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Analysis of the Influence of Heavy Vehicles on Air Quality in the Transportation System Freight Transport

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ABSTRACT
The transportation sector, particularly heavy diesel-fueled vehicles, is one of the major contributors to air pollution due to exhaust emissions. The implementation of B50 Biodiesel as part of the national energy transition policy is expected to reduce vehicle emissions and improve air quality. This study aims to analyze the influence of heavy vehicles on air quality based on variations in vehicle weight and mileage, compare emission levels between vehicles using B50 Biodiesel and non-B50 Biodiesel fuels, and project the potential reduction of air pollution in freight transportation systems. The study employed a quantitative approach using experimental and comparative methods involving diesel vehicles weighing 8.5 tons, 8.6 tons, 25 tons, and 26 tons, which were tested over distances ranging from 5,000 km to 40,000 km. Data analysis was conducted using linear regression, independent samples t-test, descriptive analysis, and emission trend projection. The results showed that vehicle weight and mileage significantly affected opacity emissions, with a coefficient of determination of 51.8%. Furthermore, the use of B50 Biodiesel resulted in lower opacity emissions compared with non-B50 fuels and demonstrated the potential to reduce air pollution by up to 34%. Therefore, the implementation of B50 Biodiesel can serve as an effective policy alternative to support sustainable transportation and improve air quality.

INTRODUCTION

The transportation sector is one of the major contributors to greenhouse gas emissions and air pollution worldwide, with diesel-fueled heavy-duty vehicles being significant contributors due to their high operational intensity and fossil fuel consumption. Countries worldwide are facing increasing pressure to control road transportation emissions through low-carbon energy and fuel transition policies, in line with efforts to achieve sustainable development targets and international carbon emission reduction commitments. Studies examining the relationship between traffic volume, urban driving conditions, and motor vehicle emission levels have shown that vehicle operating patterns, including stop-and-go conditions on urban roads, significantly influence emission levels and fuel consumption (Tong & Hung, 2011). In addition, meteorological factors, such as wind speed, affect the altitude and dispersion distance of pollutants from vehicle emissions, indicating that transportation-related air quality problems are not only local issues but also involve broader and more complex environmental dimensions (Suleymanov et al., 2024). This phenomenon confirms that declining air quality due to land transportation activities, particularly heavy-duty vehicles, is a global challenge requiring sustainable solutions, including alternative fuel innovations such as biodiesel (Kochanek et al., 2025; Ogunkunle & Ahmed, 2021; Reddy et al., 2024; Teixeira et al., 2021).

In Indonesia, transportation-related air pollution is influenced by several interconnected factors. Road transportation dominates national mobility, accounting for approximately 85% of passenger movements and 90% of freight transportation, resulting in a substantial number of motor vehicles operating daily (Humami, 2024). Vehicle operational characteristics are also determining factors, as mileage, vehicle age, and engine displacement have been shown to significantly influence increases in carbon monoxide (CO), hydrocarbons (HC), and exhaust gas opacity (Humami, 2024). Another study demonstrated that accumulated mileage of diesel vehicles contributes to changes in particulate emission factors as vehicle age increases in EURO 5 and EURO 6 diesel engine vehicles (Boveroux et al., 2021). High dependence on fossil fuels, limited innovation in environmentally friendly fuel adoption for heavy-duty vehicles, and insufficient studies on the operational impacts of heavy vehicles under actual road conditions contribute to increasing air pollution risks in the freight transportation sector.

The accumulation of these factors directly affects air quality degradation, particularly in urban areas and logistics corridors with high heavy vehicle traffic intensity. Based on data from the Ministry of Environment and Forestry of the Republic of Indonesia, the transportation sector contributes approximately 44% of total air pollution in DKI Jakarta, making it the dominant source of air pollution in the capital city. Land transportation, while serving as a primary component of community mobility and national economic growth, also generates negative externalities in the form of declining air quality, which may increase public health risks (Amalia et al., 2025). High exhaust gas opacity is not only an indicator of air pollution but also reflects inefficient fuel combustion (Kochanek et al., 2025; Ogunkunle & Ahmed, 2021; Sobczuk & Borucka, 2024; Teixeira et al., 2021). Therefore, transportation system performance can no longer be assessed solely based on mobility and operational efficiency but must also consider its environmental impact on long-term transportation sustainability.

