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Analysis of Electric Vehicle Range Using Regression Techniques: A Case Study of Electric Vehicles at the University of Mataram

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ABSTRACT

The development of electric vehicles (EV) represents a strategic approach to reducing carbon emissions and decreasing reliance on fossil fuels. This study analyzes the driving range of electric vehicles at the University of Mataram using regression techniques to examine the relationship between vehicle load, energy consumption, and range efficiency. Field tests were conducted under various vehicle load conditions (120.5 kg, 130.5 kg, and 140.5 kg) and gear ratio variations. A linear regression analysis was applied to determine the influence of independent variables (vehicle load and gear ratio) on the dependent variables (energy consumption and driving range). The results indicate a positive correlation between vehicle load and energy consumption, alongside a negative correlation with driving range. Specifically, at a load of 120.5 kg, energy consumption was recorded at 29.29 Wh/km, achieving a maximum range efficiency of 82.82 km per kWh. In contrast, at 140.5 kg, energy consumption increased to 44.00 Wh/km, while range efficiency declined to 54.56 km per kWh. Additionally, gear ratio variations significantly affected vehicle performance, with a gear ratio of 10.29 yielding the highest range efficiency of 112.55 km per kWh, whereas a gear ratio of 6.43 exhibited lower efficiency. These findings emphasize the critical role of vehicle load management and optimal gear ratio selection in enhancing energy efficiency. The study provides valuable insights for the design and development of more efficient and sustainable electric vehicles, contributing to advancements in EV technology.

Keywords: Electric vehicles, Energy consumption, Electric vehicles load, Energy efficiency of electrical vehicle, Gear ratio.

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1. Introduction

The increasing recognition of electric vehicles (EV) as a sustainable transportation option is attributed to their zero-emission capability, which significantly reduces air pollution, particularly in densely populated urban environments [1]. The International Energy Agency (IEA) reports a rapid increase in global EV adoption, with battery electric vehicle (BEV) sales reaching 9.5 million units in 2023, a 30% increase from the previous year, and projected to attain 17 million units by 2024 [2-3]. This trend is evident in Indonesia, where substantial progress in EV development is crucial for future sustainable mobility [4]. Furthermore, EVs play a vital role in mitigating climate change by reducing greenhouse gas emissions, notably carbon dioxide (CO_2) [5]. As the automotive industry transitions towards electrification, enhancing EV performance, particularly in terms of range, has become increasingly critical. Key factors influencing EV efficiency include vehicle weight, battery capacity, transmission systems, and driving conditions, all of which require careful consideration to promote widespread adoption [6-7].

Vehicle weight is a primary determinant of the energy efficiency of electric cars. Research conducted

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by Ermawati et al. demonstrated a clear correlation between the vehicle weight and energy consumption. With a battery capacity of 5664 Wh, the electric car's motor power consumption on flat roads was measured at 148.8 W when unloaded and 206.4 W when loaded. On inclined roads, these values increase to 600 W and 667.2 W for unloaded and loaded conditions, respectively [8]. Speed and usage duration also significantly affect energy consumption. Mara et al's findings indicate that energy consumption increases proportionally with speed increases. Moreover, extended usage periods resulted in higher electrical energy consumption. For instance, the lowest energy consumption of 0.18752 kWh was recorded at a speed of 30 km/h and usage time of 15 min [9].

Vehicle speed, in conjunction with weight, plays a crucial role in determining the EV energy consumption. The correlation between speed and energy usage is complex. Energy consumption tends to be higher at lower-to-moderate speeds [10]. However, as the speed increases, the energy usage also increases owing to the heightened aerodynamic and rolling resistance [11]. This effect is particularly evident in urban driving scenarios where frequent stops and starts can lead to increased energy consumption. Similarly, high-speed highway driving imposes additional strain on the energy system of vehicles [12]. Thus, understanding the influence of speed on energy consumption is vital for enhancing EV performance, particularly under real-world driving conditions with inevitable speed variations. Although the relationship between weight, speed, and energy consumption has been extensively studied, there remains a gap in understanding how the gear ratio affects the energy efficiency of electric vehicles. The primary focus of this study is to examine the relationship between vehicle weight and gear ratio on the energy consumption of the Mandalika Desantara prototype electric vehicle. Furthermore, there is a lack of in-depth research exploring the interaction of these factors with the vehicle travel time under various operating conditions.

