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*Research Article*

# Title Impact of Engine Downsizing on Fuel Economy and Carbon Footprint: A Simplified Modeling Approach

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**Abstract:** Global climate change demands immediate technological advancements, particularly in the transport industry that continues to use fossil fuels. One viable solution is to reduce the size of vehicle engines to make them more fuel-efficient and lower carbon emissions. The purpose of this research is to assess the effect of reducing engine size on fuel consumption and $CO_2$ emissions in low-cost green car hatchbacks in Indonesia. The technique employed is straightforward analytical modeling, employing Pearson correlation analysis and linear regression among three significant variables: engine capacity, fuel economy, and $CO_2$ emission. The data are obtained from the technical specifications of four hatchback automobile models, all of which have an engine capacity of less than 1,200 cc. Findings indicate that smaller engine capacity is accompanied by greater fuel economy and lower carbon emissions. The lowest engine size of 998 cc is used in the Toyota Agya, which demonstrates the most efficient fuel and lowest emissions. The statistical analysis shows that there is an inverse relationship between engine size and fuel efficiency, but a positive relationship between engine size and $CO_2$ emissions. The limitation of sample size causes reduced statistical power of the model. In conclusion, engine downsizing can prove to be a productive approach in promoting green schemes, but additional research with a larger data set and other determinants must be undertaken to establish a more advanced and precise model.

**Keywords:** carbon emissions; energy efficiency; Engine downsizing; fuel consumption; LCGC

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## 1. Introduction

Climate change and rising global temperatures have become urgent issues across the planet that require quick and effective responses (Humaida, 2024). The main cause of this predicament is the reliance on fossil fuels, which produce large amounts of greenhouse gas emissions (Dewi, 2010). Carbon dioxide ($CO_2$) and methane ($CH_4$) emissions from fossil fuel combustion significantly affect global warming and disrupt severe weather patterns (Sudarti, 2022).

In recent years, technologies for renewable energy have developed rapidly to reduce dependence on fossil fuels and lower greenhouse gas emissions (Darlin, 2023). Despite this, the transportation sector is still heavily dependent on fossil fuels (Kholiq, 2015). This highlights the importance of improving vehicle fuel efficiency (Andry & Narelle, 2015).

Hatchback vehicles in Indonesia, which embrace the Low Cost Green Car (LCGC) concept, have gained significant popularity due to their affordable price and better fuel economy (Purba & Nizmi, 2015). Nevertheless, reducing engine capacity can be an efficient approach to improve fuel economy and minimize carbon emissions (Benjamin et al., 2003). By utilizing a smaller engine, fuel usage and greenhouse gas emissions can be reduced, thus benefiting the environment (Michelle et al., 2022).

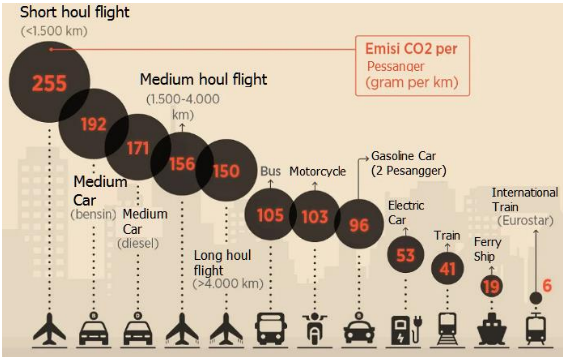


**Figure 1.** Global Transportation Sector $CO_2$ Emissions Trend Chart

Source: (Our world in Data Eurocontrol, 2022)

From an academic point of view, engine size reduction relies on the concept of improving energy efficiency (Ameya, 2018). By using less powerful engines, cars can reduce weight and drag, thereby minimizing the energy required for propulsion (Antonio, 2010). This can be illustrated by the energy efficiency formula, which calculates output energy as a fraction of input energy, where output signifies energy produced and input signifies energy consumed (René & Henri, 2006). Therefore, by shrinking the size of the machine, the input energy is reduced, which leads to an increase in output energy (Richard & Philip, 2014).

Previous research has shown that engine size reduction can lead to significant reductions in fuel use and carbon emissions. Research into LCGC vehicles shows that the use of smaller engines can reduce $CO_2$ emissions by up to 20% when compared to standard vehicles (Saptoadi, 2016). Therefore, this study aims to examine how engine size reduction affects the fuel efficiency and carbon footprint of LCGC hatchback cars.

