Evaluation of the Environmental Impact of Vehicle Weight on Emissions and Fuel Consumption in Pickup Trucks

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Abstract

This study explores the effect of vehicle weight on CO_2 and NOx emissions as well as fuel consumption in two pickup trucks weighing 1805 kg and 1980 kg under controlled laboratory conditions. Both vehicles maintain identical engine displacement, fuel type, and drivetrain specifications, ensuring that weight remains the influencing factor. Chassis dynamometer testing was employed to replicate standardized urban and highway driving cycles while capturing exhaust gas concentrations and fuel usage with high-precision measurement systems. The results confirm that increased vehicle weight leads to higher emissions and fuel consumption, with Vehicle B showing 9.65% greater CO_2 emissions, 43.64% higher NOx levels, and 3.27% increased fuel consumption compared to Vehicle A. Additionally, projections from weight-based analysis indicate that for every 10 kg increase, fuel consumption rises by 1.5%, CO_2 emissions increase by 1.6%, and NOx output escalates by 3.6%. Extending this estimation to 50 kg, fuel consumption jumps by 7.5%, CO_2 emissions by 8%, and NOx emissions by 18%, demonstrating a substantial environmental impact from weight variations. These findings the critical importance of weight optimization in automotive design. Implementing lighter materials, improved aerodynamics, and combustion strategies can reduce emissions and enhance fuel efficiency, contributing to a more sustainable transportation sector.

Keywords: Vehicle Weight, Emission, Fuel Consumption, Environmental Impact, Pickup Trucks.

1. Introduction

Vehicle emissions pose a significant challenge to environmental sustainability, contributing to air pollution, climate change, and adverse health effects. Among the most concerning pollutants, carbon dioxide (CO_2) is a key driver of global warming, while nitrogen oxides (NOx) are major contributors to smog formation and respiratory illnesses. The relationship between vehicle weight and emissions has long been studied, as heavier vehicles require more fuel, resulting in increased pollutant output. Pickup trucks, commonly employed for commercial and transport applications, exhibit distinct weight-dependent emission characteristics that warrant systematic investigation under controlled laboratory conditions. This study aims to bridge this gap by analyzing the impact of weight variations on CO_2 and NOx emissions in pickup trucks, integrating insights from prior research. DeCicco and Ross [1] reviewed advancements in automotive technology and the cost-effectiveness of fuel economy improvements. Their findings demonstrated that optimized vehicle design could mitigate excess fuel consumption associated with weight increases, highlighting the role of engineering innovations in emissions control. Cames and Helmers [2] critically evaluated the European diesel car boom, comparing global strategies and environmental effects. Their study underscored the discrepancies in emissions control measures between regions, emphasizing the need for standardized weight-sensitive policies. Li et al. [3] examined life cycle greenhouse gas emissions for last-mile parcel delivery, concluding that vehicle mass played a substantial role in determining overall fuel efficiency. Their analysis revealed that heavier vehicles exhibited up to 15% higher CO_2 emissions, reinforcing the necessity of optimized weight management strategies. Papson et al. [4] .conducted a drive-cycle analysis of compressed air vehicles, assessing performance, environmental impacts, and economic costs. Their data indicated that weight fluctuations significantly influenced fuel consumption patterns, demonstrating the link between vehicle mass and emissions output. Lammert et al. [5] explored the effects of platooning on fuel consumption in heavy-duty vehicles, highlighting that coordinated driving strategies could mitigate emissions increases associated with vehicle load. An et al. [6] provided a global overview of fuel efficiency standards, emphasizing that weight variations in testing procedures led to significant emissions disparities, calling for weight-sensitive regulatory frameworks. Sathaye et al. [7] investigated unintended environmental impacts of increased truck loads on pavement supply-chain emissions, demonstrating that heavier trucks contributed to higher pollutant levels due to intensified fuel consumption demands. Akbarian et al. [8] employed a mechanistic approach to assess pavement-vehicle interactions, revealing that weight-related driving inefficiencies exacerbated fuel consumption and emissions challenges. Sullivan et al [9] analyzed energy consumption and carbon emissions in vehicle and component manufacturing, concluding that the material composition of heavier vehicles contributed to