This study examined the effects of vehicle weight and gear ratio on energy consumption at the University of Mataram Mandalika Desantara prototype electric vehicle through field testing. It addresses gaps in the existing literature by analyzing their combined impact under various flat track conditions. Unlike previous research that focused on individual factors, this study uniquely investigated the interplay of these variables. The objectives are to identify the relationship between weight and energy consumption, and to analyze how the gear ratio affects travel time and energy consumption. Data gathered from controlled tests demonstrate that optimizing the gear ratio decreases the energy consumption and travel time while influencing the average speed and energy efficiency. These findings provide actionable insights for manufacturers regarding weight management, speed optimization, and gear selection. The distinctive aspect of this research lies in its integrated approach to studying multiple factors concurrently, which contributes to the development of more efficient and sustainable electric vehicles. By addressing a critical gap in the literature, this study offers a framework for optimizing electric vehicle performance through the strategic management of intrinsic factors.

2. Methods

Experiments were conducted with varying loads and gear ratios under standardized conditions to minimize variability that could influence the results. The data generated from the measurements were systematically recorded for subsequent analyses. This data acquisition process is crucial for elucidating the relationship between the vehicle load, energy consumption, energy efficiency, and average speed, thereby enhancing the validity and reliability of the research findings.

2.1. Drive system

The electric motor is mechanically linked to the front sprocket, generating rotational power that is transmitted via the chain drive system to the center and rear sprockets. As shown in Figure 1, this system efficiently transfers power to the rear wheels, enabling vehicle propulsion. The variation in sprocket diameters allows for adjustable transmission ratios, directly influencing the vehicle's speed and torque characteristics. Furthermore, a chain stabilizer mechanism ensures optimal chain tension, minimizing

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slippage and excessive slack, thereby enhancing drivetrain efficiency, durability, and overall operational reliability.

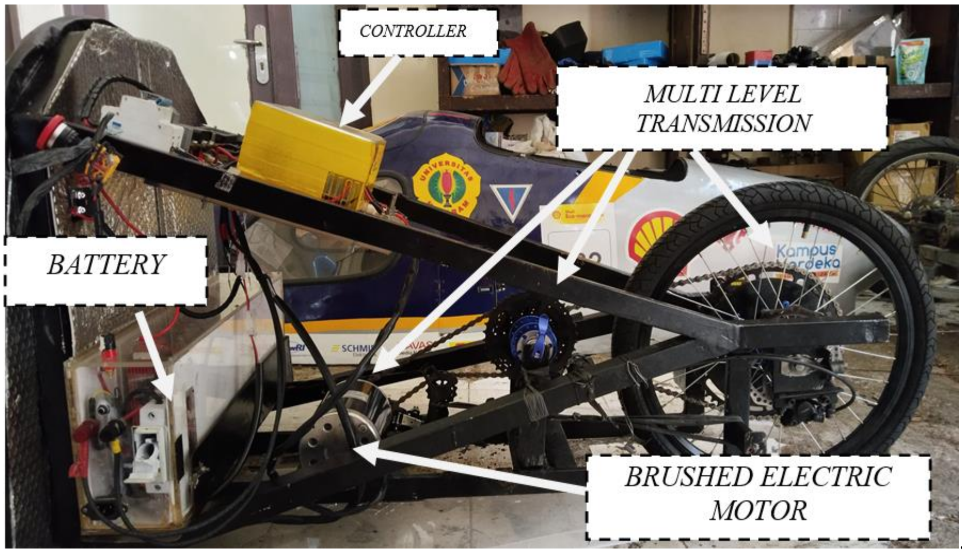

Figure 1. Configuration of the electric vehicle drive system.

2.2. Data collection

Prior to conducting the regression analysis, the researchers collected data on four key variables: vehicle weight (kg), speed (km/h), travel distance (km), and energy consumption (Wh). The primary objective of this data collection was to investigate the impact of gear ratio and load on several electric vehicle performance metrics, including average speed, travel time, energy consumption, and travel distance. The collected data will be utilized to analyze the effects of different gear ratios on vehicle energy efficiency and to identify the optimal gear ratio that minimizes energy consumption while maximizing travel range.

The theoretical basis of Equation (1), which is employed to calculate energy efficiency of electrical vehicle (EV), η (km/kWh), is the fundamental relationship between energy consumption and distance travelled. This relationship has been widely applied in studies focused on the energy consumption in electric vehicles. The equation for energy efficiency is formulated as follows [13, 17]:

$$\eta\ [\mathrm{km/Wh}] = (\text{Trip Distance [km]}/(\text{Net Energy [Wh]} \quad (1)$$

Equation (1) is based on the principle that the vehicle energy efficiency can be quantified by calculating the distance a vehicle can travel per unit of energy consumed. This concept has been extensively utilized in the literature on electric vehicles, as discussed by Larminie and Lowry in the book "Electric Vehicle Technology Explained" [13], and by Ehsani et al. in "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles" [14].