The uniqueness of this study stems from its emphasis on a car model that is highly preferred in Indonesia and an uncomplicated modeling technique that can be widely used. As a result, this study has the potential to enhance the advancement of green technologies and more efficient environmental regulations in the automotive sector.

This study is crucial as the challenges posed by climate change and rising global temperatures demand quick and efficient solutions. By minimizing fuel use and lowering carbon emissions, this study can help reduce the ecological footprint associated with vehicle operation and support environmentally sustainable initiatives. Therefore, this study seeks to provide appropriate and valuable insights to the automotive sector and ecological regulations.

## 2. Study Literature

Numerous investigations regarding engine downsizing have taken place, revealing that cutting down engine size greatly influences fuel economy and emissions of greenhouse gases. Benjamin et al. (2003) and Michelle et al. (2022) pointed out that opting for smaller engines can lead to a substantial decrease in $CO_2$ emissions because of diminished fuel consumption. On the other hand, Antonio (2010) and René & Henri (2006) discuss that enhancing vehicle energy efficiency can be achieved by minimizing engine weight and aerodynamic drag through downsizing. This idea is supported by the thermal efficiency principle, which argues that a smaller energy input increases the likelihood of improved vehicle output efficiency.

Moreover, earlier studies conducted by Saptoadi (2016) and Humaida (2024) endorse promoting fuel-efficient vehicles, particularly LCGC, as a climate change mitigation measure. Research on the correlation of engine capacity with vehicle efficiency by Abdel-Halim et al. (2013) and Yusoff et al. (2015) found that bigger engines use more fuel and emit more emissions. ICCT (2021) and Al-Arkawazi (2020) reports further established that regulations on motor vehicles should take into account technological advances like downsizing to minimize the environmental effects, particularly in rapidly expanding car markets like Indonesia.

## 3. Research Method

In this research, a modeling strategy has been adopted in order to study the effect of reducing engine size on fuel economy and carbon dioxide emissions in hatchback vehicles belonging to the LCGC category. The analysis here is specifically focused on three areas: engine size, fuel economy, and $CO_2$ emissions. To keep the model basic and concentrated on the analysis, variables like vehicle weight, size, or engine technology have been excluded in this study.

All the hatchback models employed by LCGC in Indonesia are covered under this study. The chosen models are those cars whose engines have a displacement less than 1,200 cc, and one car model with the same engine displacement is present in this comparison. This approach is created to ensure consistency in the information and prevent any bias that would be brought by differences in other technical specifications not related to the engine, with emphasis on the impact of reducing engine size on fuel efficiency and greenhouse gas emissions. The automobile manufacturers' official product brochures were directly used to gain the technical specifications of the vehicles.

**Table 1.** Technical Specifications Comparison of LCGC Hatchback Vehicles

| Vehicle Model | Engine Type & Code | Engine Displacement (cc) | Max Power (PS/rpm) | Max Torque (Nm/rpm) | Transmission Type | Fuel Consumption (km/l) |
|---|---|---|---|---|---|---|
| Toyota Agya (2013) | 1KR-DE, 3-cylinder DOHC | 998 | 65 PS / 6,000 rpm | 85 Nm / 3,600 rpm | 5-speed Manual / AT | 20.6 |
| Mitsubishi Mirage (2012) | 3A92, 3-cylinder DOHC | 1,193 | 77 PS / 6,000 rpm | 100 Nm / 4,000 rpm | 5-speed Manual / CVT | 17.8 |
| Datsun GO (2014) | HR12DE, 3-cylinder DOHC | 1,198 | 68 PS / 5,000 rpm | 104 Nm / 4,000 rpm | 5-speed Manual | 20.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Honda Brio Satya (2012) | L12B i-VTEC, 4-cylinder SOHC | 1,199 | 88 PS / 6,000 rpm | 110 Nm / 4,800 rpm | 5-speed Manual / AT | 20.0 |

The measurement of carbon dioxide emissions is obtained using a standard formula to convert fuel consumption into emission rates :

$CO_2$ Emissions (g/km) = Fuel Consumption (L/100 km) × 23.2… (1)

The figure 23.2 is a conversion factor giving the average emission from combustion of a liter of petrol as calculated by the International Council on Clean Transportation (ICCT, 2021).

There were two primary stages of data analysis. The first involved the application of Pearson correlation analysis in examining the direction and magnitude of linear correlations between fuel consumption and engine capacity, as well as between engine capacity and $CO_2$ emissions (Susanti et al., 2019). The application of Pearson correlation analysis was guided by its effectiveness in identifying correlations between continuous numeric datasets (Schober et al., 2018). The second phase consisted of the use of simple linear regression analysis to analyze the correlation between engine capacity as an independent variable and fuel consumption and $CO_2$ emissions as dependent variables. The modeling approach enables researchers to determine the degree to which engine size changes affect fuel consumption and carbon dioxide production (Ehsani et al., 2016).

