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Original Article

Analysis of the Influence of Transmission System and Vehicle Weight on the Range Efficiency of the Mandalika Desantara Prototype

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ABSTRACT

The development of electric vehicles (EVs) plays a vital role in reducing carbon emissions and decreasing dependence on fossil fuels. This study examines the range efficiency of the Mandalika Desantara electric prototype by investigating the impact of vehicle weight and transmission configuration on energy consumption. Experimental tests were conducted using three different vehicle weights (120.5, 130.5, and 140.5 kg) and multiple transmission ratios. The results indicate a positive correlation between vehicle weight, energy usage, and travel performance. The lowest energy consumption was recorded at 21.33 Wh for the 120.5 kg configuration, achieved at an average speed of 14.42 km/h. The highest was 46 Wh for the 140.5 kg configuration, attained at 20.00 km/h. Motor power output ranged from 113.01 W to 177.22 W, with a range efficiency varying between 0.052 km/W and 0.113 km/W. Travel times ranged from 548 seconds at a transmission ratio of 6.43 to 822 seconds at a ratio of 10.29. These findings underscore the importance of optimized weight management and transmission selection in enhancing EV performance, thereby contributing to the development of more energy-efficient and sustainable electric mobility solutions.

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1. Introduction

The urgent need to reduce greenhouse gas emissions and decrease reliance on fossil fuels has driven a global transition toward electric vehicles (EVs), which are now considered the cornerstone of sustainable transportation strategies [1, 2]. EVs are lauded for their zero tailpipe emissions, low operating costs, and compatibility with renewable energy systems, making them integral to the decarbonization of urban mobility. Technological advancements in battery energy density, charging speed, and thermal stability have addressed concerns related to range anxiety and performance limitations [1-4]. Concurrently, improvements in electric motor design and power electronics have significantly enhanced vehicle drivability and energy efficiency, placing EVs in direct competition with internal combustion engine (ICE) vehicles [5-8].

Although most commercial EV developments have focused on maximizing battery capacity and expanding fast-charging infrastructure [9, 10], enhancing the mechanical energy efficiency of EVs, particularly lightweight and prototype-scale vehicles, remains a significant challenge. Among the mechanical parameters, vehicle mass and drivetrain configuration, particularly the transmission system, play crucial roles

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in determining the energy consumption, motor workload, and overall driving range [11-13]. An increase in vehicle mass leads to higher energy demands during acceleration and stop-and-go urban cycles, emphasizing the need for lightweight designs and strategic power management [14]. Additionally, the choice of transmission system affects the torque distribution and efficiency, particularly under varying loads and road conditions [15].

Several studies have explored these aspects separately. Saepuddin et al. [16] conduted analysis of electric go-kart prototype was developed using cain transmission system design with capacity of 2.6 HP. Rențea et al. [17] analyzes the influence of two gears transmission on energy consumption comparing with single gear transmission. Pinto et al. [18] demonstrated that a four-wheel drive (4WD) system with a single-speed transmission could reduce energy consumption by up to 9% compared with a two-wheel drive (2WD) system. Spanoudakis et al. [19] further emphasized the importance of selecting an optimal gear ratio to maximize the drivetrain efficiency. Likewise, Sweeting et al. [20] highlighted how vehicle mass reduction significantly improves the range of urban mobility scenarios. Despite these insights, few studies have investigated the combined influence of vehicle weight and transmission ratio in real-world field tests, particularly for experimental or early-stage EV prototypes [20, 21]. Mabrur et al. [22] examined the combined effects of vehicle weight and gear ratio on energy consumption in an electric vehicle prototype through field testing. They found that optimizing the gear ratio reduced both energy consumption and travel time, offering practical guidance for enhancing efficiency through weight management and gear selection. The prototype used in their experiments is shown in Figure 1.

