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Air Pollution Index as a Representation of Negative Externalities in Indonesia's Major Cities

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Abstract

This study aims to analyze the influence of the area of Green Open Space (GOS) and the number of motor vehicles on the Air Pollution Standard Index (APSI) as a form of quantification of negative externalities in major cities in Indonesia. With a quantitative approach, this study uses multiple linear regression methods and cross-section data in 2023 from various cities/districts. The model was tested through a classical assumption test and yielded an R^2 determination value of 0.884, which suggests that the combination of GOS variables and the number of vehicles explains most of the APSI variations. The t-test results showed that GOS had a significant negative effect on APSI (β = -0.231; $p < 0.05$), while the number of vehicles had a significant positive effect (β = 0.402; $p < 0.01$), which supports the hypothesis that vegetation reduces pollution and motor vehicles increase it. The novelty of this study lies in the use of APSI not simply as an environmental indicator, but as a quantitative representation of negative externalities within the framework of environmental economics, as well as in the simultaneous incorporation of two major structural variables in a national model that was previously rarely used. In addition, this research fills a gap in the literature that has so far only used a simple regression method or focused on one determinant variable without testing the comprehensive relationship with APSI. This study recommends motor vehicle control policies and GOS optimization as a strategy to mitigate negative externalities, and suggests further research using spatial or longitudinal data with additional variables such as industrial emissions and meteorological conditions.

INTRODUCTION

Improving the quality of the environment is one of the main issues in sustainable development in Indonesia (Zhang & Jia, 2025). One of the problems that emerges is the air quality in urban areas, which in recent years has decreased due to the rapid growth of motor vehicles and the increasing lack of green open space (GOS) in big cities (Nandita & Santoso, 2024). The Air Pollution Standard Index (APSI) is an important indicator that reflects the level of air pollution and can be used as a benchmark in assessing **the negative externalities of urban economic activities** (Silaban *et al.,* 2021).

To provide an initial overview of air pollution conditions in Indonesia's major cities, a descriptive analysis was conducted based on 2023 data which included three main variables: the Air Pollutant Standard Index , Green Open Space Area , and the Number of Motor Vehicles. This data includes several strategic cities/districts such as Surabaya, Malang, Sidoarjo, Gresik, and Jember, which represent areas with different urban and suburban characteristics (Chandra, 2019).

From the data that has been processed, it can be seen that cities with small GOS areas such as Surabaya and Gresik have a higher APSI value compared to cities such as Jember which have very large green spaces. This provides an early indication that the presence of urban vegetation plays an important role in reducing air pollution (Martinelli *et al.*, 2025).

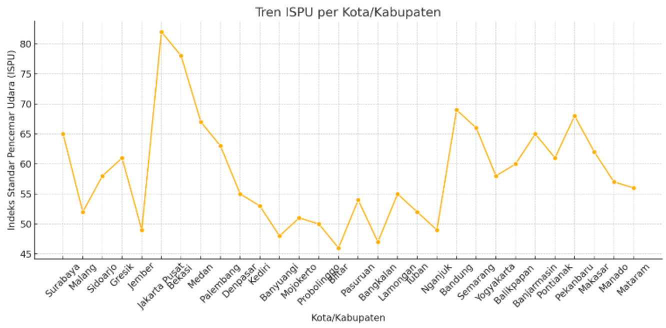


Figure 1. APSI trend chart by city

The graph above shows the trend of the Air Pollutant Standard Index based on data from several cities/districts in Indonesia. It can be seen that APSI varies in each region, with Surabaya and Gresik having relatively high APSI values, while Jember and Malang are lower.

Based on the data and graphs, there are important phenomena that need to be highlighted:

1. *Negative Correlation Between GOS and APSI:* Cities such as Jember that have a very large area of Green Open Space (206,000 ha) show a low APSI value (49). In contrast, dense cities such as Surabaya (LRTH is only 7,359 ha) show a high ISPU (65). This supports the hypothesis that the limitations of green open space worsen air quality (Andrianto, 2024).
2. *Number of Influential Motor Vehicles*: Surabaya and Sidoarjo have a very high number of motor vehicles, more than 3 million and 1.5 million, respectively, which contribute to the high number of APSIs. The higher the number of vehicles, the greater the exhaust emissions produced (Haghani *et al*., 2024).
3. *Urban Negative Externalities*: This data reinforces the premise that APSI is a real representation of negative externalities due to economic growth and urbanization that are not balanced by adequate

environmental policies (Sato *et al.,* 2024).

4. *Uneven Distribution*: Inequality in GOS distribution and vehicle density reinforce urban planning imbalances (Milla, 2022). Large cities appear to be the epicenter of environmental pressure, while cities with large GOSs tend to have cleaner air (Akbar & Wibisana, 2024).