Various studies have investigated the relationship between vehicle characteristics, fuel types, and emissions. Boveroux et al. (2021) demonstrated that accumulated diesel vehicle mileage contributes to changes in particulate emission factors as vehicle age increases in EURO 5 and EURO 6 diesel engine vehicles. Humami (2024) found that vehicle mileage, age, and engine displacement significantly influence increases in carbon monoxide (CO), hydrocarbon (HC), and exhaust gas opacity emissions in commercial vehicles in Indonesia. Sitorus et al. (2018) conducted laboratory-based biodiesel emission testing, while Hakim et al. (2025) discussed the opportunities and challenges of the B50 Biodiesel policy in supporting Indonesia’s national energy transition but did not specifically examine the environmental impacts of B50 use in heavy-duty vehicles under real operational conditions. Tomo and Brunner (2022) reported a reduction in greenhouse gas emission intensity of approximately 28.19% through B30 Biodiesel use compared with pure diesel in generator applications, while Suleymanov et al. (2024) showed that meteorological factors, such as wind speed, influence the altitude and dispersion distance of pollutants from vehicle emissions. Kraus (2021) emphasized that transportation performance should be evaluated not only from technical and operational perspectives but also from environmental dimensions. Furthermore, Amalia et al. (2025) confirmed that land transportation produces negative externalities through declining air quality, which may increase public health risks.

Heavy-duty vehicles with a gross vehicle weight exceeding 3.5 tons represent the main focus of this study because their operational characteristics, including large payload capacity, high fuel consumption, and long travel distances, result in a more dominant contribution to exhaust emissions compared with light-duty vehicles. As a policy response to these challenges, the Indonesian government has implemented biodiesel mandates progressively from B20 and B30 to B40 and has prepared the implementation of B50 Biodiesel in 2026 as one of the national energy transition policy instruments (Hakim et al., 2025). This policy is expected to reduce greenhouse gas emissions, decrease dependence on fossil fuels, and strengthen national energy security sustainably (Addo et al., 2023; Belaïd et al., 2023; Falcone, 2023; Rabbi et al., 2022; Zhang & Usman, 2025). In this context, exhaust gas opacity (%) was used as the primary parameter to evaluate the impact of B50 utilization on heavy-duty vehicles with weight variations of 8.5 tons, 8.6 tons, 25 tons, and 26 tons, tested at cumulative mileages ranging from 5,000 km to 40,000 km to represent actual freight transportation operating conditions.

This research presents novelty in terms of research objects, policy context, transportation technical approach, variables and indicators, and prospective analysis. Unlike previous studies that primarily analyzed biodiesel emissions through static or laboratory-based approaches (Sitorus et al., 2018), this study applied a real operational condition approach involving variations in vehicle weight and cumulative mileage of up to 40,000 km. This study also represents one of the initial investigations in Indonesia examining the environmental impact of B50 fuel implementation in heavy-duty vehicles within the context of national policy preparation for 2026. Exhaust gas opacity emissions were used as an indicator of freight transportation environmental performance, complemented by prospective analysis of potential emission trends over the next five years (Čokorilo et al., 2019; Ding et al., 2025; Merkisz et al., 2017; Parris et al., 2024; Sharma et al., 2020).

The urgency of this study is based on the limited number of studies specifically examining the environmental impacts of B50 Biodiesel use in heavy-duty vehicles under actual road operational conditions in Indonesia, despite the planned national implementation of the B50 policy in 2026. The lack of sufficient scientific evidence regarding the effect of B50 on heavy vehicle exhaust opacity emissions may hinder policy evaluation and evidence-based decision-making in supporting sustainable transportation. This is particularly important because transportation performance must now be assessed not only from technical and operational aspects but also from environmental perspectives (Kraus, 2021). Therefore, investigating the influence of heavy-duty vehicles on air quality within freight transportation systems, particularly through B50 fuel utilization, is essential as a basis for anticipating environmental impacts before large-scale implementation of the policy across Indonesia.

Based on this background, this study aims to: (1) analyze differences in B50 exhaust emission test results based on vehicle weight and mileage of 5,000 km, 10,000 km, 20,000 km, 30,000 km, and 40,000 km; (2) compare exhaust emission test results between vehicles using B50 and non-B50 fuels in vehicle categories weighing 8.5 tons, 8.6 tons, 25 tons, and 26 tons; and (3) project potential increases in exhaust gas opacity (%) emissions from the use of B50 fuel over the next five years.