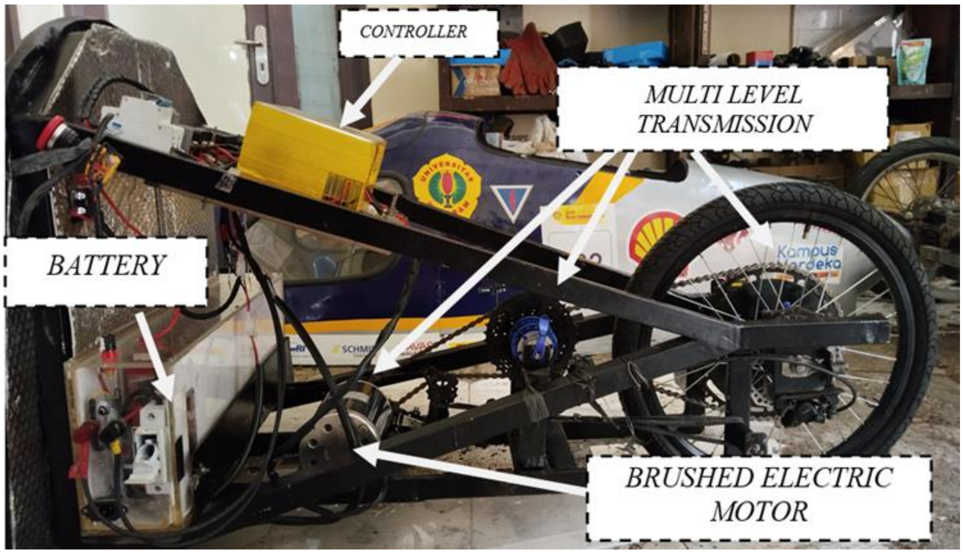

Figure 1. A prototype electric vehicle was used for field testing to evaluate the effects of vehicle weight and gear ratio on energy consumption, as previously demonstrated in a related study [22].

The effectiveness of EVs propulsion is also influenced by the motor type and power ratings. For example, brushless DC motors (BLDC) are preferred for their torque consistency and low maintenance; however, their efficiency under varying transmission configurations and payloads requires further investigation [18, 19]. Similarly, energy storage systems, especially lithium iron phosphate ($LiFePO_3$) batteries, are increasingly being adopted owing to their thermal stability, long cycle life, and safety profile [23, 24]. However, battery performance is not independent; it depends on load conditions and discharge patterns, which are inherently linked to the drivetrain and vehicle mass [25].

Transmission systems remain critical in EV architecture, despite the trend toward simplified single-speed configurations. An optimized transmission allows the electric motor to operate within its most efficient torque-speed range, minimizing energy losses [20, 26]. However, literature that integrates the interplay between vehicle mass and transmission system design in the context of range efficiency remains scarce [24-

27]. Such integration is particularly essential for small-scale prototypes intended for urban use, where energy economy and structural simplicity are the key priorities.

This study aims to bridge this research gap by experimentally analyzing the influence of both vehicle mass and transmission ratio on energy consumption, travel time, motor output, and range efficiency using a Mandalika Desantara EV prototype. Three different weight configurations (120.5, 130.5, and 140.5 kg) and varying transmission ratios (6.43 to 10.29) were tested under controlled field conditions. In contrast to previous studies focusing on simulation or single-variable analysis, this study adopts a holistic and empirical approach to quantify the drivetrain-mass interaction. The outcomes are expected to inform design strategies for lightweight and energy-efficient EVs tailored to short-distance travel and localized innovation efforts, particularly in developing countries and academia.

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2. Methods

2.1. *Prototype vehicle testing*

This research began with the preparation of the Mandalika Desantara prototype, a single-seater electric vehicle developed by the mechanical engineering department of the University of Mataram. Figure 2 shows the prototype, which features a lightweight chassis and modular drivetrain layout tailored for the experimental testing. It is powered by a 48 V, 1000 W brushed DC (BDC) electric motor, which was chosen for its simplicity, affordability, and suitability for low-speed applications. The energy source consists of a Lithium Iron Phosphate ($LiFePO_4$) battery, selected for its high thermal stability, long cycle life, and safety advantages over conventional lithium-ion chemistries. As reported by Omar et al. [28], $LiFePO_4$ batteries exhibit excellent durability and consistent performance, making them ideal for small-scale electric vehicle testing.

