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Fuel Efficiency Evaluation of Automatic Motorcycles in Indonesia Using MATLAB-Based Clustering

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Abstract

The continuous rise in fuel prices in Indonesia has made fuel efficiency a crucial factor for consumers when selecting vehicles, particularly motorcycles. Automatic scooters with engine capacities below 160 cc have become increasingly popular in urban areas due to their fuel-saving benefits. This study aims to analyze the influence of engine capacity, vehicle weight, and engine torque on the fuel consumption of automatic scooters with engine capacities ranging from 109 cc to 156.9 cc. The study also considers additional performance parameters, including average fuel consumption, power output, and Power-to-Weight Ratio (PWR). Using statistical analysis and MATLAB-based modeling, the data were classified into three distinct clusters. Cluster 1 comprises scooters with engine capacities between 109 and 125 cc; Cluster 2 includes those with capacities between 150 and 160 cc; and Cluster 3 represents scooters with unique component specifications. The results show that Cluster 2 records the highest average maximum power output at 11.47 kW and torque at 14.25 Nm, while Cluster 1 has the lowest at 6.1 kW and 9.64 Nm, respectively. In terms of weight, Cluster 3 is the heaviest, averaging 129.33 kg, while Cluster 1 is the lightest at 96.14 kg. Fuel efficiency is highest in Cluster 1 at 55.3 km/L and lowest in Cluster 3 at 38.67 km/L. Comparative analysis using MATLAB confirms that scooters with lower engine capacities and weights tend to be more fuel-efficient, whereas higher engine capacities lead to increased torque, power, weight, and fuel consumption. These findings can guide consumers in selecting motorcycles that align with their usage needs and assist manufacturers in developing more efficient and high-performing scooters tailored to diverse market segments.

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1. Introduction

Developing countries, especially in Southeast Asia, use motorcycles as the primary mode of transportation, resulting in a significant increase in motorcycle usage alongside rapid economic growth and urbanization [1]. In daily travel and mobility across Indonesia, motorcycles are an essential means of transportation. This is evidenced by the high sales of new motorcycles—particularly automatic models—which contribute to more than 85% of total motorcycle sales in the country [2]. Indonesia faces significant pressure to reduce its reliance on fossil fuels due to the extensive use of motor vehicles, especially in private transportation. According to the Institute for Essential Services Reform (IESR) and the Central Statistics Agency (BPS), fuel consumption in Indonesia increased from 30.41 km/L to 30.57 km/L between 2015 and 2020. During the same period, the number of motorized vehicles rose by 77.35%. Worsening environmental problems are largely attributed to greenhouse gas emissions, which contribute to climate change. The rise in fuel prices, driven by high import costs and increasing demand, further exacerbates environmental challenges. Therefore, understanding the factors that influence fuel consumption is crucial [3].

Engine capacity, vehicle weight, and torque are key parameters that influence motorcycle performance and fuel efficiency [4], [5]. These parameters have been extensively explored in previous studies, especially regarding their impact on fuel consumption across different vehicle categories. Among these, motorcycles with engine capacities under 160 cc have gained popularity due to their balanced performance, fuel efficiency, and affordability [6]. However, complex engineering challenges arise in understanding the interrelationship between these factors, necessitating further

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research [7]. Recent studies have emphasized optimizing engine capacity to improve fuel efficiency [8]. Engine capacity is directly related to the volume of the engine cylinder and the power output potential. Larger-capacity engines generally consume more fuel, particularly under high-load conditions. Nevertheless, advancements such as thermal management systems and start-stop technologies have contributed to reducing fuel consumption even in larger engines [7].

Larger engines also tend to produce higher carbon dioxide (CO_2) emissions. Research by Deymi-Dashtebayaz et al. (2014) showed that motorcycles with engine sizes ranging from 100 cc to 150 cc display unique fuel consumption patterns compared to those with larger engines, primarily due to differences in engine load and efficiency [9]. Smaller engines typically operate at lower loads under normal riding conditions. When engine load is reduced, the engine components work less intensively, lowering internal friction and increasing overall efficiency. This finding is consistent with the study by Sign et al. (2016), which found a significant correlation between engine capacity and fuel efficiency in small motorcycles [10]. Another critical factor influencing fuel consumption is vehicle weight. Heavier motorcycles consume more fuel due to increased rolling resistance and inertia [11].

Heavier vehicles, due to their greater inertia and rolling resistance, tend to consume more fuel. One effective way to improve fuel efficiency is by reducing vehicle weight. A study conducted by Li and Wang (2017) under urban driving conditions found a strong correlation between vehicle weight and fuel consumption [12]. To significantly improve fuel economy, weight optimization is essential through the use of lightweight materials and design strategies [13, 14]. Enhancing rider comfort and ease of use has driven advancements in automatic transmission technology design for motorcycles [15]. However, these advancements introduce new complexities in understanding fuel consumption patterns due to variations in transmission efficiency and control strategies [16]. Research by Kumar et al. [17] highlights a trade-off between engine capacity and fuel efficiency, where increasing engine capacity may reduce fuel economy due to higher fuel consumption at elevated power outputs.