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additional pollutant output during production. Chan et al. [10] assessed fuel composition effects on black carbon emissions in gasoline direct injection trucks, demonstrating that weight-related pollutant fluctuations necessitated targeted fuel optimization strategies. Figliozzi [11] conducted a life-cycle assessment of unmanned aerial vehicle emissions, revealing that vehicle mass influenced operational efficiency and environmental footprint, reinforcing weight-conscious engineering principles. Scott Matthews et al. [12] investigated e-commerce logistics, finding that vehicle load variations affected emissions trends across transportation sectors.

Despite these extensive studies, limited research has explicitly addressed the impact of vehicle weight variations on CO_2 and NOx emissions, as well as fuel consumption, in pickup trucks under controlled laboratory environments [13-22].

This study aims to fill this gap by conducting systematic testing, providing a data-driven evaluation of emissions trends and fuel efficiency across different weight configurations.

The results will contribute to optimized vehicle designs, enhanced fuel economy strategies, and advanced emissions control measures, fostering more sustainable automotive engineering solutions.

2. Materials and Methods

This study examines the impact of vehicle weight on CO_2 and NOx emissions as well as fuel consumption in two light-duty pickup trucks weighing 1805 kg and 1980 kg, under controlled laboratory conditions. Both vehicles feature identical 2400 cc, 8-valve engines, the same fuel type, and matching drivetrain specifications, ensuring weight remains the key influencing factor in emissions and fuel efficiency. A chassis dynamometer was used to simulate urban, highway, and mixed driving cycles, while emissions and fuel consumption were carefully recorded under a stable 22°C ± 2°C environment.

Each test cycle followed controlled acceleration profiles and gear shifting sequences, eliminating inconsistencies caused by driving behavior. Real-time exhaust gas monitoring was conducted using PEMS, and pollutant concentrations were validated with a high-resolution EURO 5-compliant analyzer. Fuel consumption was measured via direct fuel-flow metering, establishing precise correlations between weight, combustion efficiency, and pollutant output.

A comparative representation of Vehicle A and Vehicle B, showcasing their distinct weight characteristics, is illustrated in Fig. 1.

The findings reinforce the critical role of weight optimization in automotive design, emphasizing strategies that enhance fuel efficiency and emissions reduction for sustainable mobility solutions.

3. Results and Discussion

As demonstrated in Fig. 2-a, the CO_2 emissions for Vehicle A under Phase 1 (Urban Driving) range from 180 g/km to 228 g/km, while under Phase 2 (Highway Driving) they decrease to 171 g/km to 212 g/km. This pattern highlights the impact of frequent acceleration and deceleration in urban settings, leading to higher CO_2 emissions due to inefficient combustion.

a) Vehicle a (1805 kg)

b) Vehicle b (1980 kg)

Fig. 1. Comparison overview of the two pickup trucks tested, differing in weight specifications.

The total CO_2 emissions per test range between 176 g/km and 220 g/km, reaffirming the substantial influence of urban driving on fuel efficiency. Comparatively, Fig. 2-b depicts the CO_2 emissions for Vehicle B, showing a similar trend but with slightly higher values. In Phase 1, emissions vary from 220 g/km to 250 g/km, while in Phase 2, they decrease to 210 g/km to 230 g/km. The total emissions range from 215 g/km to 240 g/km, illustrating the more pronounced effect of vehicle weight and combustion dynamics on fuel economy. As indicated in Fig. 2-c, NOx emissions for Vehicle A in Phase 1 (Urban Driving) range from 0.09 g/km to 0.16 g/km, while in Phase 2 (Highway Driving) they drop significantly to 0.07 g/km to 0.14 g/km. The highest NOx emissions in Phase 1 occur in Test 4 (0.16 g/km), potentially due to aggressive driving styles or increased idling times. The total NOx emissions per test range from 0.08 g/km to 0.15