Figure 2. *Mandalika Desantara Electric Prototype Vehicle*

The drivetrain system uses a chain-driven mechanism to transfer power from the motor to the rear wheels of the vehicle. A custom sprocket assembly mounted between the motor shaft and rear axle allows the use of nine selectable gear ratios. This multiratio system enables manual adjustment of the transmission configuration during testing, making it possible to adapt to varying load conditions and track profiles of the vehicle. Such flexibility is essential in research-oriented EVs, in which different mechanical settings must be compared under controlled conditions. The transmission layout enables the investigation of the relationship between the gear ratio and propulsion efficiency in real time, particularly under variable vehicle mass conditions.

In contrast to conventional EVs, which often employ single-speed transmissions, this setup allows for a deeper exploration of the drivetrain performance. Previous studies have emphasized the importance of optimizing gear ratios to improve energy efficiency, particularly in lightweight electric vehicles that operate within narrow torque-speed envelopes [19]. By combining multiple transmission settings with varying vehicle weights (120.5, 130.5, and 140.5 kg), this prototype facilitates a structured analysis of how the mechanical load and drivetrain configuration influence the energy consumption, travel time, and overall range efficiency. Thus, the experimental platform provides valuable insights into drivetrain-energy interactions relevant to the future design of efficient urban electric vehicles.

The field tests were conducted within the controlled environment of the University of Mataram campus, which features a relatively flat terrain with minimal elevation changes and only a few mild turns, as shown in Figure 3. These conditions ensured consistency across all test iterations and minimized the influence of road gradient on power consumption. Additionally, to isolate the mechanical and electrical performance variables from driver-induced variations, all trials followed a standardized driving protocol in which the rider released the throttle when the vehicle reached its designated cruising speed. This method was used to capture the minimum energy consumption and maximum travel distance under steady-state conditions. Furthermore, the transmission system was equipped with a chain stabilizer to reduce slack and slippage during rotation transfer, thereby enhancing the reliability, efficiency, and torque response of the drive train. Adjustments to the sprocket diameter were also made to accommodate load variations, allowing the system to modulate the torque and speed effectively based on different vehicle weights and transmission settings.

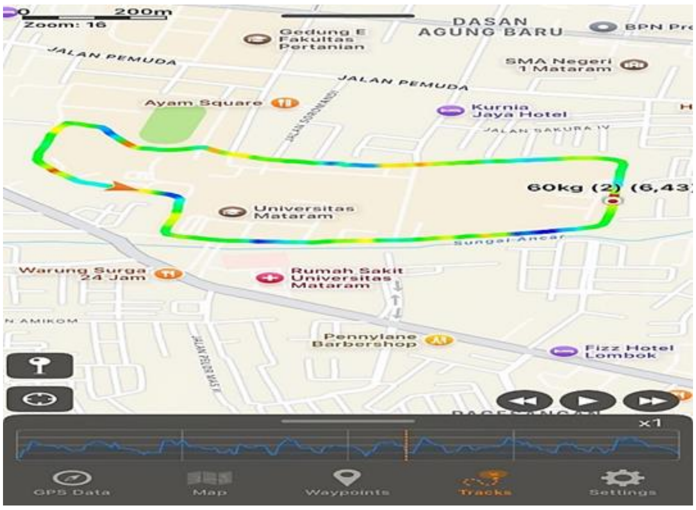

Figure 3. *Layout of the test route used for prototype vehicle performance measurements*

2.2. *Data Collections*

This study employed a quantitative experimental approach, focusing on the direct collection and analysis of numerical data obtained from prototype electric vehicle testing. The data collection process was initiated after completing each controlled test run. Several key variables were measured and recorded during the experiments, including the vehicle weight (kg), transmission ratio (i), travel distance (km), average speed (km/h), and energy consumption (Wh). These primary measurements served as the basis for calculating performance indicators such as average speed, travel time (s), motor power (W), and distance-per-energy efficiency (km/Wh), as suggested in previous EV performance assessments [4, 13]. All vehicle energy consumption data were obtained using an onboard Joulemeter installed on the prototype. This instrument provided accurate real-time readings of the total energy usage for each run. The electric motor power output was calculated using the following standard electrical power formula:

$$Power\ (W) = Voltage\ (V) \times Current\ (I) \tag{1}$$

To assess the range efficiency, the effective distance traveled by the vehicle per unit of energy consumed was calculated using [29, 30]:

$$\eta\ [\text{km/Wh}] = (\text{Trip Distance [km]}/(\text{Net Energy [Wh]})) \tag{2}$$

These equations were used to analyze the relationships between energy consumption, distance, and power output under various experimental conditions. Eq. (2) offers a clear metric for assessing the efficiency with which the prototype vehicle converts electrical energy into distance traveled. Assuming consistent driving behavior and stable terrain conditions, increased energy consumption generally correlates with extended travel times and distances, thereby affecting overall efficiency.