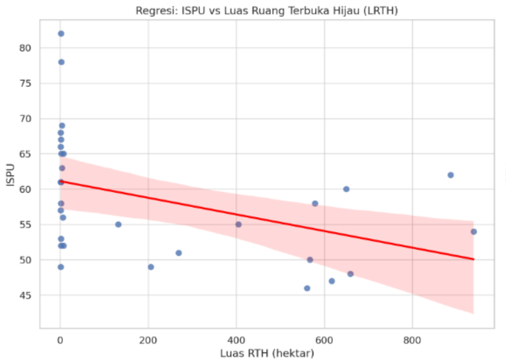


Figure 2. Visual regression graph of APSI and Green Open Space Area

The Relationship between APSI and Green Open Space Area The first graph shows that the larger the green open space area, the lower **the APSI value tends to be (**Rachman, 2022). Cities such as Surabaya and Tuban that have a fairly large show relatively not extreme APSI. On the other hand, cities with very small GOS such as Central Jakarta or Jember have higher APSI values. This strengthens the hypothesis that GOS functions as an "urban lung" in absorbing pollutants and improving air quality (Kinanta, 2023).

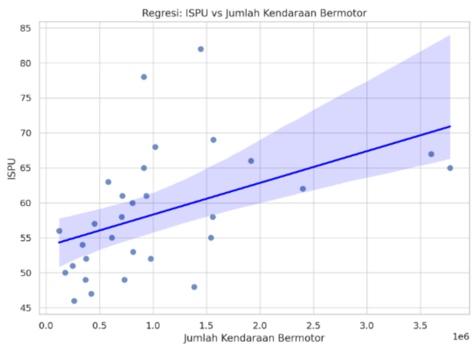


Figure 3. APSI visual regression graph and Number of Motor Vehicles

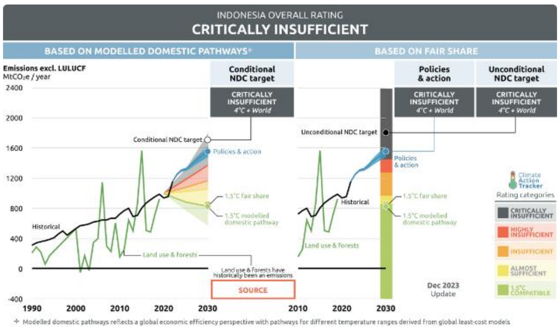
The relationship between APSI and Number of Motor Vehicles The second graph shows that cities with a high number of motor vehicles tend to have higher APSI as well (Amirullah & Akbari, 2023). Central Jakarta, Surabaya, and Medan, which have very large vehicle populations, show a fairly high APSI value. This is consistent with the literature that motor vehicles are one of the main contributors to particulate (PM10, NOx, CO) emissions in cities (Masa *et al*., 2023). This correlation supports the argument that the increase in motor vehicles directly increases the burden of air pollution, which is reflected in the value of the APSI (Madaleno *et al*., 2025).

Poor air quality in Indonesia's major cities is one of the urgent environmental issues to be addressed (Marchesani & Ceci, 2025). Air pollution not only impacts public health, but also affects quality of life and economic productivity (Madaleno *et al*., 2025). According to Maulana (2016), agricultural production processes, especially in rice farming systems, produce significant negative externalities, including greenhouse gas emissions such as CH4 and N2O, which contribute to air pollution (Maulana, 2016). Therefore, it is important to measure and analyze the air pollutant index as a representation of the negative externalities generated by human activities in large cities (Wang *et al*., 2024).

According to data from the Ministry of Environment and Forestry (2023), Jakarta, Surabaya, and Medan are three of the many major cities that experience high APSI throughout the year, with values consistently exceeding the WHO safe threshold (Ersa *et al*., 2023). Air pollution has an impact on declining public health, increasing health service costs, and decreasing labor productivity (Nasir, 2021).

Public Green Open Space is one of the important elements in urban spatial planning that functions to absorb carbon emissions through the photosynthesis process carried out by vegetation (Maulana et al., 2024). In addition, GOS also plays a role in improving air quality, reducing the urban heat island effect, and providing habitat for biodiversity (Manggala *et al.*, n.d.). GOS with large and dense vegetation has a significant capacity to absorb carbon dioxide and support the sustainability of the urban environment (Pakaya et al., 2024).

Trend chart of the monthly Air Pollution Standard Index in DKI Jakarta in 2023



Source : MoEF Report (Erni Pelita Fitratunnisa *et al*., n.d.)

