to conventional cars, which is especially beneficial for vehicles like SUVs, Light trucks, and buses that require high torque for rapid acceleration [27]. In hybrid vehicles, improved power distribution and energy management enable higher torque performance, particularly in heavy vehicles. The hybrid system can increase peak power and reduce vehicle weight, enhancing acceleration performance and climbing ability [28].

This study offers a comparison of hybrid and non-hybrid vehicles to evaluate their respective fuel efficiency, weight, torque, and cost in terms of Focusing on the price category of IDR 600 million to IDR 1.6 billion; the research approach applied is a quantitative comparison study gathering performance data from reliable sources and examines it under standard settings. The findings of this study should give consumers thorough knowledge of weighing cost and energy efficiency in vehicle choice.

2. RESEARCH METHODOLOGY

The following are the methodology or steps in data processing and the methodology that can be used in a Comparative Analysis of Hybrid and Non-Hybrid Car Efficiency: The Impact of Weight, Torque, and Price.

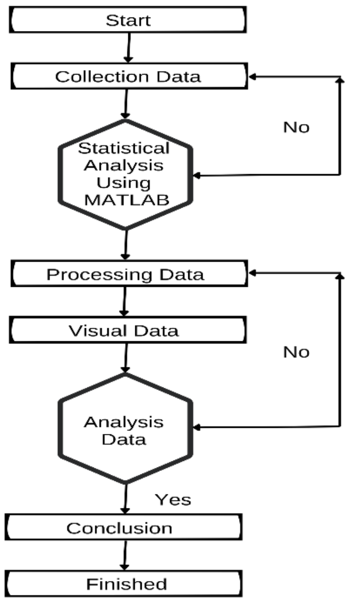

Figure 1. Research Process Flow

1. Start:

The study project aims to compare non-hybrid and hybrid vehicles with respect to efficiency criteria.

2. Collection Data:

Collect relevant data for hybrid and non-hybrid cars, focusing on weight, torque, and price variables. Sources may include car manufacturers' specifications, market reports, and fuel efficiency ratings.

3. Statistical Analysis Using MATLAB:

Perform MATLAB statistical analyses to explore correlations and impacts of the selected variables (weight, torque, and price) on car efficiency. Tools like regression analysis, ANOVA, or other comparative metrics may be applied here.

4. Processing Data:

Process the collected and analyzed data to structure it in formats suitable for further interpretation. This could include normalization, filtering outliers, or calculating weighted averages.

5. Visual Data:

Represent the processed data through visualizations like bar charts, scatter plots, or line graphs to identify patterns and differences in the efficiency of hybrid versus non-hybrid cars.

6. Analysis Data:

Evaluate the visualized data critically to understand the chosen variables' relative efficiencies and role. Assess whether weight, torque, and price influence a significant differential impact on hybrid versus non-hybrid cars.

7. Conclusion:

Draw conclusions based on data analysis to determine the efficiency comparison. Provide insights into how each variable (weight, torque, and price) affects the efficiency and the overall performance of hybrid and non-hybrid cars.

8. Finished:

Conclude the research process with a comprehensive report, including findings, discussions, and recommendations for stakeholders or policymakers.

3. RESULTS AND DISCUSSION

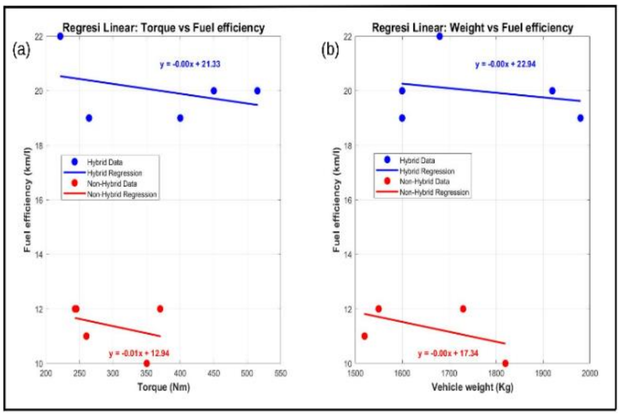

Figure 2. Linear Regression Analysis. (a) Torque (Nm) vs Fuel Efficiency (km/l). (b) Weight (kg) vs Fuel Efficiency (km/l)

Figure 2 illustrates the linear regression analysis of torque and vehicle weight against fuel efficiency for both hybrid and non-hybrid cars, providing insights into how these parameters influence fuel efficiency.