The power-to-weight ratio (PWR) is a critical factor influencing motorcycle performance and fuel efficiency [18]. The fundamental principle is that a motorcycle with good acceleration and agility has a lighter weight and requires less power to move. However, a higher PWR can negatively affect fuel consumption, even though it enhances acceleration and overall performance. This ratio reflects the balance between the motorcycle's weight and the power it produces [19]. Studies by Lasocki (2021) have shown that optimizing PWR can improve fuel efficiency without compromising engine performance [20]. Torque management is also vital in determining overall fuel efficiency, especially in urban riding conditions involving frequent stop-and-go traffic [21]. Engine torque plays a crucial role in fuel consumption, as it influences vehicle dynamics, including the ability to reach maximum speed and handle inclines. High-torque engines are more efficient when carrying heavy loads or navigating challenging terrain. However, without efficient fuel management technology, this can also lead to increased fuel consumption. Recent research on torque control methods has aimed to optimize torque output and minimize fuel consumption during vehicle operation.

Motorcycles with 110–150 cc engines tend to be more fuel-efficient than those with 150–160 cc engines, although larger engines typically provide greater power and torque. Generally, the larger the engine capacity, the higher the performance and fuel consumption. Good engine performance is closely associated with adequate torque. Advanced engine management systems have enabled better control over torque delivery, thereby optimizing fuel consumption [22]. These systems are instrumental in improving torque control and fuel efficiency [22]. There is a non-linear relationship between torque and fuel consumption, with an optimal torque range for achieving maximum fuel efficiency [23]. One of the key focuses in improving motorcycle efficiency is addressing environmental concerns and rising fuel costs [24]. According to a study by Ahmed and Rahman [25], optimizing the relationship between engine capacity, vehicle weight, and torque can reduce fuel consumption by up to 15% in automatic motorcycles.

Rising consumer demand for performance has encouraged manufacturers to invest heavily in research and development to enhance fuel efficiency [26, 27]. To explore how variables such as engine capacity, weight, and torque correlate, comprehensive data analysis methods—such as correlation matrices, scatter plots, and cluster analysis—are necessary. Overall, motorcycle engine capacity increasingly influences both performance and fuel consumption. Manufacturers can leverage this information to develop strategies for producing fuel-efficient motorcycles, thus supporting environmental sustainability and offering economic benefits to consumers [28, 29, 30].

Previous studies have rarely utilized software-based analysis methods, making the application of MATLAB in this research a distinguishing aspect. The findings of this study are expected to assist consumers in making more informed vehicle choices based on their needs, supported by MATLAB-based data analysis. The results indicate that clustering and regression techniques implemented in MATLAB can offer new insights into the factors affecting motorcycle fuel efficiency. The study concludes that motorcycles with 110–150 cc engines tend to be more fuel-efficient than those with 150–160 cc engines, while motorcycles with larger capacities provide greater power and torque.

2. Methods

The appropriate methodology for this research involves several stages of quantitative and statistical analysis. The following is an outline of the method applied:

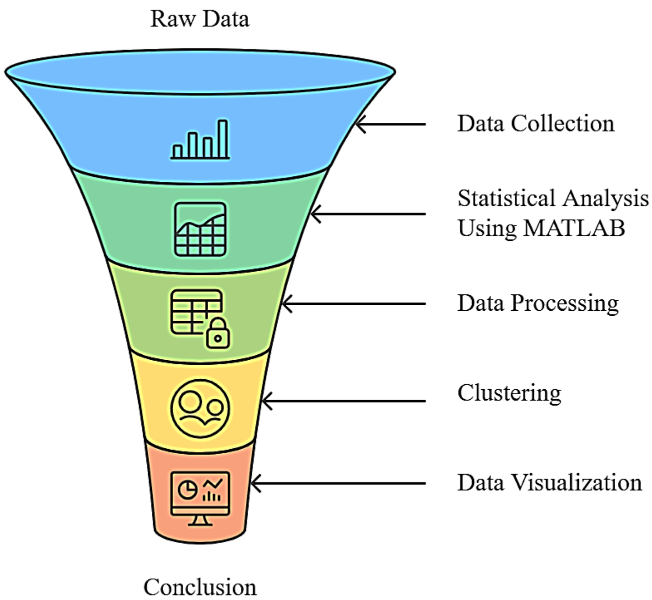


Figure 1. Research flow diagram

2.1. Data collection

The range of engine capacities, vehicle weights, and torques in this study was selected based on the standard specifications of automatic scooters commonly found in Indonesia. Engine capacities ranged from 110 cc to 160 cc, representing the most widely used categories of automatic scooters by consumers. Vehicle weights ranged from 90 kg to 130 kg.

Table 1 and Table 2 present the engine capacity datasets of motorcycles, specifically categorized into the 110–125 cc and 150–160 cc ranges, respectively. The study began by collecting detailed data on various models of automatic scooters, specifically examining their engine capacity, vehicle weight, engine torque, fuel consumption, power output, and Power-to-Weight Ratio (PWR). This initial step ensured a comprehensive dataset for thorough analysis.

Table 1. This dataset presents the engine capacities of motorcycles, specifically focusing on those within the 110-125 cc ranges.