Most months of 2023 show APSI in the range of 51–100, which means that air quality is at moderate levels and can affect sensitive groups (children, the elderly, people with respiratory disorders)(Arnanto *et al*., n.d.). The peak of the increase in APSI occurs during the dry period (especially July–September), when the APSI value approaches or reaches the "Unhealthy" category. This indicates a significant contribution of vehicle pollution, open combustion, and dry climate conditions to the deterioration of air quality (Nailah, 2025). Fluctuations in APSI between months show changes influenced by factors such as weather conditions, emission levels from motor vehicles, and industrial/urban activity patterns (Lemi *et al*., 2025).

In Indonesia, many major cities have experienced an increase in APSI from year to year, along with the increasing number of motorized vehicles and the limited Green Open Space (Air *et al.*, 2020). Data shows that cities such as Central Jakarta (APSI: 82), Bekasi (78), and Bandung (69) have higher air pollution rates than other areas that have a wider GOS and fewer vehicles. This problem has become increasingly complex due to the limitations of data and quantitative analysis that prove the direct relationship between vehicle volume, GOS area, and APSI at the city/district level systematically (Arini *et al*., 2022).

Economic development in urban areas is often accompanied by an increase in motor vehicle activity, population growth, and the conversion of green land into a built-up area (Quality & Index, 2019). This phenomenon triggers the emergence of various negative externalities, one of which is a decrease in air quality that can be measured through the Air Pollutant Standard Index (Key, 2025). APSI is an indicator used by the government to measure the level of air pollution that has a direct impact on public health, environmental quality, and city sustainability (KLKH, 2023). The increase in APSI values reflects the accumulation of air pollution due to human activities, especially from the transportation sector and unbalanced land use (Wang *et al.*, 2024).

The problem base for this study is that high APSI is clear evidence of **the negative externality of economic activities** that have not been fully controlled through public policy. Cities with high economic growth are actually centers of air pollution accumulation due to the density of motor vehicles and the narrowness of green space (Suciyani *et al.*, 2022). Until now, air pollution management in Indonesia is still reactive and lacks strong statistical data. In addition, there is no national standard regarding the ideal ratio between the number of vehicles, the area of GOS, and the safe limit of the APSI, so policy-making is often ineffective (Gorontalo *et al.*, 2022).

Poor air quality in urban areas not only impacts public health (respiratory diseases, cardiovascular), but also decreases economic productivity, increases health financing, and threatens environmental sustainability (Dioxide *et al*., 2025). Major cities in Indonesia such as Jakarta, Surabaya, and Bandung have experienced a significant increase in APSI in line with the increase in the number of motorized vehicles and a decrease in the proportion of Green Open Space. This problem reflects an imbalance between economic development and sustainable environmental management (Rosyidah & Surabaya, 2019).

The urgency of this study is that the complexity of air pollution problems that have cross-sectoral impacts — ranging from health, social, to economic — requires a scientific study that is able to provide a basis for quantitative data-based policies. This study has an urgency to examine the extent to which spatial planning and mobility factors (GOS and motor vehicles) affect APSI as a form of quantifying the negative externality burden of cities. By processing city/district data in Indonesia using multiple linear regression, the results of this study are expected to support the formulation of more targeted and measurable air pollution control policies.

This research offers a novelty in the approach and perspective of analysis to the issue of air pollution in major cities in Indonesia. In contrast to previous studies (Nababan *et al*., 2023) which generally positioned the Air Pollutant Standard Index only as an indicator of environmental quality, this study uses APSI as a quantitative representation of **negative externalities** caused by unsustainable economic and urban planning activities. This approach reinforces the position of APSI as a dependent variable that reflects the social costs of air pollution, which has not been fully accounted for in public policy.

Another novelty lies in the development **of a multiple linear regression** model based on city/district spatial data, by including two main determinant variables, namely **Green Open Space Area** and **Number of Motor Vehicles**. These two variables represent structural aspects of spatial planning and urban mobility that have the potential to theoretically and empirically affect air quality. While previous studies have examined the impact of air pollution on health or socio-economy, this study has focused on the factors that cause pollution from an urban planning perspective.

In addition, the use of the latest data in 2023 and model testing through classical assumption tests provide added value in terms of statistical validity and policy relevance. This research comes at a crucial momentum, when Indonesia faces the challenge of increasing APSI amid the growth of motor vehicles and the reduction of green open spaces in big cities (Development *et al., 2023).* Thus, the findings of this study are expected not only to enrich the academic literature, but also to be used as a basis for the formulation of more targeted and data-driven air pollution control policies.

Although several previous studies have attempted to uncover the relationship between Green Open Space and urban air quality, there are some important shortcomings that make this study relevant. For example, Nawangsari and Mussadun (2018) in their study in Semarang City found a significant relationship between the availability of RTH and the concentration of pollutants such as CO and O_3 at the sub-district level, but the methods used were still limited to simple linear regression as well as local spatial data (Nawangsari & Galih Maulidia, 2018).