3. Results and Discussions

3.1. *Impact of vehicle mass and transmission ratio on energy consumption*

Each test scenario was repeated three times to ensure the reliability and consistency of the data, as well as to minimize the influence of measurement errors or anomalies. The experiments were conducted using three different vehicle weight configurations: 120.5, 130.5, and 140.5 kg. The key performance parameters, including the vehicle mass, transmission ratio, energy consumption (Wh), motor power output (W), range efficiency (km/Wh), and travel time (s), were systematically recorded and analyzed. The results of each test variation are graphically presented in Figure 4 to facilitate trend observation and comparative evaluation.

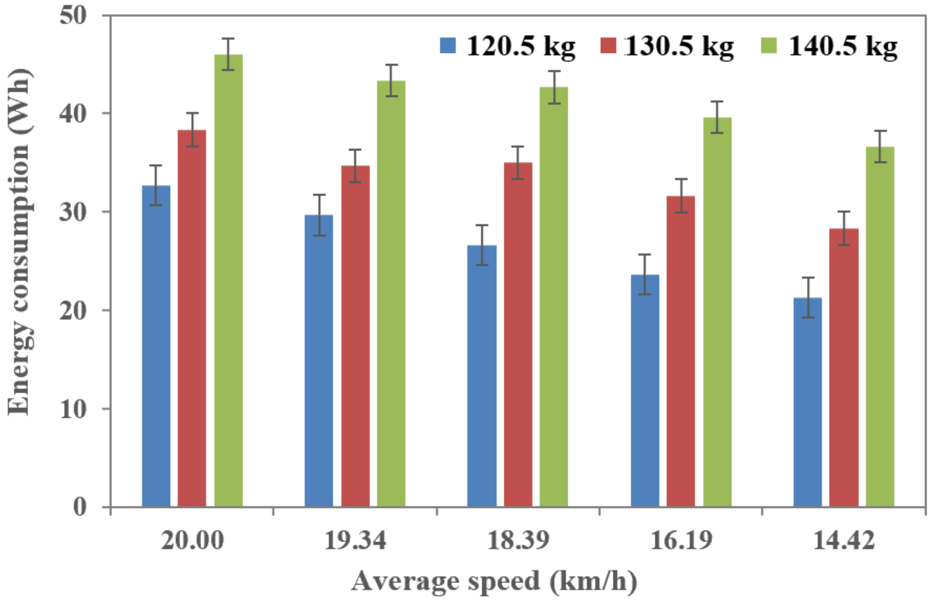

Figure 4. Relationship between energy consumption and average speed.

As shown in Figure 4, the energy consumption (Wh) increases with vehicle mass and average speed. Among all the test conditions, the configuration with a total vehicle mass of 120.5 kg consistently demonstrated the lowest energy consumption across the transmission settings. This trend aligns with previous studies emphasizing that a reduced vehicle mass leads to a lower energy demand during the acceleration and cruising phases, particularly in low-power electric drivetrains [17, 20, 31]. Moreover, the findings support the assertion that variations in the transmission system significantly influence energy efficiency, particularly in lightweight EV platforms.

Additionally, the results emphasize that optimizing the transmission ratio selection plays a critical role in minimizing energy consumption and enhancing overall vehicle performance. Previous studies have confirmed that appropriate transmission matching can improve torque delivery and motor efficiency without requiring additional power inputs [2, 5, 6]. The present findings support this conclusion by demonstrating that proper gear selection, particularly under varying load conditions, directly influences the propulsion behavior and energy demand. These insights contribute to a broader understanding of energy-efficient electric vehicle development, particularly in contexts where drivetrain modularity and operational load variability are critical design considerations. Furthermore, this study highlights the importance of adopting integrated strategies that balance the transmission configuration with the vehicle mass to ensure optimal energy usage and dynamic performance.