Model	Engine Cap. (cc)	Curb Weight (kg)	Toque Max (Nm/rpm)	Ave. Fuel Cons. (km/L)	Max. Power (kW/rpm)	PWR (kW/kg)
Honda Beat	109.5	88	9.2 / 6,000	60.6	6.6 / 7,500	0.075
Honda Scoopy 110 Fi	109.5	95	9.3 / 5,500	59	6.6 / 7,500	0.06947
Suzuki Nex II	113	93	8.5 / 6,000	44	8.2 / 8,500	0.08817
Yamaha Grand Fillano	124.86	95	10.4 / 5,000	55.6	6.1 / 6.500	0.06421
Yamaha Fazzio	124.86	90	10.6 / 4,500	51.6	6.2 / 6500	0.06813
Yamaha Mio GT	113.7	92	8.5 / 5,000	55	7.0 / 8000	0.07608
Yamaha FreeGo 125	125	102	9.5 / 5,500	52.7	7.0 / 8000	0.06862
Suzuki Brugman Street Ex 125	124	111	10 / 5,500	52.6	6.3 / 6.500	0.05675

Table 2. The engine capacities of motorcycles datasets, specifically focusing on those within the 150-160 cc range.

Model	Engine Cap. (cc)	Curb Weight (kg)	Torque Max (Nm/rpm)	Ave. Fuel Cons. (km/L)	Max. Power (kW/rpm)	PWR (kW/kg)
Honda Vario 160 ABS	156.9	115	13.8 / 7,000	46.9	11.3 / 8,500	0.09826
Yamaha NMAX 155	155	135	14.2 / 6,500	39.5	11.3 / 8,000	0.0837
Honda PCX 160	156.9	131	14.7 / 6,500	42.2	11.8 / 8,500	0.09007
Yamaha Aerox 155	155	125	13.9 / 6,500	43.63	11.3 /8,000	0.0904
Vespa Sprint 150	155	145	12.7 / 5,750	32.5	8.9 / 7,250	0.06137
Honda ADV 160 ABS	156.9	133	14.7 / 6,500	45	11.8 / 8,500	0.08872
Yamaha Lexi LX 155	155	118	14.2 / 6,500	42.2	11.3 / 8,000	0.09576
Vespa GTS 150	155	150	13.5 / 6,750	39.5	11.5 / 8,250	0.07666

2.2. Software and tools

In analyzing the data for this study, MATLAB was used. MATLAB is a software platform designed for data analysis, numerical computing, and visualization. It is widely utilized across various fields, including engineering, mathematics, and science.

2.3. Data processing

To effectively categorize automatic scooters based on fuel efficiency, this study employed the K-means clustering algorithm in MATLAB. The elbow method and silhouette score were used to determine the optimal number of clusters. Following this, ANOVA was applied to validate the differentiation among clusters.

2.4. Descriptive analysis

Key variables were analyzed using standard statistical metrics, including mean, median, standard deviation, and range. These descriptive statistics provide an initial understanding of the data distribution and variation, forming the foundation for more in-depth analysis.

2.5. Clustering

Advanced clustering techniques, such as K-means, were used to group the data into distinct clusters based on shared characteristics. This step involved determining the optimal number of clusters, revealing natural groupings within the dataset and highlighting similarities and differences among motorcycle models.

$$X' = {X - X_{min}} / {X_{max} - X_{min}} \quad (1)$$

Here, X' is the standardized value, X is the original value, X_{min} is the minimum value, and X_{max} is the maximum value in the dataset. This normalization process prevents variables with larger scales from dominating the clustering analysis.

Cluster Analysis: Each cluster was thoroughly analyzed to extract insights into its unique characteristics. This analysis helped identify significant patterns and differences between clusters, providing a deeper understanding of how various factors influence fuel efficiency

2.6. Regression and correlation

Regression analysis was conducted to explore the relationships between the independent variables (engine capacity, vehicle weight, and engine torque) and the dependent variable (fuel consumption). Correlation coefficients were calculated to quantify the strength of these relationships, helping to identify the factors that most significantly impact fuel consumption.

3. Results and Discussion

The results of this study, which analyzed the effects of engine capacity, vehicle weight, and engine torque on fuel efficiency using MATLAB, involve several statistical tests to examine the relationships between these variables. The outputs include scatter plots and histograms, which provide both visual and statistical insights into the relationships between fuel efficiency and engine capacity, vehicle weight, and engine torque.