(a). Torque vs Fuel Efficiency:

In **Figure 2(a)**, The regression lines represent the relationship between torque (Nm) and fuel efficiency (km/l) for hybrid (blue line) and non-hybrid (red line) vehicles. The regression equation for hybrid cars is y = -0.01x + 21.33, indicating a slight negative slope. As torque increases, fuel efficiency marginally decreases for hybrid vehicles. The gentle slope reflects the efficiency of hybrid technology in maintaining fuel efficiency even at higher torque levels, likely due to the assistance of electric motors that reduce the reliance on internal combustion engines at lower efficiency ranges [29][30].

Vehicles maintain a higher overall efficiency due to their advanced powertrain technologies [31].

(b). Weight vs. Fuel Efficiency:

Figure 2(b) Displays the relationship between vehicle weight (kg) and fuel efficiency (km/l). The regression equation for hybrid vehicles is y = -0.01x + 22.4, indicating a negative correlation between weight and fuel efficiency. This negative slope implies that heavier hybrid cars tend to have lower fuel efficiency, although the decrease is gradual. Hybrid vehicles often incorporate regenerative braking and efficient energy management systems, which help mitigate the adverse effects of additional weight on fuel efficiency [32].

Similarly, the regression equation for non-hybrid cars is y = -0.01x + 17.34, demonstrating a negative trend with a lower intercept. This pattern suggests that non-hybrid vehicles not only start with lower fuel efficiency but also experience a comparable rate of efficiency decline as weight increases. The higher intercept for hybrids indicates an inherent advantage in fuel efficiency across various weight classes [33].

The analysis reveals that torque and weight negatively impact fuel efficiency in hybrid and non-hybrid vehicles. However, hybrid cars consistently exhibit higher intercepts in the regression equations, indicating superior base fuel efficiency. The similar slopes (-0.01) suggest that the rate at which fuel efficiency decreases with increasing torque or weight is comparable between the two vehicle types. This may indicate that while hybrid technology provides a significant efficiency advantage, the marginal impact of torque and weight on fuel efficiency is similar for both hybrids and non-hybrids.

These findings align with general automotive research indicating that hybrid vehicles achieve better fuel efficiency due to their ability to utilize electric propulsion alongside traditional engines, effectively reducing fuel efficiency, especially in situations that demand high torque or involve heavier vehicles [34][35]. The ability of hybrids to recover energy through regenerative braking and operate more efficiently at various loads contributes to their enhanced fuel efficiency compared to non-hybrid counterparts.

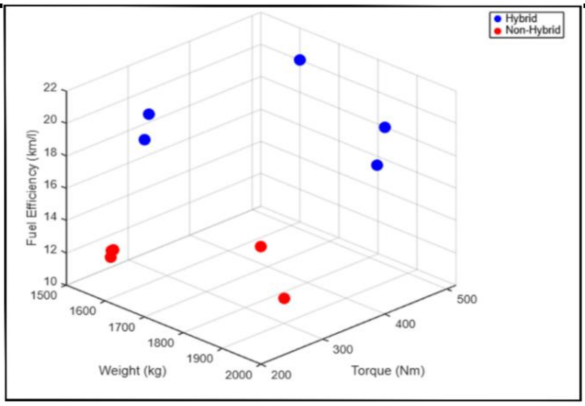

Figure 3. 3D Scatter Plot Analysis Of The Relationship Between Vehicle Weight, Torque, And Fuel Efficiency In Km/l For Two Types Of Vehicles, Namely Hybrid And Non-Hybrid**.**

Figure 3 Presents a 3D scatter plot that visualizes the relationship between vehicle weight (kg), torque (Nm), and fuel efficiency (km/l) for both hybrid (blue) and non-hybrid (red) vehicles. This representation provides a comprehensive view of how these three parameters interact simultaneously.