3.2. *Electric motor power analysis in relation to average speed and vehicle mass*

Figure 5 presents the analysis of electric motor power (in watts) as a function of the average vehicle speed (km/h) for different vehicle weight configurations. The results demonstrate a clear positive correlation between motor power and average speed; as motor power increases, the vehicle's operational velocity also increases. This relationship is especially evident under the lightest load condition (120.5 kg), where the vehicle achieved a peak average speed of 20.00 km/h with a motor power output of 177.22 W. Conversely, the lowest recorded average speed of 14.42 km/h was observed under the same weight conditions at a reduced motor power level of 113.01 W.

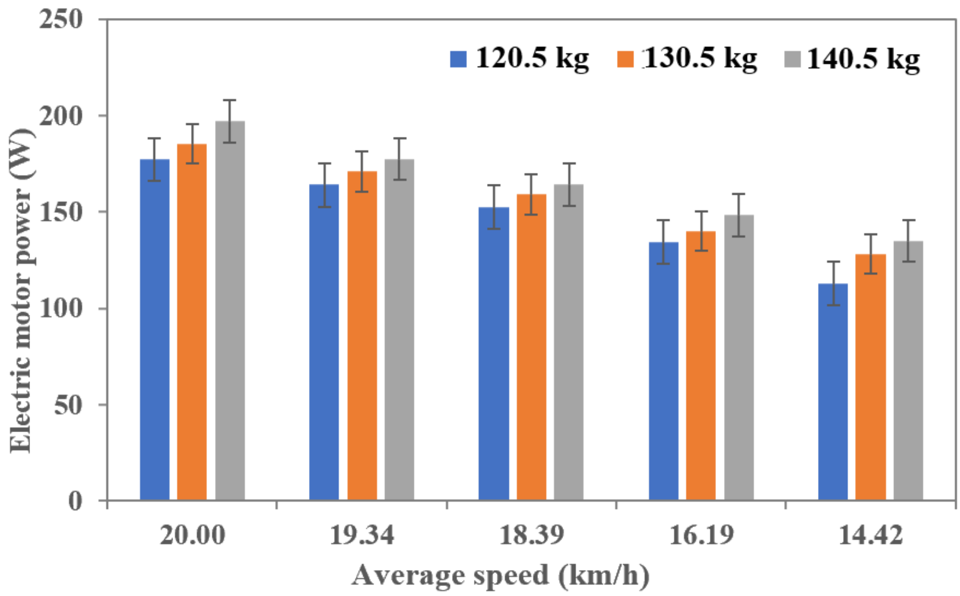

Figure 5. Relationship between motor power and average speed.

This trend underscores the critical role of electric motor power in determining the performance of prototype EV. While greater power enables higher speeds, it also demands an optimized transmission and drivetrain design to minimize energy loss. An appropriate gear ratio selection enables the motor to operate near its optimal efficiency range, thereby improving performance without significantly increasing energy consumption.

These findings are supported by earlier studies that emphasized the influence of the transmission configuration on electric motor performance. Prior research has shown that appropriate transmission selection can reduce motor power demands while simultaneously improving the vehicle speed [1, 4]. Moreover, incremental increases in the transmission ratio have been found to enhance the torque efficiency, thereby minimizing the mechanical load imposed on the motor [2, 6]. Additional evidence suggests that direct modifications to the transmission system can substantially affect both the motor load and vehicle acceleration [2, 13]. These insights underscore the importance of aligning the motor characteristics with the drivetrain configurations to optimize the energy use and dynamic performance in electric vehicle applications. This confirms that the careful integration of the motor power output and transmission settings not only enhances the average speed but also contributes to the overall powertrain efficiency. These insights are critical for developing lightweight EV platforms that require optimized energy distribution without compromising operational performance.

3.3. *Influence of vehicle mass and transmission on range efficiency*

Figure 6 presents the relationship between the range efficiency (km/Wh), vehicle mass, and average speed, highlighting how different loading conditions affect the energy performance. The results demonstrate that the vehicle weight plays a critical role in determining the effective range of an electric vehicle. Under lighter weight conditions (120.5 kg), the prototype consistently achieved a higher range efficiency across different transmission settings. In contrast, increasing the total weight to 140.5 kg resulted in a noticeable decline in the range efficiency. This inverse relationship indicates that heavier vehicles require more energy per kilometer traveled, a pattern that has been well-documented in previous electric vehicle efficiency studies [2, 32].