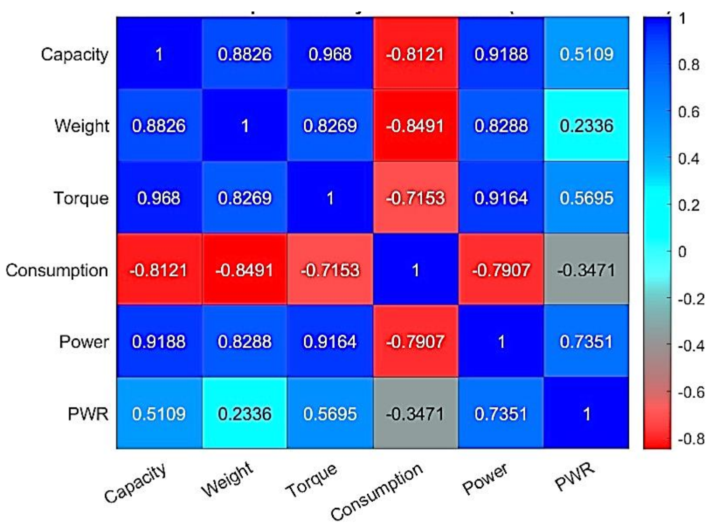


Figure 2. Correlation heatmap of motorcycle parameters

The correlation heatmap in Figure 2 illustrates the relationships among engine capacity, vehicle weight, engine torque, fuel consumption, power, and the Power-to-Weight Ratio (PWR). Engine capacity shows a strong positive correlation with torque (0.968) and power (0.9188), indicating that as engine size increases, both torque and power also increase. However, engine capacity has a strong negative correlation with fuel consumption (-0.8121), suggesting that larger engines are generally less fuel-efficient.

Vehicle weight exhibits a strong positive correlation with engine capacity (0.8826) and torque (0.8269), highlighting that heavier motorcycles tend to have larger and more powerful engines. Nevertheless, vehicle weight also negatively correlates with fuel consumption (-0.8491), meaning heavier motorcycles tend to consume more fuel.

Torque also demonstrates a significant negative correlation with fuel consumption (-0.7153), reinforcing the idea that more powerful engines are associated with higher fuel usage. Interestingly, power shows a high positive correlation with both engine capacity (0.9188) and torque (0.9164), while also displaying a negative correlation with fuel consumption (-0.7907). This indicates that power output is a critical factor influencing overall fuel efficiency.

The Power-to-Weight Ratio (PWR) exhibits a moderate positive correlation with power (0.7351), reflecting the performance advantage of motorcycles with higher power relative to their weight. However, PWR has a weaker correlation with engine capacity (0.5109) and an even lower correlation with fuel consumption (-0.3471), suggesting a more complex interplay between weight, power, and efficiency.

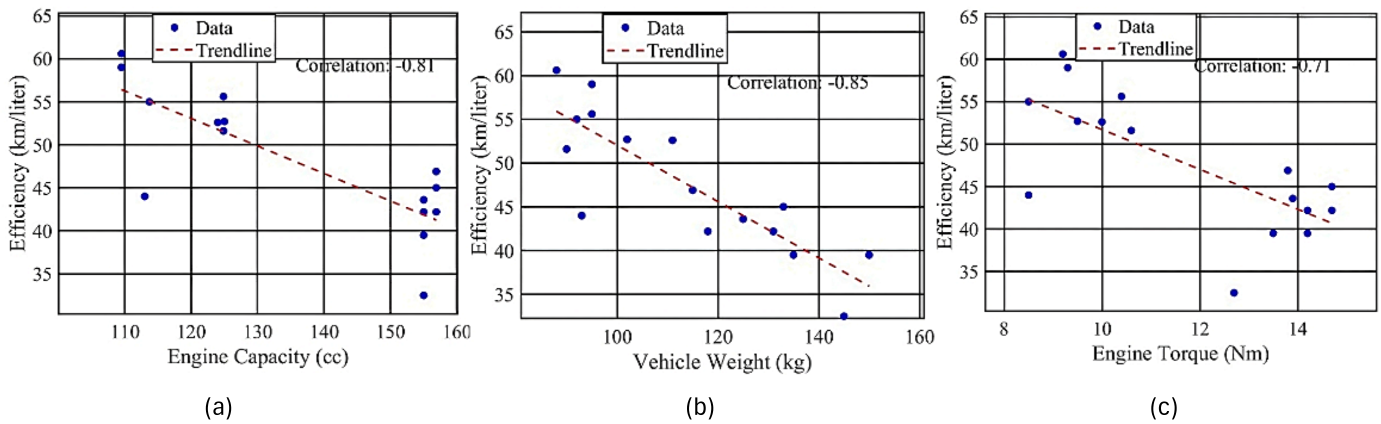


Figure 3. The influence of engine capacity on fuel efficiency (a), vehicle weight on fuel efficiency (b), and torque on fuel efficiency (c)

The relationship between fuel consumption and engine capacity, torque, and vehicle weight is illustrated in Figure 3. Figure 3(a) shows the relationship between fuel efficiency (in km/L) and engine capacity (in cc). The scatter plot displays a clear negative correlation (correlation coefficient: -0.81), indicating that as engine capacity increases, fuel efficiency decreases. The trendline highlights this inverse relationship, suggesting that motorcycles with larger engine capacities consume more fuel. This aligns with the expectation that larger engines require more fuel to generate higher power output, emphasizing the trade-off between performance and fuel efficiency.

Figure 3(b) explores the relationship between fuel efficiency and vehicle weight. The data reveals a strong negative correlation (correlation coefficient: -0.85), indicating that heavier motorcycles tend to have lower fuel efficiency. The downward trendline underscores the impact of weight on fuel consumption, as heavier vehicles experience increased rolling resistance and require more energy to maintain speed. This finding suggests that optimizing weight could be a key strategy for enhancing fuel efficiency.

Figure 3(c) examines the relationship between fuel efficiency and engine torque. The correlation is moderately negative (correlation coefficient: -0.71), indicating that motorcycles with higher torque values generally have reduced fuel efficiency. This suggests that engines producing higher torque tend to consume more fuel, particularly during acceleration or when carrying heavy loads. However, efficient torque management could help mitigate some of these losses, achieving a better balance between performance and fuel economy.