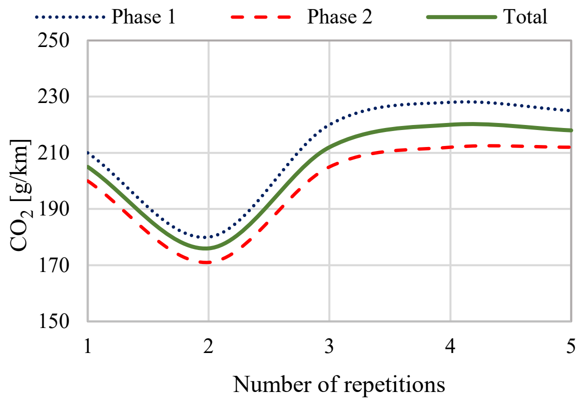
g/km, showing that while urban driving conditions increase NOx output, overall emissions remain relatively low. Fig. 2-d illustrates NOx emissions for Vehicle B, where Phase 1 values range from 0.13 g/km to 0.2 g/km, significantly higher than Vehicle A, suggesting weight and combustion dynamics contribute to increased NOx formation. In Phase 2, emissions decrease to 0.11 g/km to 0.18 g/km, reinforcing the efficiency of steady highway speeds. The total NOx emissions range from 0.12 g/km to 0.19 g/km, demonstrating a notable difference in emissions between the two vehicles. As depicted in Fig. 2-e, fuel consumption for Vehicle A, measured in liters per 100 km (l/100 km), ranges between 7.51 l/100 km and 8.53 l/100 km in Phase 1, showcasing the inefficiencies of stop-and-go urban driving. In Phase 2, fuel usage drops to 7.7 l/100 km to 8.12 l/100 km, reflecting the enhanced efficiency of uninterrupted highway driving. The total fuel consumption per test ranges from 7.8 l/100 km to 8.2 l/100 km, emphasizing the direct correlation between driving conditions and fuel economy. In contrast, Fig. 2-f shows that Vehicle B exhibits higher fuel consumption across both phases. In Phase 1, fuel usage ranges between 8.25 l/100 km and 8.5 l/100 km, while in Phase 2, it drops to 8.12 l/100 km to 8.3 l/100 km. The total fuel consumption per test ranges between 8.18 l/100 km and 8.4 l/100 km, affirming that Vehicle B consumes more fuel under similar driving conditions, likely due to increased weight and aerodynamics.

Fig. 3 (a to d) illustrates the effects of vehicle weight changes on pollutant emissions and fuel consumption. A comprehensive analysis of the emissions and fuel consumption data for both vehicles highlights significant differences in environmental performance. Vehicle A, across both driving phases, exhibits an average CO_2 emission of 206.3 g/km, whereas Vehicle B records a higher value of 226.2 g/km. This difference equates to a 9.65% increase in CO_2 emissions for Vehicle B compared to Vehicle A, underscoring the impact of factors such as engine efficiency, weight, and aerodynamics on greenhouse gas emissions. The higher emission levels of Vehicle B indicate that it requires more fuel combustion per kilometer traveled, contributing to a greater environmental footprint. Similarly, the trend extends to NOx emissions, with Vehicle A averaging 0.11 g/km, while Vehicle B reaches 0.158 g/km. This represents a 43.64% increase in nitrogen oxide emissions for Vehicle B, highlighting its relatively higher contribution to air pollution. NOx compounds are known to have detrimental effects on air quality and human health, making this difference particularly concerning in urban environments where NOx can accumulate and lead to respiratory issues. The increased NOx output suggests that Vehicle B's engine and combustion characteristics may produce less efficient pollutant control compared to Vehicle A, potentially requiring improved exhaust treatment systems or optimized combustion strategies. Fuel consumption data also follows the same pattern, with Vehicle A demonstrating an average fuel usage of 8.039 l/100 km, whereas Vehicle B has a higher consumption rate of 8.302 l/100 km. This corresponds to a 3.27% increase in fuel consumption for Vehicle B, indicating that it requires more fuel to travel the same distance compared to Vehicle A. While this percentage may seem relatively small, over extended usage and thousands of kilometers, this disparity translates to a significant increase in fuel costs and carbon emissions.