This research is expected to provide academic and practical benefits for various stakeholders. Academically, this study contributes to the development of knowledge in sustainable transportation and renewable energy, particularly regarding the effects of B50 Biodiesel on heavy-duty vehicles. It may also serve as a reference for future research related to energy transition in the land transportation sector and clean air development in transportation systems. For the government, the findings are expected to provide scientific insights into the environmental impacts of B50 Biodiesel implementation, serving as input for transportation and energy policy formulation while supporting national efforts to reduce emissions and improve air quality in the freight transportation sector sustainably.

RESEARCH METHODS

This research employed a quantitative approach with experimental and comparative research designs to analyze the effect of B50 Biodiesel utilization on air quality based on exhaust gas opacity emission indicators in heavy-duty vehicles within freight transportation systems. The research was designed to provide empirical evidence regarding the relationship between vehicle weight, operational mileage, and fuel type on emission levels, thereby supporting sustainable transportation policy development. The research was conducted at vehicle emission testing facilities and freight transportation operational routes in the Jakarta area during 2025. The research stages were systematically organized, including research object identification, data collection, emission testing, data processing, and result interpretation to address the research objectives comprehensively.

The research population consisted of heavy-duty diesel vehicles weighing more than 3.5 tons operating in freight transportation systems. The research sample was selected using purposive sampling based on the suitability of vehicle characteristics with the research objectives, including heavy-duty vehicles weighing 8.5 tons, 8.6 tons, 25 tons, and 26 tons that used B50 Biodiesel and non-B50 fuels. Observations were conducted at several cumulative mileage intervals, namely 5,000 km, 10,000 km, 20,000 km, 30,000 km, and 40,000 km, to observe changes in emission characteristics over time. Primary data were obtained through direct exhaust gas opacity measurements using smoke testers following diesel vehicle emission testing procedures. Secondary data were obtained from vehicle technical documents, government regulations, previous research findings, and scientific literature related to sustainable transportation, biodiesel, and air quality. The research instruments included observation sheets, emission testing equipment, field documentation, and data processing software to support the validity and reliability of the results.

Data analysis was conducted in several stages to describe vehicle emission characteristics based on variations in vehicle weight and mileage, compare emission levels between vehicles using B50 Biodiesel and non-B50 fuels, and project potential emission changes related to air quality improvement in freight transportation systems. The analysis began with descriptive analysis to summarize research data characteristics, followed by linear regression analysis to examine the effects of vehicle weight and mileage on exhaust gas opacity emissions. Furthermore, an independent samples t-test was conducted to compare emission characteristics between B50 Biodiesel and non-B50 fuel usage. Emission trend projection analysis was also performed to estimate the potential impact of B50 Biodiesel implementation on reducing air pollution in the freight transportation sector. All data processing was performed using SPSS software, and the analysis results were used as a basis for developing sustainable transportation policy recommendations oriented toward emission reduction and air quality improvement.

RESULTS AND DISCUSSION

To ascertain the magnitude and statistical significance of the vehicle weight category and cumulative mileage on emission opacity, multiple linear regression analysis was performed with the help of SPSS. A summary of the regression model results (model summary) is presented in Table 1.

Tabel 1. Model Summary

Parameter	Value
R	0,720
R Square	0,518
Adjusted R Square	0,492
Std. Error of the Estimate	1,135

Source: Researcher Data Processing (SPSS)

The value of the correlation coefficient (R) of 0.720 and the determination coefficient (R Square) of 0.518 showed that the regression model was able to explain 51.8% of the variation in the opacity of exhaust gas emissions, while the remaining 48.2% was influenced by other factors outside the model. The results of the simultaneous test (F test) showed a statistically significant regression model.

Table 2. Simultaneous Test Results (F)

Source	F	Sig.
Models	19,895	< 0.001

Source: Researcher Data Processing (SPSS)

Furthermore, the results of the partial test (t-test) for each independent variable are presented in Table 3.