To ensure unit consistency, it is imperative to convert the energy term in the denominator from Wh to kWh, as the left-hand side (LHS) of the equation is expressed in km/kWh. This conversion is essential for maintaining congruence between the units on both sides of the equation. When the original energy data are provided in Wh, they must be divided by 1,000 to convert them into kWh. Consequently, the equation is revised as follows [17]:

$$\eta\ [\mathrm{km/kWh}] = \text{Trip Distance [km]}/(\text{Net Energy [kWh]} \quad (2)$$

This modification ensures that LHS (km/kWh) and RHS (km/kWh) are dimensionally consistent. When formulating such equations independently, it is essential to elucidate the rationale underlying their development and the assumptions made therein. For instance, this equation presupposes that energy consumption is directly proportional to the distance travelled under constant operating conditions, which is a prevalent assumption in vehicle energy efficiency studies [15-17]. The driving rage can be calculated by Equation (3).

$$\text{Driving rage [km]} = \eta \left[\frac{\text{km}}{\text{kWh}}\right] \times \text{Battery Capacity of fully charged EV[kWh]} \quad (3)$$

2.3. Regression analysis

The relationships between the vehicle load, energy consumption, and energy efficiency were analyzed using linear regression. To evaluate the effect of vehicle load on the energy consumption and maximum energy efficiency, a linear regression model was employed, which is expressed as follows:

$$Y = a + b_1 X_1 + b_2 X_2 \quad (4)$$

Furthermore, the data obtained from the electric car testing were used to calculate the mean value of each variable. The least-squares method was applied to determine the regression coefficients a and b. This process allowed the researcher to evaluate the significant relationship between the variables and provide in-depth insight into the energy efficiency of electric vehicles.

3. Results and Discussion

This study examines the impact of gear ratio variations and vehicle load on the performance of the Universitas Mataram electric vehicle, as illustrated in Figure 2. The analysis considers three distinct vehicle loads: 120.5 kg, 130.5 kg, and 140.5 kg. Key parameters such as vehicle load, gear ratio variations, energy efficiency (km/kWh), average speed, energy consumption, and travel time were systematically recorded and analyzed.

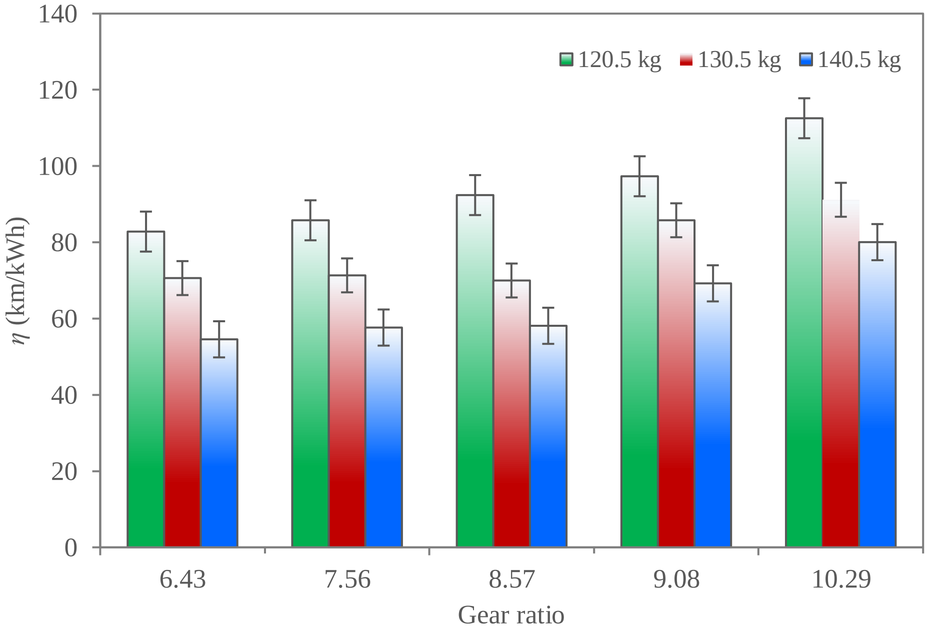

Figure 2. Effect of gear ratio on energy efficiency.