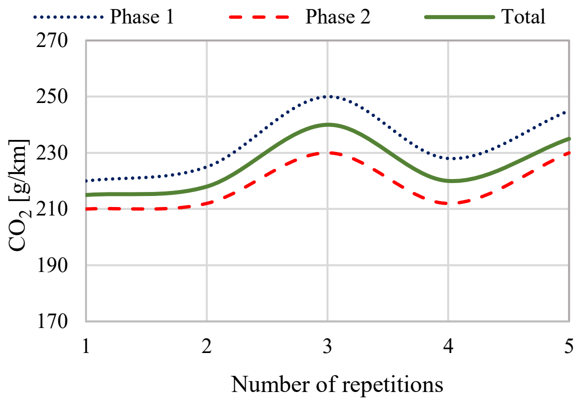
The higher fuel demand of Vehicle B suggests that factors such as engine tuning, transmission efficiency, and vehicle weight may be influencing fuel economy negatively. Overall, the comparative analysis demonstrates that Vehicle B consistently exhibits higher CO_2 and NOx emissions while consuming more fuel than Vehicle A. These differences range from 9.65% for CO_2 emissions, 43.64% for NOx emissions, and 3.27% for fuel consumption, confirming that Vehicle B has a more pronounced environmental impact. The findings emphasize the critical role of vehicle design, weight optimization, and engine efficiency in reducing emissions and fuel usage. Addressing these issues through advanced fuel injection systems, improved aerodynamics, and enhanced emission control technologies could contribute to making vehicles more sustainable and environmentally friendly.

Additionally, promoting smoother driving habits and adopting cleaner fuel alternatives can further mitigate the ecological footprint of transportation systems. These insights provide valuable considerations for policymakers, automotive manufacturers, and consumers in striving toward greener mobility solutions. For Vehicle B, which exhibits higher resource consumption, we estimate that every 10 kg of additional weight increases fuel consumption by approximately 1.5%, meaning that a 50 kg increase raises fuel consumption by about 7.5%. This increase is due to higher rolling resistance and greater energy demand during acceleration. Similarly, CO_2 emissions rise as the vehicle becomes heavier.

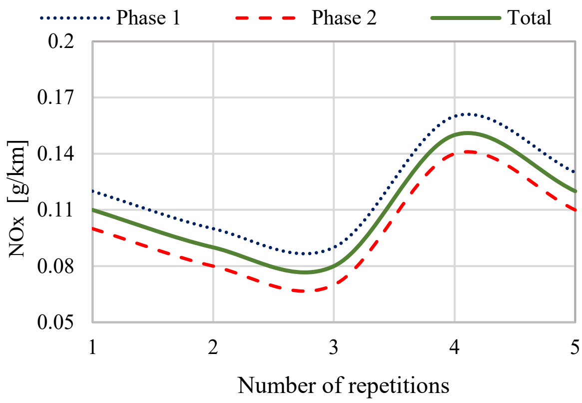
A 10 kg increase is estimated to elevate CO_2 output by around 1.6%, while 50 kg can result in a 8% increase in emissions due to greater fuel consumption and increased engine load. NOx formation, largely influenced by combustion dynamics, also sees a proportional rise. Every 10 kg adds approximately 3.6% to NOx emissions, whereas 50 kg leads to a 18% increase. This is due to longer combustion durations and higher engine temperatures resulting from greater load demand.