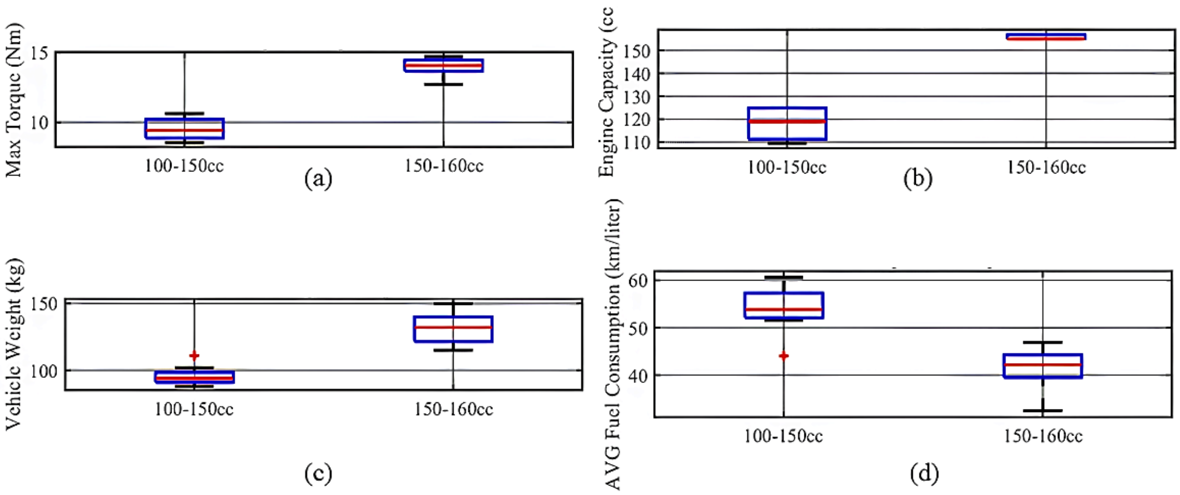


Figure 4. Performance comparison: 100 cc–150 cc vs. 150 cc–160 cc

Figure 4 illustrates a performance comparison between motorcycles with engine capacities of 100–150 cc and those with 150–160 cc, focusing on four key metrics: engine capacity, vehicle weight, engine torque, and average fuel consumption. Figure 4(a) presents a box plot analysis of engine torque for motorcycles in the 100–150 cc range compared to those in the 150–160 cc range. While Figure 4(b) displays the box plot analysis of engine capacity across both groups, and Figure 4(c) shows the box plot analysis of motorcycle weight for the two capacity ranges. Finally, Figure 4(d) presents the box plot analysis of average fuel consumption for motorcycles in both engine capacity categories.

- The influence of engine capacity: The negative regression coefficient for engine capacity (-0.3199) indicates that average fuel consumption decreases by 0.3199 km/L for every 1 cc increase in engine capacity. This means that larger engine capacities are associated with lower fuel efficiency. While larger engines typically require more fuel, this coefficient suggests that increases in engine capacity significantly impact fuel consumption.
- The influence of vehicle weight: The negative regression coefficient for vehicle weight is -0.3218, indicating that for every 1 kg increase in vehicle weight, average fuel consumption decreases by 0.3218 km/L. This demonstrates that heavier vehicles tend to be less fuel-efficient. Reducing vehicle weight is therefore essential for improving overall efficiency, as lighter vehicles require less energy to move.
- The influence of engine torque: The regression coefficient for engine torque is -2.3454, indicating that for every 1 Nm increase in torque, average fuel consumption decreases by 2.3454 km/L. This substantial coefficient suggests that increased torque significantly reduces fuel efficiency. Although torque is critical for performance, especially under heavy loads, it has a noticeable effect on increased fuel consumption.