The findings indicate that vehicle load significantly influences energy consumption and average speed. Lighter vehicle loads (e.g., 120.5 kg) demonstrate higher energy efficiency, whereas heavier loads (e.g., 140.5 kg) require greater energy input to achieve the same travel distance. Additionally, variations in gear ratios play a critical role in optimizing energy consumption. Lower gear ratios generally contribute to improved energy efficiency by reducing power losses. The analysis identified an optimal gear ratio for each vehicle load that maximizes energy efficiency. For instance, at a load of 120.5 kg, the highest energy efficiency is achieved at a gear ratio of approximately 8.57. However, as vehicle load increases, energy efficiency decreases, confirming that heavier vehicles consume more energy per kilometer traveled. At a gear ratio of 6.43, the energy efficiency for a 140.5 kg load is significantly lower than that of a 120.5 kg load, reinforcing the inverse relationship between vehicle weight and energy efficiency.

These findings align with previous studies demonstrating that the final drive gear ratio significantly influences energy consumption and vehicle performance [18-19]. Additionally, recent research has confirmed that gear ratio selection plays a critical role in optimizing energy efficiency, particularly under varying load conditions [20-21]. The results of this study highlight the necessity of optimizing gear ratio selection to enhance the energy efficiency of electric vehicles under different load conditions. Furthermore, these insights provide valuable implications for drivetrain optimization in future electric vehicle development, ensuring more sustainable and energy-efficient transportation solutions.

Figure 3 presents a comparative analysis of energy consumption (Wh) as a function of gear ratio variations and total gear stages for three vehicle weight categories: 120.5 kg, 130.5 kg, and 140.5 kg. The analysis reveals an inverse relationship between energy consumption and gear ratio, where a higher gear ratio (10.29) consistently results in lower energy consumption across all weight categories. Specifically, in the 120.5 kg weight category, the maximum energy consumption was recorded at a gear ratio of 6.43, reaching 29.00 Wh, whereas at a gear ratio of 10.29, energy consumption decreased to 21.33 Wh. A similar pattern was observed in the 130.5 kg category, with energy consumption peaking at 34.67 Wh for a gear ratio of 6.43, while the lowest consumption of 26.00 Wh was achieved at a gear ratio of 10.29. Likewise, in the 140.5 kg category, energy consumption followed the same trend, with the highest value of 41.33 Wh at a gear ratio of 6.43 and the lowest value of 30.00 Wh at a gear ratio of 10.29.

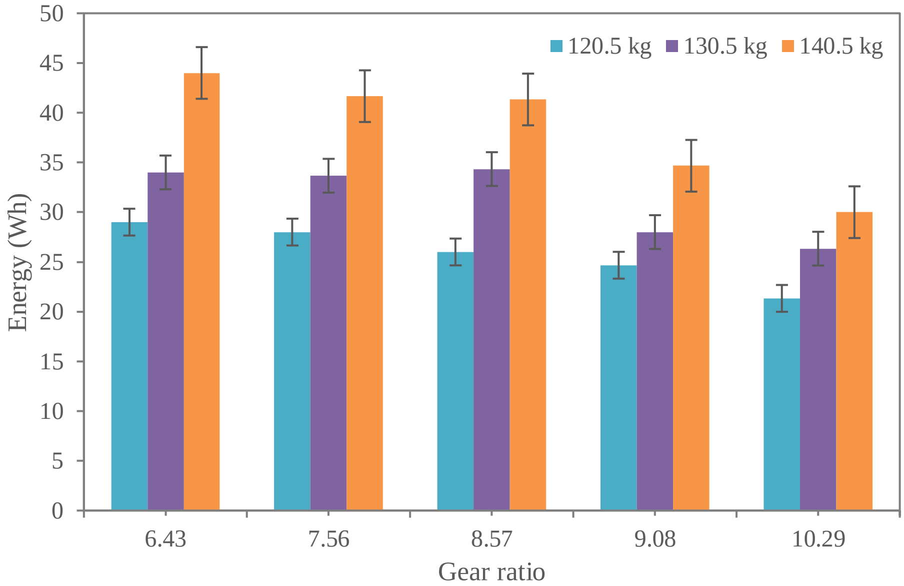

Figure 3. Effect of gear ratio on energy consumption.