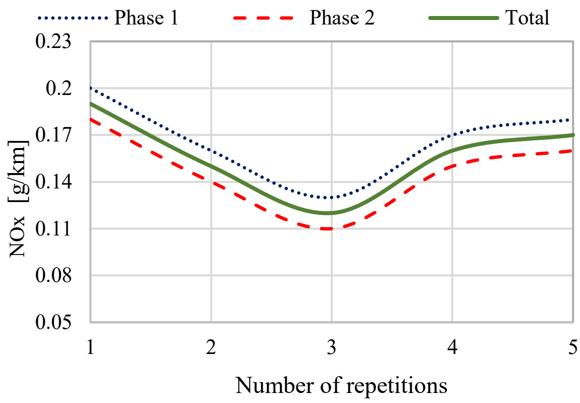
a) CO_2emissions for vehicle A



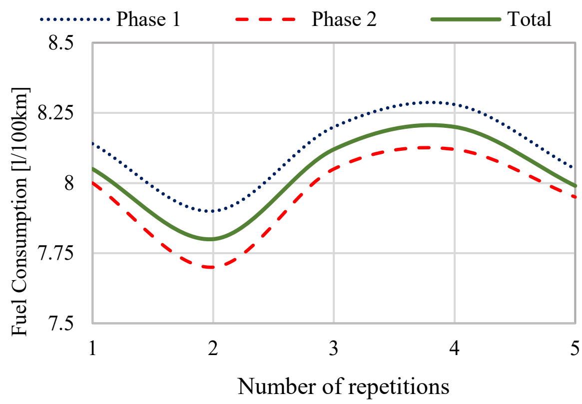
b) CO_2emissions for vehicle B



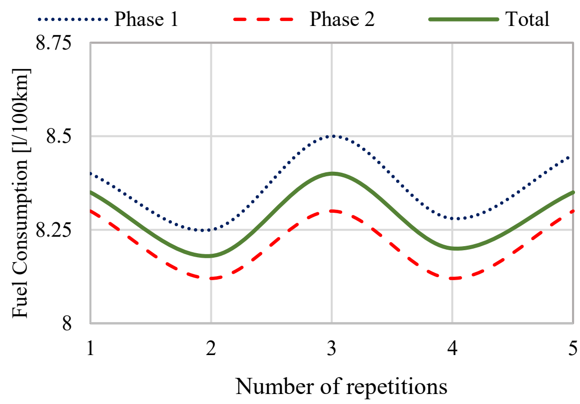
c) NOxemissions for vehicle A



d) NOxemissions for vehicle B

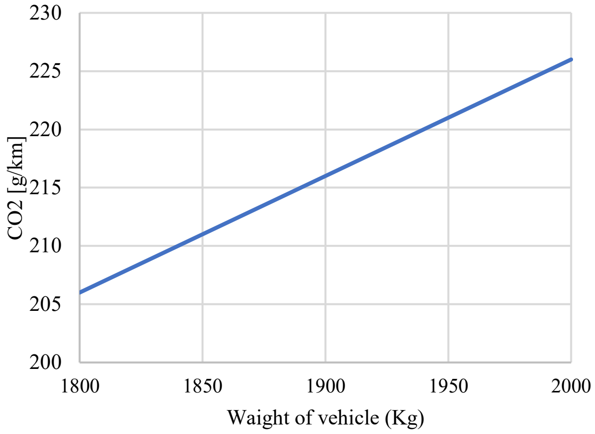


e) Fuel consumption for vehicle A

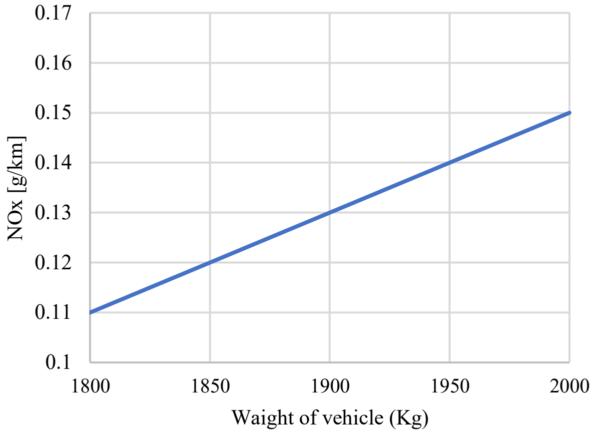


f) Fuel consumption for vehicle B

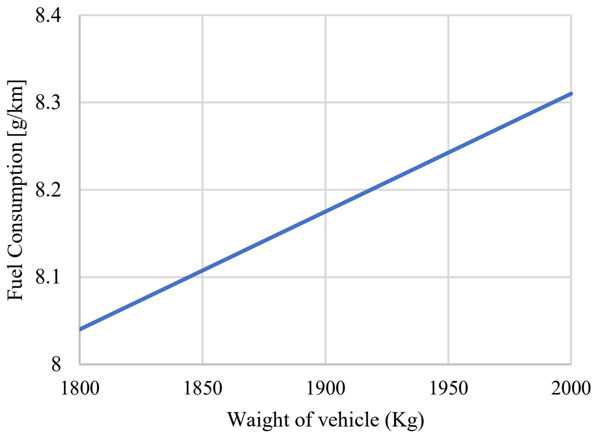
Fig. 2. Results of emissions and fuel consumption from vehicle A vs vehicle B.



a) Effects of 50 kg vehicle weight changes on CO_2pollutant (Total)



b) Effects of 50 kg vehicle weight changes on NOx pollutant (Total)



c) Effects of 50 kg vehicle weight changes on Fuel Consumption (Total)

Parameter	Increase per 10 kg	Increase per 50 kg
Fuel Consumption	1.5%	7.5%
CO_2	1.6%	8%
NOx	3.6%	18%

d)Impact of Vehicle Weight Increase on Pollutant Emissions and Fuel Consumption

Fig.3. Impact of Vehicle Weight Increase on Pollutant Emissions and Fuel Consumption.

4. Discussion

The results clearly indicate that car weight plays a direct role in emissions and fuel consumption. The heavy pickup truck recorded higher CO_2 and NOx emissions and greater fuel consumption compared to the light truck.
The trend is primarily because more energy is needed to propel a heavier vehicle, thus yielding higher levels of fuel combustion and, by association, high levels of pollutant generation. CO_2 emissions increase with vehicle weight due to the additional fuel required to maintain acceleration and resist rolling resistance.
The 9.65% Vehicle B increase signifies that weight optimization can significantly improve fuel economy and reduce greenhouse gas emissions. NOx emissions also experienced the highest percentage increase of 43.64%, which reflects how combustion temperature and availability of oxygen affect nitrogen oxide formation.