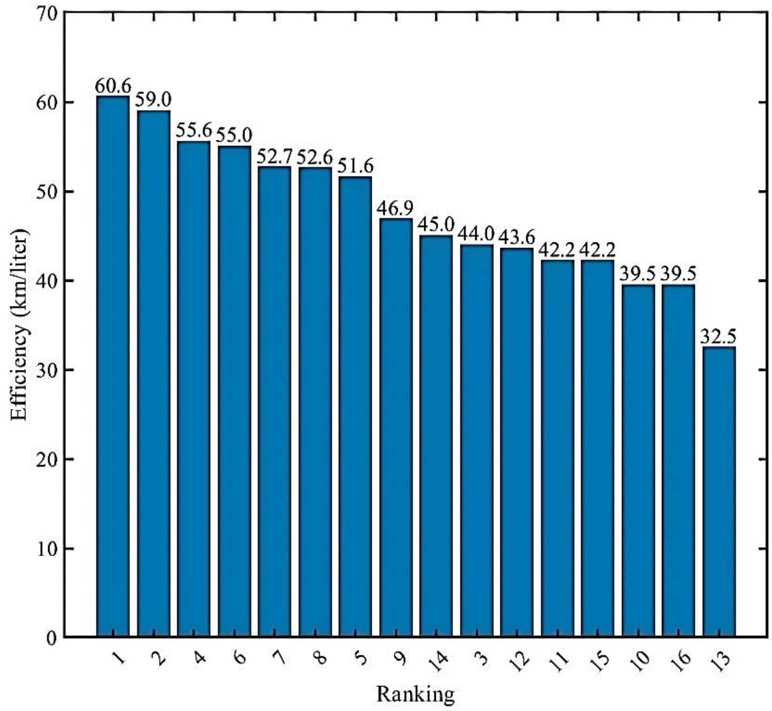
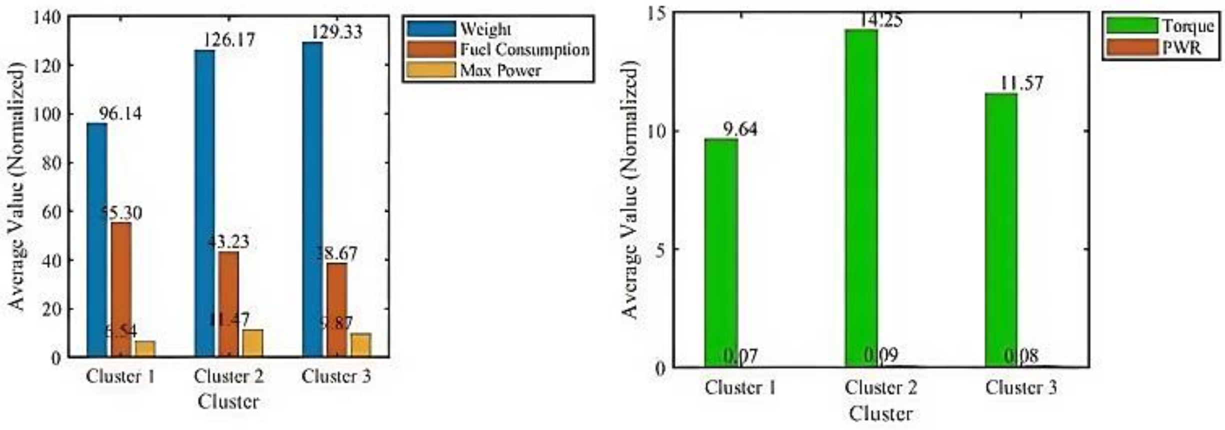


Figure 5. Fuel efficiency ranking table

Figure 5 presents a bar chart ranking various motorcycle models based on their fuel efficiency, measured in kilometers per liter (km/L). The chart reveals a clear descending trend: the top-ranked motorcycle achieves an impressive fuel efficiency of 60.6 km/L, while the lowest-ranked model records only 32.5 km/L.

This substantial variation in fuel efficiency among different models underscores the impact of design choices and engineering optimizations on performance. The top-performing motorcycles (ranks 1 to 5) achieve fuel efficiencies above 50 km/L, indicating that these models likely feature optimized engine capacities, reduced vehicle weight, and effective torque management. As the rankings descend, fuel efficiency declines—likely due to higher engine loads, increased vehicle weight, or less favorable power-to-weight ratios.

Figure 6 presents five bar charts offering a comparative analysis of three automatic motorcycle clusters. The motorcycles are grouped based on torque, power-to-weight ratio (PWR), vehicle weight, fuel consumption, and maximum power output.



(a) (b)

Figure 6. Average characteristics of each cluster (a), Average torque and PWR of each cluster (b)

Figure 6(a) provides an overview of the average characteristics of each cluster, including vehicle weight, fuel consumption, and maximum power. Cluster 1 contains the heaviest motorcycles, with an average weight of 126.17 kg and correspondingly lower fuel efficiency at 43.23 km/L. However, it delivers the highest average power output of 11.47 kW, emphasizing performance. Cluster 2, the lightest group at 96.14 kg, achieves the best fuel efficiency of 55.30 km/L but has a lower power output of 6.54 kW, highlighting a design focused on efficiency over raw power. Cluster 3, with an average weight of 129.33 kg and fuel efficiency of 38.67 km/L, strikes a balance between performance and weight, delivering an intermediate power output of 8.97 kW.

Figure 6(b) displays each cluster's average torque and PWR values. Cluster 1 stands out with the highest torque of 14.25 Nm but the lowest PWR of 0.09, indicating a focus on engine torque, potentially at the expense of power-to-weight performance. In contrast, Cluster 2 has a lower torque of 9.64 Nm and an even lower PWR of 0.07, suggesting a more conservative and efficiency-oriented performance profile. Cluster 3, with a torque of 11.57 Nm and a PWR of 0.08, adopts a middle-ground approach, balancing torque and power output effectively.

These findings reveal the trade-offs inherent in motorcycle design. Cluster 1 prioritizes power and torque, making it suitable for performance-oriented applications but less fuel-efficient. Cluster 2 focuses on maximizing fuel efficiency, ideal for urban commuters. Cluster 3 represents a segment appealing to specific consumer preferences, where fuel efficiency is not a primary concern due to lifestyle choices, brand loyalty, or particular vehicle designs.