Table 3. Partial Test Results (t)

Variable	Coefficient (B)	t	Sig.
Constanta	1,429	2,457	0,019
Vehicle Weight	0,781	4,867	< 0.001
Mileage	-0,509	-4,013	< 0.001

Source: Researcher Data Processing (SPSS)

The vehicle weight category variable has a positive regression coefficient of 0.781 with a significance of < 0.001, which means that an increase in the vehicle weight category is followed by an increase in emission opacity. The pattern of these relationships is visualized in Figure 5.

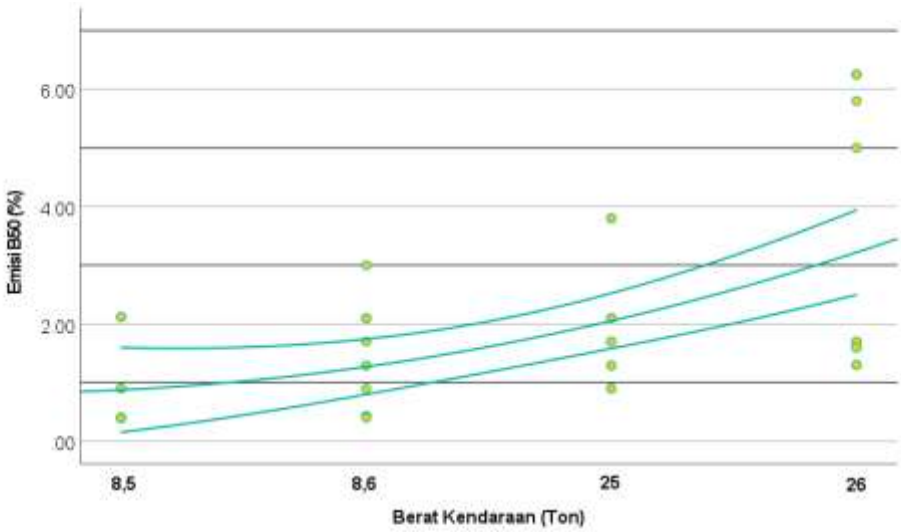

Figure 1. Scatter Plot Graph (SPSS) of B50 Emissions with Vehicle Weight

Source: Researcher Data Processing (SPSS)

On the other hand, the cumulative mileage variable had a negative regression coefficient of -0.509 with a significance of < 0.001, which means that the increase in mileage in the vehicle of this study object was followed by a decrease in emission opacity. The pattern of these relationships is visualized in Figure 6.

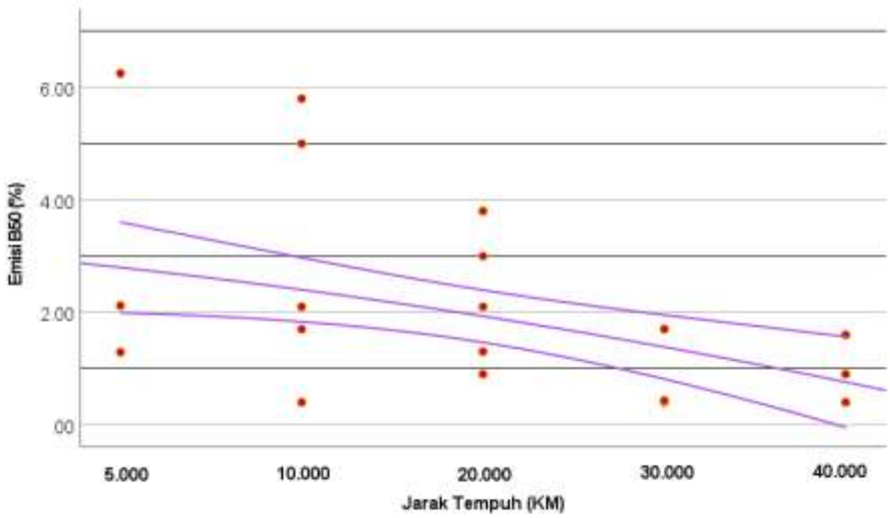

Figure 2. Scatter Plot Graph (SPSS) of B50 Emissions with Mileage

Source: Researcher Data Processing (SPSS)

The integration between the results of field observation (Sub-chapter 3) and the regression results (Sub-chapter 4) shows the compatibility of the findings that corroborate each other. The observation results showed that vehicles in the 25 ton and 26 ton categories consistently produced higher opacity than 8.5 ton and 8.6 ton vehicles, in line with the positive and dominant regression coefficient in the vehicle weight variable. Meanwhile, the fluctuating pattern of emissions to mileage in the observation data with peak emissions at medium mileage and decrease at longer mileage is consistent with the direction of the negative coefficient on the mileage variable in the regression model. Thus, it can be stated that vehicle weight is the dominant factor that affects B50 emissions, while the effect of mileage is dynamic and highly dependent on the operational and maintenance conditions of the vehicle during the period of use.