All results of the analysis are represented as scatter plots that include linear regression lines to demonstrate how different variables interact with one another. Each of these visualizations includes a correlation coefficient (r) and a coefficient of determination ($R^2$) to evaluate the strength of the relationship and the model's predictability. The visual outputs and quantitative analysis are interpreted to shed light on how downsizing influences fuel efficiency and carbon emissions, following the traditional methods employed in studies examining vehicle performance as a result of downsizing (Balaja et al., 2021). This methodology aims to provide a clear yet fairly accurate explanation of how variations in engine size impact two critical environmental factors: fuel usage and $CO_2$ emissions, particularly for LCGC hatchback models.

## 4. Results and Discussion

In this section, the author needs to explain the hardware and software used, dataset sources, initial data analysis, results, and results analysis/discussion. Presenting the results with pictures, graphs and tables is highly recommended. Formulas or evaluation measuring tools also need to be included here. There must be discussion/analysis, and you can't just rewrite the results in sentence form, but you need to provide an explanation of their relationship to the initial hypothesis. In addition, this section needs to discuss and elaborate on important findings.

Total emissions exhausted in the combustion process of every LCGC vehicle are computed using the formula:

$CO_2$ Emissions (g/km) = Fuel Consumption (L/100 km) × 23.2

$CO_2$ emissions of the Toyota Agya: (100:20.6) x 23.2 = 112.6 g/km

The outcome of such calculations is given in the following table:

**Table 2.** $CO_2$ Emission Calculation Results Based on Fuel Consumption

| No | Vehicle Type | Engine Displacement (cc) | Fuel Consumption (Km/L) | $CO_2$ Emission (g/Km) |
|---|---|---|---|---|
| 1 | Toyota Agya | 998 | 20.6 | 112.6 |
| 2 | Mitsubishi Mirage | 1,193 | 17.82 | 130.2 |
| 3 | Nissan Datsun Go | 1,198 | 20.0 | 116.0 |
| 4 | Honda Brio Satya | 1,199 | 20.0 | 116.0 |

Based on the data shown in the table, it's evident that the four vehicles in the LCGC (Low Cost Green Car) segment exhibit notable variations regarding engine size, fuel efficiency, and $CO_2$ output. The Toyota Agya, featuring the smallest engine at 998 cc, provides excellent fuel efficiency at 20.6 km/l and registers the least $CO_2$ emissions at 112.6 g/km. This indicates that a smaller engine leads to reduced fuel usage and fewer carbon emissions.

In contrast, the Mitsubishi Mirage, which has an engine capacity of 1193 cc, performs the poorest in terms of fuel efficiency with a rate of 17.82 km/l and the highest $CO_2$ emissions among all the vehicles, measuring at 130.2 g/km. This suggests that, although its engine size is comparable to the other two cars, the Mitsubishi Mirage falls short in energy efficiency and emissions. This disparity can be explained by factors such as engine design, the weight of the car, or the kind of transmission employed.

While the Nissan Datsun Go and Honda Brio with engine capacities of 1198 cc and 1199 cc, respectively, share the same fuel efficiency of 20 km/l and produce $CO_2$ emissions of 116 g/km. While the two cars have relatively good fuel efficiency, it is far from the exemplary work of the Toyota Agya. This means that parameters such as aerodynamic engineering, compression ratios, and internal combustion mechanisms are important to vehicle efficiency and overshadow the contribution of engine displacement (Johnsoin & Joshi, 2018).

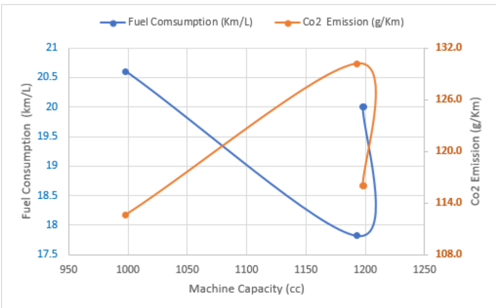


**Figure 2**. Relationship between Engine Capacity and Fuel Consumption and CO2 Gas Emissions

### 4.1. Effect of Engine Capacity on Fuel Consumption

The results from the analysis are a weak negative correlation between engine size and fuel efficiency, which is supported by a Pearson correlation of -0.520. This implies that fuel efficiency (km/L) reduces with an increase in engine size in cars. Therefore, cars with bigger engines are less fuel efficacious. The linear regression equation derived from this is:

Fuel Efficiency (Km/L) = -0.0064 × Engine Size (cc) + 26.95

This equation demonstrates how fuel efficiency decreases by approximately 0.64 km/L with each rise of 100 cc in engine capacity. This result agrees with that of other research, such as the study by Abdel-Halim et al. (2013), which indicated larger engine sizes have a detrimental effect on fuel efficiency as larger engines demand more energy to be efficient. Similarly, Yusoff et al.'s (2015) research indicated a size increase in the engine is usually followed by increased car weight and energy demand, promoting fuel use.

The model validation discovers that, while the model can pick up trends quite well, statistically there are flaws due to the small data set (with only 4 data points). A larger data set is required to ascertain the significance of the coefficients and to calculate $R^2$ accurately.

### 4.2. Effect of Engine Capacity on $CO_2$ Gas Emissions

The Pearson correlation coefficient between engine capacity and $CO_2$ emissions is 0.497, denoting a moderate positive correlation between both variables. In essence, it shows that as engine capacity increases, so do the $CO_2$ emissions of the car. The resulting formula for linear regression is given as:

$CO_2$ Emissions (g/Km) = 0.0392 × Engine Capacity (cc) + 73.79

This equation indicates that for each additional 100 cc of engine capacity, $CO_2$ emissions will increase by approximately 3.92 grams per kilometer. This is in accordance with a research study by the International Council on Clean Transportation (ICCT, 2014), which was able to establish that cars with larger engines emit higher levels of pollutants as they use more fuel. Furthermore, Al-Arkawazi et al. (2020) were able to conclude in their research that the size of an engine directly correlates with exhaust emissions, applicable in the case of gasoline cars.

However, just like the model in the case of fuel consumption, this framework also needs further verification, as it does not have backing data. While this model gives an initial glimpse at the linear relationship, it cannot be used as a valid predictor without further, more rigorous statistical analysis using significance testing, $R^2$ values, and residue checking.

## 5. Research Limitations

There are several limitations to this study that need to be mentioned in order to accurately assess the findings. Foremost, the study used an extremely small sample size of just four cars, which affects the generalizability of the findings and reduces statistical power. Furthermore, the study only considered engine displacement and did not consider other important determinants of fuel consumption and emissions, including vehicle weight, fuel type, engine or compressor type, and test procedures. Also, as there was insufficient data, no significant analysis such as t-tests or p-value tests was run; hence, the validity of the regression model could not be determined statistically. Finally, the simple linear regression model presupposes a straight-line relationship between the variables, but in automotive engineering, the relationships can be non-linear and are liable to interference from a number of other variables. Thus, additional studies with more samples and full statistical analyses must be carried out to yield more stable and precise results.

## 6. Conclusions

This research examined the effect of reducing the size of the engine on fuel efficiency and carbon dioxide ($CO_2$) emissions in hatchback cars that belong to the Low Cost Green Car (LCGC) category. Through correlation and simple linear regression tests, it was confirmed that engine size has a major influence on both environmental factors. As engine size reduces, fuel efficiency increases, and $CO_2$ emissions reduce. The outcome of the regression analysis indicated that there was a negative correlation between engine size and fuel usage, while a positive correlation between engine size and carbon emissions; however, their statistical significance is limited because of the small sample size. The results are significant as far as car design and the creation of environmental policies are concerned. Technically, taking up downsized engine designs has proven to be an efficient method of making cars more energy efficient as well as environmentally friendly. Car manufacturers are thus advised to research and develop further this type of smaller engines, which can provide high performance through the preservation of new technologies. For future work, it is highly advised to use a greater dataset and incorporate additional variables such as mass of vehicle, type of fuel, technology of the engine, and aerodynamics in order to form a more accurate and representative model. With more advanced statistical tools used along with non-linear modeling or machine learning, it will also be possible to provide a more accurate and detailed model of the correlation between engine size, fuel efficiency, and emissions.

**Author Contributions:** For finishing the study of the article manuscript, everyone's collaboration and contribution are required. Mr. Priyono is the idea generator. Mr. Fahrizal is responsible for the research method. Damianus Manesi is responsible for applications in data analysis and processing and templates. Edy Suprapto is responsible for data validation and tools as well as the supervision of field operations. Mr. Wofrid Bianome is responsible for the administrative task.

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