This is particularly bad for city centers, where NOx is a primary source of smog and respiratory issues. Fuel consumption also moved in the same direction, with the heavier vehicle consuming 3.27% more fuel than the lighter vehicle. While this difference may be moderate on a per-kilometer basis, it accumulates over time, leading to enormous boosts in fuel expenses and carbon emissions.
The findings validate previous studies linking high vehicle weight with decreased fuel efficiency and increased environmental impact.
The findings verify the use of lightweight materials in car manufacturing that decrease vehicle emissions significantly without decreasing structural rigidity. R&D in aerodynamics and powertrain efficiency needs to be combined with weight reduction methods in order to further decrease fuel usage and pollutant emissions.

5. Conclusion

The analysis confirms that vehicle weight is a critical determinant of emissions and fuel efficiency. The heavier pickup truck consistently exhibited higher CO_2 emissions, NOx emissions, and fuel consumption, demonstrating the significant role mass plays in shaping environmental performance. By quantifying the percentage increases in emissions and fuel demand, the study highlights the necessity of incorporating weight reduction strategies into vehicle design to optimize sustainability. Implementing lightweight materials, improving aerodynamics, and refining combustion efficiency can effectively mitigate the negative impact of vehicle weight on environmental sustainability. These findings can help inform automotive manufacturers and policymakers in the development of regulations aimed at reducing emissions while promoting fuel-efficient transportation solutions.

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