These findings indicate that an increase in the gear ratio improves energy efficiency, suggesting that vehicles can optimize their energy utilization through appropriate gear ratio selection. This trend aligns with previous research demonstrating that variations in the final drive gear significantly influence power transmission efficiency; specifically, utilizing a pinion gear with a higher number of teeth enhances energy efficiency [22]. Additionally, other studies have confirmed that selecting an optimal gear ratio not only reduces energy consumption but also improves overall vehicle performance [23-24]. The results of this study provide critical insights into the development of energy-efficient electric vehicles, emphasizing the necessity of optimizing gear ratio selection to maximize operational efficiency across different weight categories. Moreover, these findings underscore the potential for future advancements in electric vehicle drivetrain design, enabling manufacturers to develop more sustainable and energy-efficient transportation solutions.

Figure 4 presents a comparative analysis of average speed (km/h) across different gear ratio configurations and total gear stages for three vehicle weight categories: 120.5 kg, 130.5 kg, and 140.5 kg. The data exhibit a general trend in which higher gear ratios correspond to increased average speeds, with a gear ratio of 10.29 consistently yielding the highest speeds across all weight categories. Specifically, for the 120.5 kg vehicle, the maximum average speed of 18.77 km/h was achieved at a gear ratio of 10.29, whereas the minimum speed of 16.20 km/h was observed at a gear ratio of 6.43. A similar pattern was identified in the 130.5 kg category, where the maximum speed reached 18.74 km/h at a gear ratio of 10.29, compared to 14.63 km/h at a gear ratio of 6.43. Likewise, for the 140.5 kg vehicle, the highest average speed of 19.12 km/h was recorded at a gear ratio of 10.29, while the lowest speed of 16.90 km/h was observed at a gear ratio of 6.43.

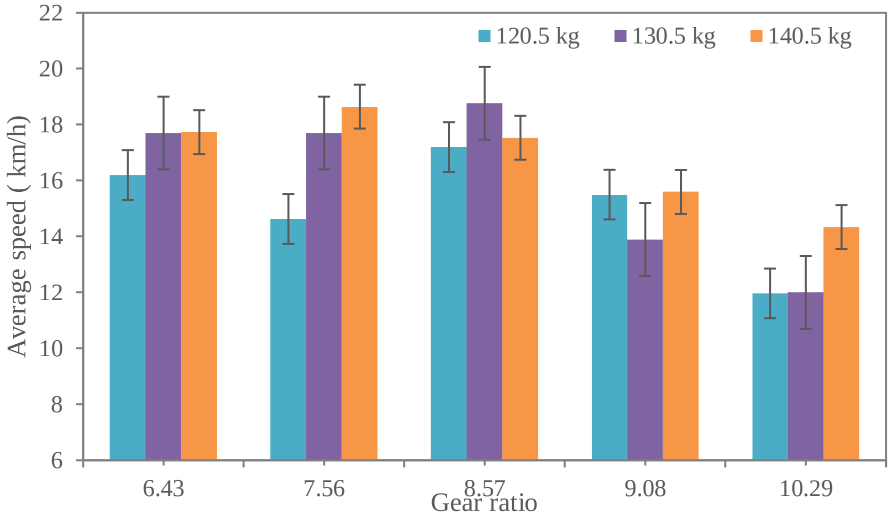

Figure 4. Effect of gear ratio on average speed ratio.

This analysis demonstrates a positive correlation between gear ratio and vehicle speed, highlighting the critical role of selecting an appropriate gear ratio to optimize electric vehicle performance. These findings align with previous studies, which have established that the final gear ratio significantly influences both vehicle speed and energy efficiency. Prior research has indicated that increasing the number of teeth on a pinion gear enhances energy efficiency while reducing travel duration [19]. Additionally, other studies have confirmed that gear ratio modifications directly impact vehicle acceleration and top speed [25]. Given these insights, determining the optimal gear ratio is essential for maximizing electric vehicle performance while maintaining a balance between speed, efficiency, and energy consumption.

Figure 5 presents a comparative analysis of travel duration (in seconds) across different gear ratio variations and total gear stages for three vehicle mass categories: 120.5 kg, 130.5 kg, and 140.5 kg. The results indicate an inverse correlation between travel time and gear ratio, suggesting that higher gear ratios enhance travel efficiency.