The blue data points, representing hybrid vehicles, are distinctly separated from the red data points (non-hybrid vehicles) in terms of fuel efficiency. Hybrid vehicles consistently exhibit higher fuel efficiency, ranging from 18 to 22 km/l, even as vehicle weight and torque vary. This suggests that hybrid technology effectively manages the trade-offs between power and efficiency. Notably, some hybrid models achieve high efficiency despite higher torque values, reflecting electric motor assistance's benefits that boost performance without sacrificing fuel efficiency.

In contrast, the red data points for non-hybrid vehicles are clustered at lower fuel efficiency levels, generally between 10 and 14 km/l. As weight and torque increase, the fuel efficiency of non-hybrid cars decreases more rapidly compared to hybrids. The scatter plot clearly illustrates that non-hybrid vehicles are more adversely affected by increases in weight and torque, which directly impacts their overall performance and fuel efficiency.

The 3D scatter plot effectively highlights the advantage of hybrid vehicles in balancing performance and fuel efficiency. The spatial distribution of the data points indicates that while both vehicle types experience some efficiency loss with increasing weight and torque, hybrid models are significantly more efficient. This efficiency is crucial in urban and mixed driving conditions, where frequent acceleration and varying loads demand a system capable of optimizing energy usage.

The visual representation in Figure 3 also emphasizes the engineering challenges for non-hybrid vehicles. With electric motor assistance, these vehicles can maintain efficiency as power demands increase. The clustering of red data points at lower efficiency levels reinforces the need for advancements in conventional vehicle technology or a transition to more energy-efficient systems like hybrids.

Figure 3 presents a 3D scatter plot illustrating the relationship between vehicle weight (kg), torque (Nm), and fuel efficiency (km/l) for both hybrid (blue points) and non-hybrid (red points) vehicles. This visualization provides a comprehensive view of how these three parameters interact simultaneously, highlighting the performance differences between hybrid and non-hybrid technologies.

The blue data points representing hybrid vehicles are distinctly positioned at higher fuel efficiency levels compared to the red data points of non-hybrid cars. Hybrid vehicles consistently exhibit fuel efficiency ranging from 18 to 22 km/l, even as vehicle weight and torque vary.

This trend suggests that hybrid technology effectively manages the trade-offs between power and efficiency. The ability of hybrid models to maintain efficiency despite higher torque values underscores the benefits of electric motor assistance, which provides additional torque without significantly increasing fuel efficiency [36][37].

In contrast, the red data points for non-hybrid vehicles cluster at lower fuel efficiency levels, generally between 10 and 14 km/l. As vehicle weight and torque increase, the fuel efficiency of non-hybrid cars decreases more rapidly than that of hybrids. This observation indicates that non-hybrid vehicles are more adversely affected by increases in weight and torque, directly impacting their overall performance and fuel efficiency [38].

The 3D scatter plot effectively highlights the advantage of hybrid vehicles in balancing performance and fuel efficiency. The spatial distribution of the data points shows that while both vehicle types experience some efficiency loss with increasing weight and torque, hybrid models are significantly more efficient. This efficiency is particularly crucial in urban and mixed driving conditions, where frequent acceleration and varying loads demand a system capable of optimizing energy usage [39].

The visual representation in Figure 3 emphasizes the engineering challenges faced by non-hybrid vehicles. Without electric motor assistance, these vehicles rely solely on internal combustion engines, which are less efficient during conditions requiring frequent acceleration and low speeds [40]. The clustering of red data points at lower efficiency levels reinforces the need for advancements in conventional vehicle technology or a transition to more energy-efficient systems like hybrids.

Hybrid vehicles utilize regenerative braking, electric motor assistance, and advanced energy management systems to optimize fuel efficiency across various operating conditions [41]. These technologies allow hybrids to maintain higher fuel efficiency despite increased vehicle weight and torque demands. The ability to recuperate energy and reduce reliance on the internal combustion engine contributes to the superior fuel efficiency observed in hybrid vehicles [42].