The findings in the results section need to be reinterpreted in the context of the urgency behind this research. Road transportation in Indonesia dominates the mobility of people and goods, with a share of up to 85% of passengers and 90% of freight transportation (Humami, 2024), so that the activities of diesel-powered vehicles, especially heavy vehicles >3.5 tons, are the dominant contributors to exhaust gas emissions in the national logistics corridor. The data that is the basis for the identification of this research problem shows that the transportation sector accounts for around 44% of the total air pollution in Jakarta, so that heavy vehicles are a strategic target for emission control.

The root of the problem identified comes from the operational characteristics of the heavy vehicle itself, namely large transport load, high fuel consumption, and long operational mileage, as shown in the test results where vehicles in the 25–26 ton category consistently produce higher opacity than vehicles of 8.5–8.6 tons. This condition is in line with the view that the performance of the transportation system can no longer be measured solely in terms of smoothness, but also in terms of its environmental impact (Kraus, 2021). As a policy response, the Government of Indonesia plans to implement B50 biodiesel in 2026 as a continuation of the mandatory B20 to B40 program (Hakim et al., 2025), but environmental impact assessments on heavy vehicles with real operational conditions are still very limited. This research is here to answer this gap, by providing empirical evidence about the causes, magnitudes, and solutions to the problem of heavy vehicle emissions.

The Effect of Vehicle Weight and Mileage on B50 Emissions: Causes and Implications

The regression results showed that vehicle weight and mileage simultaneously had a significant effect on emission opacity ($R^2 = 0.518$; F = 19,895; Sig. < 0.001), with vehicle weight as the most dominant factor (B = 0.781; Sig. < 0.001). Theoretically, these findings explain the direct cause of the high emissions of heavy vehicles: the increase in vehicle weight increases the workload of the engine, so that the combustion energy requirements increase and potentially reduce combustion efficiency if the operating load exceeds the optimal capacity of the engine. This positive relationship is consistent with the working principle of diesel engines in heavy vehicles and reinforces the argument that the vehicle weight category needs to be one of the main variables in freight emission control policies.

Meanwhile, the cumulative mileage variable showed a negative coefficient (B = -0.509; Sig. < 0.001), which means that the emission opacity tends to decrease as the mileage of the research object vehicle increases. This finding is interesting to compare with the results of previous research. Boveroux et al. (2021) found that mileage has a significant influence on the increase in particle emissions in Euro 5 and Euro 6 passenger diesel vehicles, while Humami (2024) also reported that mileage and vehicle age have a significant effect on increasing CO, HC, and opacity emissions in commercial vehicles. The opposite direction of the relationship in this study indicates that the deterioration of emissions due to mileage is not a universal phenomenon, but rather depends heavily on the operational context—in this case, a consistent periodic maintenance program and the process of adaptation of the combustion system to the characteristics of B50 biodiesel which has a higher oxygen content.

Thus, the cause of the decrease in opacity over longer distances in this study does not lie in the mileage itself, but in the quality of maintenance and combustion efficiency that is maintained. The implication is that mileage cannot be treated as a single indicator of emission deterioration; Emission control policies need to be directed simultaneously to overloading, the implementation of periodic emission tests, and preventive maintenance obligations, in line with the conclusion that operational factors also determine emission performance (Humami, 2024).

The value of the determination coefficient of 0.518 also needs to be read proportionally: the regression model is able to explain more than half of the variation in emission opacity through two operational variables that are relatively simple to measure in the field, namely weight and distance categories. This shows that these two variables are practical predictors that can be used by regulators and operators as early indicators of high emission risk detection, without having to wait for more complex and expensive laboratory emission test results. In other words, the main cause of the high opacity of heavy vehicle emissions in this study can be identified early through vehicle operational data that is relatively accessible to fleet operators.