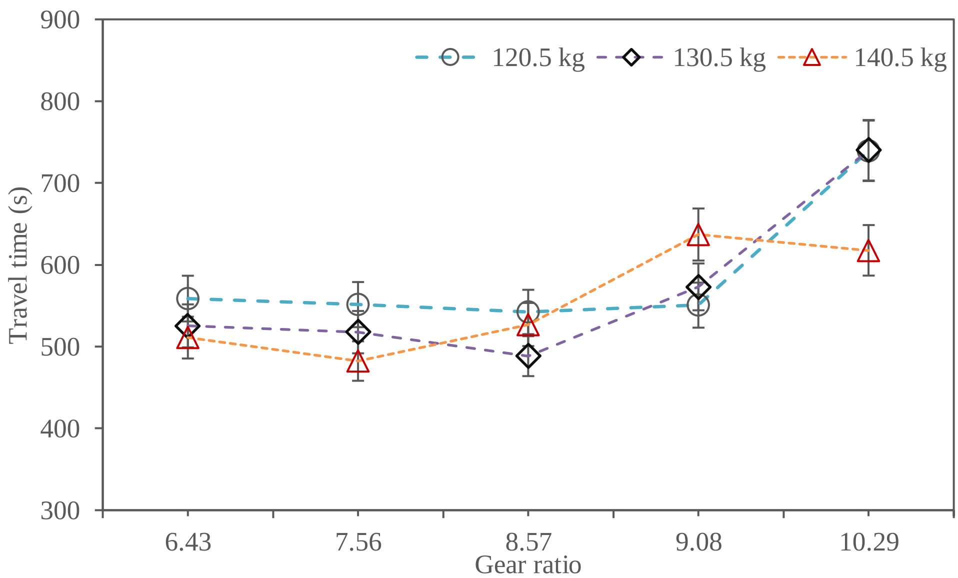

Figure 5. Effect of gear ratio on travel time.

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For the 120.5 kg category, the longest travel duration was 739.00 seconds at a gear ratio of 10.29, while the shortest was 558.67 seconds at a gear ratio of 6.43. A similar trend was observed in the 130.5 kg category, where travel time ranged from 637.00 seconds (gear ratio: 10.29) to 551.33 seconds (gear ratio: 6.43). Likewise, in the 140.5 kg category, travel duration varied from 617.67 seconds at a gear ratio of 10.29 to 542.38 seconds at a gear ratio of 6.43. These findings indicate that increasing the gear ratio enhances vehicle travel efficiency and significantly reduces overall journey duration. The results align with previous studies, which suggest that optimizing gear ratio selection improves acceleration and minimizes travel time under various driving conditions [24].

Furthermore, the shorter travel time at lower gear ratios suggests a reduction in mechanical losses, leading to improved energy efficiency. This study highlights the importance of selecting an optimal gear ratio to enhance electric vehicle performance, particularly in balancing energy consumption and travel time under varying load conditions.

4. Conclusions

This study elucidates the significant impact of vehicle weight and gear ratio variations on energy consumption and driving range in electric vehicles. The findings reveal a direct correlation between increased vehicle weight and higher energy consumption, which consequently reduces the maximum driving range. Specifically, a load of 120.5 kg results in an energy consumption of 29.29 Wh and a maximum range of 82.82 km/kWh. In contrast, increasing the load to 140.5 kg raises energy consumption to 44.00 Wh while reducing the range to 54.56 km/kWh. These results indicate that heavier loads require greater propulsion power, thereby increasing overall energy demand. Additionally, gear ratio variations play a crucial role in optimizing energy efficiency. A lower gear ratio of 10.29 enhances energy efficiency, achieving a maximum range of 112.55 km/kWh with an energy consumption of 21.33 Wh. However, this improvement comes at the expense of prolonged travel time. Conversely, a higher gear ratio of 6.43 shortens travel time but compromises energy efficiency and overall range. These findings underscore the critical importance of load management and optimal gear ratio selection in improving electric vehicle performance. By strategically optimizing these parameters, energy consumption can be minimized, leading to enhanced efficiency and an extended operational range. The insights gained from this study provide valuable guidance for the future design and development of more energy-efficient electric vehicles, particularly in balancing speed, range, and energy consumption.

Author's Declaration

Authors' contributions and responsibilities

Muh Hijjul Mabrur contributed to the conceptualization, methodology, data collection, and initial manuscript drafting. **I Made** Mara (corresponding author) supervised the research, performed critical revisions, and provided guidance on the analysis and interpretation of results. **I Dewa Ketut Okariawan** was responsible for statistical validation, visualization, and manuscript refinement. All authors reviewed, edited, and approved the final version of the manuscript.

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Availability of data and materials

All data are available from the corresponding authors.

Competing interests

The authors declare that they have no conflicts of interest.

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