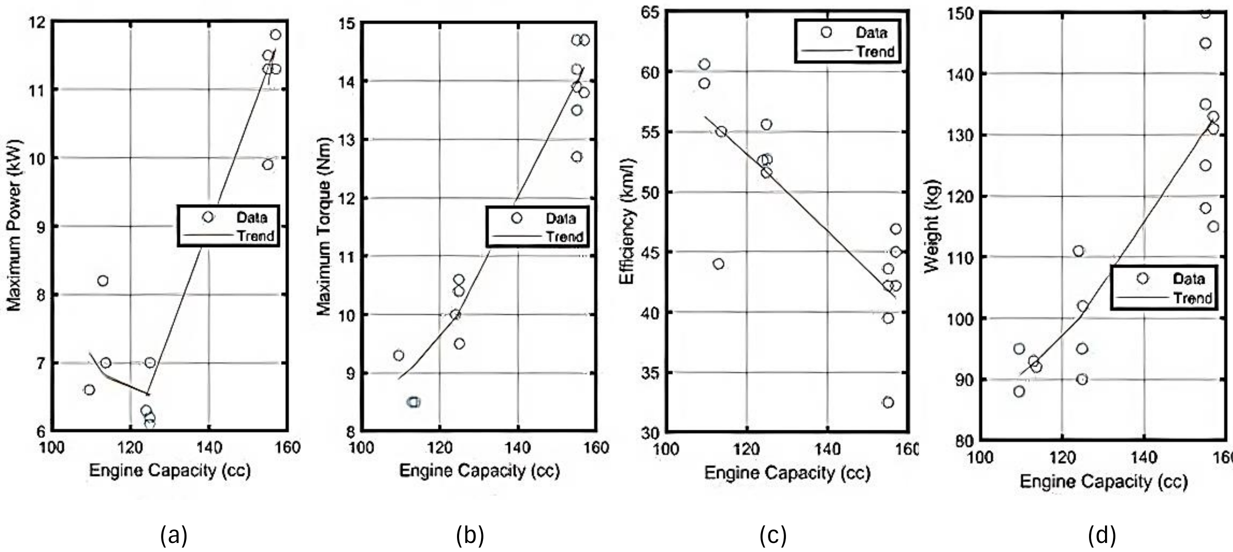


Figure 7. Overview of the average characteristics of each cluster; Trendlines for Power vs. Capacity (a), Torque vs. Capacity (b), Efficiency vs. Capacity (c), and Weight vs. Capacity (d)

Figure 7 provides a comprehensive analysis of how engine capacity influences motorcycle performance, using scatter plots with trendlines. The top three plots illustrate clear trends. First, there is a strong positive correlation between engine capacity and maximum power, demonstrating that as engine capacity increases, power output also increases—making such motorcycles suitable for performance-focused applications. Similarly, engine capacity shows a strong positive correlation with torque, indicating that larger engines generate more torque, which enhances acceleration and load-handling performance.

However, a negative correlation exists between engine capacity and fuel efficiency, indicating that as engine size increases, fuel efficiency declines. This highlights the trade-off between performance and fuel consumption.

The bottom four plots further detail these trends. The positive correlation between engine capacity and power reinforces the notion that greater engine size leads to higher power output. The correlation between engine capacity and torque confirms the role of engine size in increasing torque performance. In contrast, the inverse relationship between engine capacity and fuel efficiency emphasizes the efficiency loss associated with larger engines—an important factor for fuel-conscious consumers. Finally, the negative correlation between power and fuel efficiency illustrates that increased power typically results in higher fuel consumption, reaffirming the trade-off between performance and efficiency.

4. Conclusions

This study comprehensively analyzed the relationships between engine capacity, vehicle weight, engine torque, and fuel efficiency in motorcycles using MATLAB for both visual and statistical analysis, while excluding external factors such as road conditions, vehicle aerodynamics, and rider weight. The results revealed significant correlations among the variables, identifying engine capacity, vehicle weight, and torque as key factors influencing fuel consumption. A strong negative correlation was observed between engine capacity and fuel efficiency, indicating that larger engines, while offering higher power output, tend to consume more fuel and often result in higher vehicle tax classifications. Similarly, heavier motorcycles demonstrated lower fuel efficiency due to increased rolling resistance, highlighting the importance of weight optimization in improving fuel economy. Higher engine torque was also linked to decreased fuel efficiency, as increased torque demands more fuel, especially during acceleration or heavy-load usage; however, proper torque management could help mitigate these effects. When comparing models with engine capacities of 100–150 cc and 150–160 cc, motorcycles with smaller engines generally exhibited better fuel efficiency. Regression analysis further confirmed that increases in engine capacity, weight, and torque significantly contribute to reduced fuel economy. Fuel efficiency rankings showed substantial variation among models, emphasizing the role of design and engineering in achieving optimal performance. Top-performing motorcycles combined smaller engine capacities, lower weights, and efficient torque output to attain superior mileage. Therefore, consumers in urban environments are encouraged to opt for lightweight, low-capacity motorcycles to enhance efficiency, while those requiring higher performance for long-distance or heavy-load use may consider models in the 160 cc class. These findings underscore the importance of integrating considerations of engine size, weight, and torque into the design of motorcycles to meet consumer needs while promoting energy savings and reducing environmental impact.