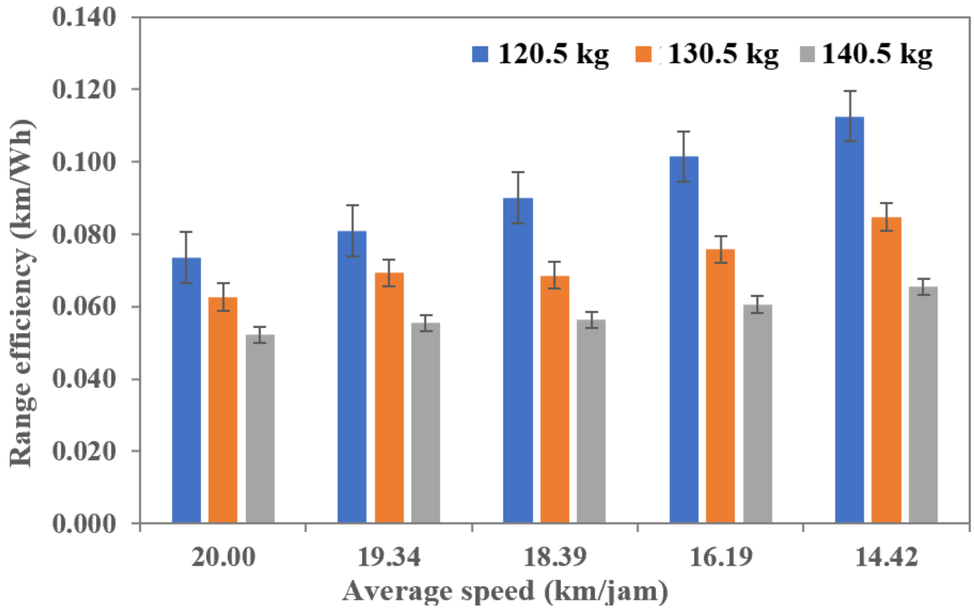

Figure 6. Relationship between distance efficiency and average speed.

In addition to weight, the transmission ratio variation was also proven to be a significant determinant of the range efficiency. The data indicate that higher transmission ratios, when appropriately matched to the load, can extend the vehicle's travel distance per unit of energy. For instance, at 120.5 kg, the vehicle achieved a maximum range efficiency of 0.113 km/Wh, whereas at 140.5 kg, the minimum value observed was 0.052 km/Wh. These findings suggest that the mechanical advantage provided by optimized transmission settings can partially compensate for the increased energy demands owing to the added weight, but only to a certain extent.

The consistency of these outcomes is in agreement with previous research, which highlighted the combined impact of vehicle mass and transmission configuration on the efficiency of electric vehicles [20, 24]. The present study reinforces these conclusions by demonstrating that incorporating weight-sensitive transmission strategies is essential for optimizing the range efficiency of lightweight electric vehicle designs. Moreover, the results provide useful implications for the advancement of compact and energy-efficient mobility solutions, particularly for urban or short-range transportation scenarios.

3.4. *Effect of transmission ratio on travel time performance*

Figure 7 illustrates the relationship between the travel time (in seconds) and different transmission ratio settings using five gear configurations: 6.43, 7.56, 8.57, 9.08, and 10.20. The results revealed an inverse correlation between the transmission ratio and travel time, where lower transmission ratios consistently led to shorter durations across all vehicle weights. Conversely, higher transmission ratios were associated with longer travel times and lower temperatures. This pattern can be attributed to the reduced average vehicle speed at higher gear ratios, resulting in extended test durations over a constant distance.