The Effectiveness of B50 in Reducing Emission Opacity: Solutions to Pollution Problems

If Sub-chapter 2 explains the causes of high emissions, the results of different tests show the solution. The average opacity of the B50 group (1.854%) was much lower and significantly different ($t = -11.031$; Sig. < 0.001) compared to the non-B50 group (8.250%), with a decrease of 77.53%. Chemically, the oxygen content in biodiesel supports a more perfect combustion process so that the formation of particulate matter and smoke can be suppressed. These findings reinforce and expand on the evidence in previous literature on the environmental benefits of biodiesel: the results of Lemigas testing the implementation of B40/B50 in diesel-powered vehicles show that increasing the biodiesel mixture does indeed reduce emission opacity, although it is accompanied by a decrease in power and torque and an increase in fuel consumption—a technical trade-off that needs to be considered by operators in the massive adoption of B50.

The magnitude of the 77.53% decrease in this study is much higher than the findings in lower biodiesel blends, for example, the reduction in greenhouse gas emission intensity by ±28.19% in the use of B30 biodiesel compared to pure diesel in generator set applications (Tomo & Brunner, 2022). This difference in magnitude is in line with the logic that the higher the percentage of biodiesel content in the fuel mixture, the greater the potential for a decrease in opacity and particulates produced, as well as the pattern of increased emission benefits that were also observed in the tiered experiment of pure soybean biodiesel on CO and HC emissions of diesel vehicles. Thus, the results of this study confirm that B50 is not just an administrative continuation of the B20–B40 policy, but a significant leap in the effectiveness of heavy vehicle emission control, so that it is feasible to be a priority solution to the problem of air pollution in the freight transportation sector identified at the beginning of the study.

Impact of B50 Projection on Air Quality and Sustainable Transportation

The projection results show that the overall implementation of B50 in vehicles >3.5 tons has the potential to reduce total air pollution in Jakarta by 34%, with a pattern of decline that increases proportionally to the adoption rate (6.8% in the first year to 34% in the fifth year assuming 100% adoption). This impact is in line with the concept of sustainable transportation, which places emission reduction as one of the key criteria for the success of urban transportation systems (Kraus, 2021). Given that land transportation is an important component of supporting national mobility and economic growth (Amalia et al., 2025), reducing emissions from heavy vehicles not only has an impact on air quality, but also supports the sustainability of the national logistics economy without sacrificing environmental aspects.

From a policy perspective, these results provide quantitative justification for the B50 implementation plan by 2026 (Hakim et al., 2025) while showing that the environmental benefits are gradual and highly dependent on the speed and consistency of adoption in the field. The implication is that the government needs to accompany the mandatory B50 policy with incentives for operators, strengthening biodiesel distribution infrastructure, and socializing the benefits of B50 to freight transportation industry players, so that the 34% reduction target can be realized consistently and not just become a potential on paper. The long-term impacts of this measure include improving urban air quality, reducing the risk of health problems due to particulate exposure, and strengthening national energy security through diversification into biofuels.

Comparison with Novelty and Gaps in Previous Research

Compared to the studies listed in the background and literature review section, the results of this study strengthen and complement some of the research gaps that have been identified. First, in terms of object and policy context, most of the previous biodiesel studies focused on B20–B30 mixtures or B40/B50 testing on a laboratory scale, while this study was one of the first studies in Indonesia to analyze the environmental impact of B50 on heavy vehicles in the context of 2026 national policy readiness, with quantitative results that support the urgency of the policy.

Second, in terms of technical approaches, previous research generally used static or laboratory-based tests, while this study used real operational conditions with accumulated mileage of up to 40,000 km. This approach has been shown to produce findings that differ from mileage-based studies under controlled conditions (Boveroux et al., 2021), i.e. the emergence of non-linear patterns influenced by vehicle maintenance—a nuance that cannot be captured by laboratory design or macro traffic studies such as dispersion of pollutants due to wind speed or the volume of small vehicle traffic in urban areas.

Third, in terms of variables and indicators, this study specifically relates emission opacity to vehicle weight and simultaneous use of B50, complementing previous studies that generally separate the study of vehicle characteristics, emissions, and transportation systems separately. Fourth, in terms of prospective analysis, this study does not stop at the evaluation of existing conditions, but compiles projections for the next five years as the basis for policy planning, so that the results are more applicable to policy makers than studies that are purely descriptive-historical. Overall, these findings confirm that this study has succeeded in filling the research gap regarding the integration between heavy vehicles, air quality, and sustainable transportation that has been partially studied.