References

[1] Asian Development Bank, *Southeast Asia and the Economics of Global Climate Stabilization*. Asian Development Bank, 2019.
[2] Indonesian Motorcycle Industry Association (AISI), *Annual Motorcycle Sales Data*. AISI, 2020.
[3] International Energy Agency (IEA), *Fuel Economy in Major Car Markets*. IEA, 2019.
[4] J. B. Heywood, *Internal Combustion Engine Fundamentals*, 2nd ed. McGraw-Hill Education, 2018.
[5] R. Stone, *Introduction to Internal Combustion Engines*, 4th ed. Palgrave Macmillan, 2012, doi: 10.1007/978-1-137-02829-7.
[6] World Bank, *Indonesia Urbanization Flagship Report*. World Bank, 2018.
[7] L. Guzzella and C. H. Onder, *Introduction to Modeling and Control of Internal Combustion Engine Systems*. Springer, 2010, doi: 10.1007/978-3-642-10775-7.
[8] H. Zhao, *HCCI and CAI Engines for the Automotive Industry*. Woodhead Publishing, 2007, doi: 10.1533/9781845693541.
[9] M. Deymi-Dashtebayaz and E. Tayyeban, "Exploring the thermoeconomic of converting 4-stroke combustion motorcycles to 2-stroke expansion models," *Research Square*, 2024, doi: 10.21203/rs.3.rs-5237999/v1.
[10] O. P. Calabokis, Y. Nuñez de la Rosa, P. C. Borges, and M. Sign, "Effect of an Aftermarket Additive in Powertrain Wear and Fuel Consumption of Small-Capacity Motorcycles: A Lab and Field Study," *Lubricants*, vol. 10, no. 7, p. 143, 2022, doi: 10.3390/lubricants10070143.
[11] D. A. Crolla, Ed., *Automotive Engineering: Powertrain, Chassis System, and Vehicle Body*. Butterworth-Heinemann, 2009.
[12] H. Huo, K. He, M. Wang, and Z. Yao, "Vehicle technologies, fuel-economy policies, and fuel-consumption rates of Chinese vehicles," *Energy Policy*, vol. 43, pp. 13–21, 2011. Doi: 10.1016/j.enpol.2011.09.064.
[13] D. Haber, "Lightweight materials for automotive applications: a review," SAE Technical Paper, no. 2015-36-0219, 2015, doi: 10.4271/2015-36-0219.
[14] European Aluminium Association (EAA), *Aluminum in Cars – Unlocking the Light-Weighting Potential*. EAA, 2016 [Online]. Available: https://european-aluminium.eu/wp-content/uploads/2022/10/aluminium-in-cars-unlocking-the-lightweighting-potential.pdf
[15] R. N. Jazar, *Vehicle Dynamics: Theory and Application*, 2nd ed. Springer, 2013, 10.1007/978-1-4614-8544-5.
[16] Robert Bosch GmbH., *Bosch Automotive Handbook*, 10th ed., SAE International, 2018.
[17] R. Kumar and W. Saleh, "Does motorcycle driving behaviour affect emission and fuel consumption?," *International Journal of Transportation*, vol. 3, no. 2, 2015, doi: 10.14257/ijt.2015.3.2.03.
[18] G. Cocco, *Motorcycle Design and Technology*. St. Paul, 2004.
[19] R. V. Dukkipati, *Vehicle Dynamics*. Narosa Publishing House, 2008.
[20] J. Lasocki, "The WLTC vs NEDC: a case study on the impacts of driving cycle on engine performance and fuel consumption," *Int. J. Automot. Mech. Eng.*, vol. 18, no. 3, 2021, doi: 10.15282/ijame.18.3.2021.19.0696.
[21] C. Mi and M. A. Masrur, *Hybrid Electric Vehicles: Principles and Applications with Practical Perspectives*, 2nd ed. Wiley, 2017, doi: 10.1002/9781118970553.
[22] R. Thring, *Fuel Cells for Automotive Applications*. Professional Engineering Publishing, 2013.
[23] M. Ivarsson, J. Åslund, and L. Nielsen, "Look-ahead control—consequences of a non-linear fuel map on truck fuel consumption," *Proc. Inst. Mech. Eng. D J. Automob. Eng.*, vol. 223, no. 4, pp. 443–452, 2009, doi: 10.1243/09544070jauto1131.
[24] United Nations Environment Programme (UNEP), *Global Outlook on Fuel Economy*. UNEP, 2016.
[25] M. A. Hossain, F. Ahmed, and M. S. Reza, "Experimental investigation of fuel and technical performance of motorcycle for modified swing arm," *Energy and Thermofluids Engineering*, vol. 4, pp. 25–36, Jun. 2024, doi: 10.38208/ete.v4.757.
[26] Honda Motor Co., Ltd., *Annual Report 2020*. Honda, 2020.
[27] Yamaha Motor Co., Ltd., *Sustainability Report 2020*. Yamaha, 2020.

[28] Ministry of Transportation, Indonesia, *National Transportation Policy*. Government of Indonesia, 2019.
[29] International Council on Clean Transportation (ICCT), *Two- and Three-Wheelers in Southeast Asia: Trends and Impacts*. ICCT, 2017.
[30] ASEAN Automotive Federation (AAF), *Automotive Industry Report*. AAF, 2019.