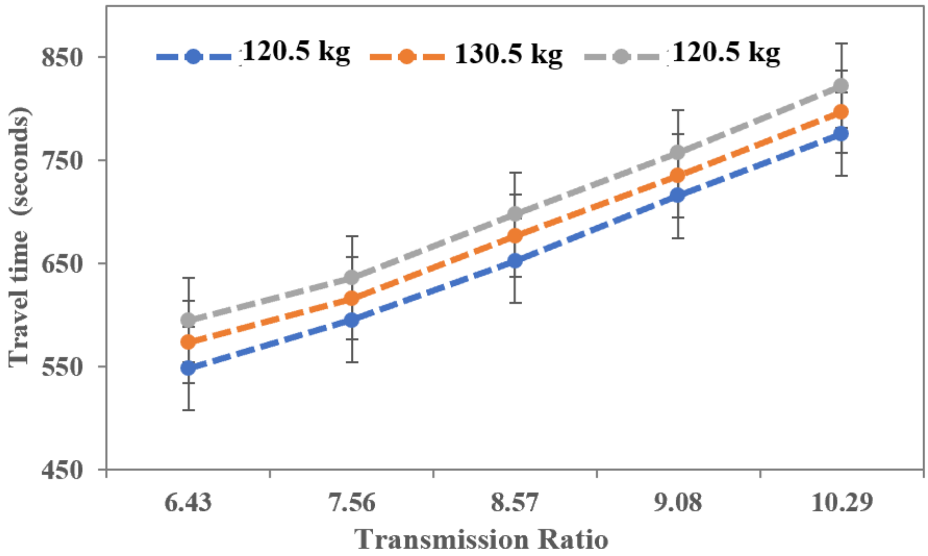

Figure 7. Relationship between travel time and transmission system ratio variations.

For instance, under the lightest load condition (120.5 kg), the prototype vehicle achieved the shortest travel time of 548 s using a 6.43 transmission ratio. In contrast, the longest duration of 822 s was recorded under the heaviest load (140.5 kg) using the highest transmission ratio of 10.20. These findings indicate that higher transmission ratios, while potentially beneficial for torque in uphill or heavy load conditions, can hinder speed and responsiveness on flat test tracks. In contrast, lower transmission settings improved acceleration and average speed, thereby minimizing the total travel time over the same test path.

These results are in agreement with those of earlier studies that emphasized the pivotal role of drivetrain optimization in improving vehicle acceleration and reducing travel time [2, 6, 24]. The present findings reaffirm that the proper selection of transmission configurations is essential for balancing speed, energy efficiency, and time optimization, particularly in lightweight electric vehicle designs intended for urban or constrained driving conditions.

4. Conclusions

This study examined the impact of vehicle mass and transmission configuration on the energy consumption, range efficiency, motor power output, and travel time of a Mandalika Desantara electric vehicle prototype. By testing the vehicle under varying weights (120.5, 130.5, and 140.5 kg) and transmission ratios (6.43–10.20), several key findings emerged.

- A positive correlation exists between the vehicle weight and energy consumption. Heavier vehicles lead to increased energy use and reduced range efficiency. The minimum energy consumption of 21.33 Wh and maximum range efficiency of 0.113 km/Wh occurred at a vehicle weight of 120.5 kg. These findings highlight the importance of weight optimization in enhancing the range of electric vehicles.

- Lower transmission ratios, such as 6.43, led to decreased travel times and higher speeds, especially in lighter vehicles. Higher ratios, such as 10.20, resulted in longer travel times and slower speeds, demonstrating the importance of matching the transmission settings to the vehicle weight and terrain.
- The power requirements of the motor were affected by both speed and load. When the average speed increased, the motor delivered more power, with an output ranging from 113.01 W to 177.22 W. These figures highlight the importance of choosing the right transmission to manage the workload and ensure efficient performance.

These findings provide insights into the development of energy-efficient electric vehicles, particularly in the prototype and lightweight commuter categories. They emphasized the importance of an integrated drivetrain design, weight management, and dynamic transmission strategies for enhancing the performance of electric vehicles. They also point to future research areas, such as terrain variations, regenerative braking effects, and real-world driving behavior, to refine the efficiency modeling for small-scale electric mobility solutions.

Author's Declaration

Authors' contributions and responsibilities

The authors contributed significantly to the conception and design of this study. The corresponding author was responsible for the data analysis, interpretation, and discussion of the results. All the authors have reviewed and approved the final version of the manuscript.

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Availability of data and materials

All data supporting the findings of this study are available from the corresponding author upon reasonable requests.

Competing interests

The authors declare no conflicts of interest related to this study.

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