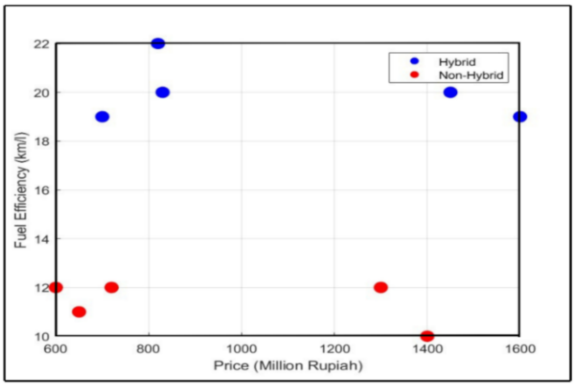

Figure 4. Price Comparison and Fuel Efficiency

Figure 4 Presents a scatter plot illustrating the relationship between vehicle prices (in a million rupiahs) and fuel efficiency (in km/l) for both hybrid (blue points) and non-hybrid (red points) cars. This visualization enables a comparative analysis of how vehicle cost correlates with fuel efficiency across different vehicle technologies.

The blue data points representing hybrid vehicles generally align higher on the fuel efficiency axis than non-hybrid models. Hybrid vehicles maintain fuel efficiencies between 18 and 22 km/l, even at higher price points ranging from approximately 800 to 1,600 million rupiah. This trend suggests that while hybrid cars may come with a premium price, they deliver superior fuel efficiency. The higher initial investment in hybrid technology potentially offers long-term cost savings through reduced fuel efficiency and lower operating costs [43]

Notably, Hybrid options are available at mid-range prices of around 800 million rupiahs that still provide high fuel efficiency. This indicates that consumers do not necessarily have to opt for the most expensive models to benefit from the advantages of hybrid technology. The consistent performance of hybrids across various price points highlights the effectiveness of hybrid systems in enhancing fuel efficiency regardless of the vehicle's cost [44].

The red data points for non-hybrid vehicles predominantly occupy the lower region of the fuel efficiency axis, with values ranging from 10 to 14 km/l. These vehicles are priced between 600 and 1,400 million rupiah, but even at the higher end of this price spectrum, the fuel efficiency does not exceed 14 km/l. This distribution implies that non-hybrid vehicles, despite potentially lower initial purchase prices, provide a different level of fuel savings over time than their hybrid counterparts [45]. The clustering of non-hybrid vehicles at lower fuel efficiency levels suggests that traditional internal combustion engine (ICE) vehicles are less capable of delivering high fuel efficiency, particularly as vehicle prices increase. This may be because more expensive non-hybrid models often include larger engines and additional features that increase weight and reduce efficiency [46].

The plot highlights a clear trade-off between initial investment and long-term fuel efficiency. Although they are usually more costly initially, hybrid cars have a notable fuel efficiency, which, over time, can result in significant savings. Accounting for fuel savings and any tax advantages, studies have indicated that hybrid car ownership costs can be less than those of non-hybrid vehicles [47][48].

Consumers looking to minimize fuel efficiency and benefit from environmental incentives may find hybrid cars a more economically viable option despite the higher initial cost. Furthermore, hybrid cars help lower greenhouse gas emissions, which fit worldwide initiatives to slow global warming [49][50].

Conversely, non-hybrid vehicles may appeal to buyers with budget constraints or those who prioritize lower initial costs. However, the lower fuel efficiency of these models may lead to higher fuel efficiency over time, potentially offsetting the savings made during the purchase. This underscores the importance of considering both initial and ongoing expenses when choosing between hybrid and non-hybrid vehicles [51][52][53].

4. CONCLUSION

The results showed that hybrid vehicles achieved significantly higher fuel efficiency, averaging 18–22 km/l, compared to 10–14 km/l for non-hybrid models ($p < 0.05$). This increase in efficiency persisted despite increases in torque and vehicle weight, indicating that hybrid technology effectively improves performance without sacrificing efficiency. However, the regression equation for non-hybrid vehicles is $y = -0.01x + 17.34$, which shows a negative trend with a lower intercept. This pattern suggests that non-hybrid cars not only have lower fuel efficiency but also experience a comparable rate of decline in efficiency as weight increases, even at the higher price range of around 800 to 1,600 million rupiah. This trend suggests that even though hybrid vehicles have a higher price tag, they provide better fuel efficiency. The higher initial investment in hybrid technology has the potential to provide long-term cost savings through reduced fuel efficiency and lower operating costs.

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