Practical Implications and Research Limitations

Practically, the findings of this study provide three main implications. For the government, the regression results that confirm vehicle weight as the dominant factor indicate the need to strengthen supervision of overloading practices that have been difficult to control, as well as accelerate the readiness of B50 technical regulations and distribution ahead of implementation in 2026. For transportation operators, the magnitude of the decrease in opacity in the B50 group (77.53%) provides a clear economic and environmental incentive to switch to B50 biodiesel consistently, accompanied by preventive maintenance programs so that the benefits of reducing emissions can be maintained throughout the vehicle use cycle. For academics, the non-linear pattern between mileage and emissions found in this study opens up space for further research on the specific role of maintenance variables, engine capacity, and operational patterns in the deterioration of plant-fuel vehicle emissions.

However, the results of this study need to be interpreted by considering a number of limitations. The determination coefficient value of 0.518 indicates that there is still about 48.2% variation in emission opacity explained by factors outside the model, such as engine condition, driving style, and maintenance quality that were not directly measured in this study. In addition, the projected reduction in air pollution by 34% is compiled based on the assumption of ceteris paribus and the linear adoption rate of B50, so its realization in the field is highly dependent on policy consistency, availability of biodiesel supply, and operator compliance in implementing B50 in heavy vehicle fleets in a sustainable manner.

As a closing of the discussion, it can be emphasized that this research has succeeded in answering three fundamental questions that are the background for its implementation. The main cause of the high emissions of heavy vehicles was identified in the combination of large vehicle weight and the use of conventional diesel fuel; a solution that has proven to be statistically effective is the substitution towards B50 biodiesel which is able to reduce emission opacity by up to 77.53%; and the impact that can be obtained if the solution is consistently applied is to reduce air pollution in the transportation sector by up to 34% within five years, as well as strengthen Indonesia's position in achieving sustainable transportation targets and national energy transition.

CONCLUSION

This study aimed to analyze the effect of B50 fuel utilization on diesel vehicle exhaust emissions, examine the influence of vehicle weight and mileage on emission levels, and evaluate the potential contribution of B50 implementation in supporting sustainable transportation. Based on the results of observational analysis, statistical testing, and discussion presented in Chapter IV, the following conclusions were drawn: (1) The vehicle weight variable had a regression coefficient of 0.781 with a significance value of < 0.001, indicating that heavier vehicles (>3.5 tons) produced relatively higher opacity levels compared with vehicles in lower weight categories. These findings suggest that increased vehicle weight is associated with greater engine power requirements and fuel consumption, which ultimately contributes to higher exhaust emissions. Meanwhile, the mileage variable had a regression coefficient of -0.509 with a significance level of < 0.001, indicating that vehicles weighing more than 3.5 tons with longer travel distances experienced changes in emission levels across different operational phases, including increases during certain periods followed by emission reductions or stabilization in subsequent phases. This condition demonstrates that vehicle emissions are influenced not only by mileage but also by operational conditions, engine characteristics, and maintenance quality throughout the vehicle’s service life.

The average exhaust gas opacity level of vehicles using B50 fuel was 1.854%, while vehicles using non-B50 fuel recorded an average opacity level of 8.250%. Statistical testing showed a significance value of 0.000 ($p < 0.05$), indicating that B50 fuel utilization had a significant effect on reducing diesel vehicle emissions. The calculation results showed that B50 fuel reduced emission opacity levels by 77.53% compared with non-B50 fuel usage in the transportation sector. These findings indicate that the biodiesel component in B50 contributes to improved combustion quality, thereby reducing the formation of particulate matter and visible smoke emissions.

The results demonstrated that B50 fuel utilization had the potential to support sustainable transportation through the reduction of diesel vehicle emissions. Based on the projection analysis, widespread B50 implementation had the potential to contribute to reducing transportation sector air pollution, including an estimated reduction of air pollution levels in the Jakarta area by up to 34%. In addition to providing environmental benefits through particulate emission reduction, B50 utilization also supported national energy diversification policies by increasing the use of renewable biodiesel-based energy sources. Therefore, B50 fuel utilization can be considered a strategic instrument for promoting a more environmentally friendly, efficient, and sustainable transportation system.

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