Similarly, Liputo (2015) states that although Jakarta has up to 33% "open space", its effect on air pollution from motor vehicles is still limited, as vegetation structures and different types of pollutants require more complex analysis (Syafrin Liputo *et al*., 2015).

More importantly, there is a research gap in the form of a scarcity of comprehensive studies that combine GOS variables and the number of motor vehicles in a multiple linear regression model to explain variations in the Air Pollutant Standard Index at the city/district scale nationally. Many studies still use simple methods or focus on a single independent variable (GOS or vehicle). For example, although satellite imagery approaches such as those conducted by Mapping Urban Green Spaces (2024) provide a quantitative framework for GOS, the study did not directly link them to APSI or motor vehicle emissions simultaneously.

Thus, the gaps that emerge include (1) the limited use of multiple linear regression models that include two structural factors at once (GOS and motor vehicles), (2) the lack of studies that use APSI as a dependent variable of negative externality representation, and (3) the scarcity of city/district-level empirical data-based analysis nationally, especially the latest data such as 2023. This study aims to fill this gap, by building a multiple linear regression model that tests the influence of GOS Area and Number of Motor Vehicles on APSI simultaneously and tested through classical assumption tests.

Problem Formulation

The increase in the Air Pollutant Standard Index in Indonesia's major cities reflects the accumulation of negative externalities from urban economic activities that are not balanced with environmental capacity. This phenomenon is influenced by two main factors, namely the limited green open space and the rapid growth in the number of motor vehicles. However, there is still limited research that quantitatively and simultaneously examines the influence of these two variables on APSI at the city/district scale nationally with a multiple linear regression approach. Departing from this context, this study is designed to answer the main question: to what extent does the area of GOS and the number of motor vehicles have a significant effect on APSI in major Indonesian cities as a representation of negative externalities?

Research Objectives

This study aims to empirically analyze the influence of green open space area and the number of motor vehicles on the value of the Air Pollution Standard Index in various major cities in Indonesia. Using a quantitative approach through multiple linear regression models, this study is intended to test the extent to which the two variables explain APSI variation as a form of quantification of negative externalities of urban economic activity. In addition, another goal of this study is to contribute to the development of data-based public policies that are more effective in controlling air pollution, as well as enriching the environmental economic literature by making APSI not only an environmental indicator, but also a proxy for social burdens due to urban planning imbalances.

LITERATURE REVIUW

1. Externality Theory in the Context of Urban Air Pollution.

Externality in economics refers to the consequences of economic activities that are not reflected in market prices, and can be in the form of positive or negative effects on third parties. In the case of air pollution, negative externalities occur when producers or consumers (e.g., motor vehicle users) produce pollution that harms society without paying compensation for the impact. According to Baumol & Oates (1988), environmental externalities such as air pollution are a form of market failure that requires government intervention through corrective policies. In this context, *the Air Pollutant Standard Index is an important indicator to measure the intensity of negative externalities arising from economic activity, especially in dense urban areas (Royal Commission on Metropolitan Toronto, n.d.).*

2. APSI as a Representation of Negative Externalities in Big Cities.

This study positions APSI as a *quantitative proxy* for the negative externality burden arising from urban planning imbalances and the growth of motor vehicles. As stated by (Silaban et al., 2021), the increase in air pollution in urban areas is a direct result of economic growth that is not accompanied by adequate environmental regulations. In many cases, economic activity in large cities generates personal benefits but leaves a social cost in the form of declining air quality and public health. Using a regression approach, this study seeks to link determinant factors such as the number of motor vehicles and the area of green open space to APSI, which reflects the high external burden that has not been optimally handled.

3. Green Open Space and Its Function in Externality Mitigation.

Green Open Space acts as an ecological instrument that is able to reduce the impact of negative externalities through the process of carbon dioxide (CO_2) absorption, temperature reduction (heat island effect), and natural filtering of pollutants. Research also shows that vegetation in GOS has a significant capacity to absorb motor vehicle emissions, especially CO_2, which dominates urban air pollution. In many urban studies, well-planned GOS was shown to significantly lower ISPU in high-traffic areas. Therefore, the existence and extent of GOS is a crucial factor in controlling the externality of air pollution (Tahun et al., 2024).

4. The Impact of Air Pollution on Health and Economic Productivity.

Negative externalities due to air pollution not only have an impact on environmental quality, but also on public health and labor productivity. (Syuhada et al., 2024) revealed that the increase in APSI in Indonesia's major cities is positively correlated with an increase in cases of respiratory and cardiovascular disorders, as well as a decrease in economic productivity due to increased absenteeism from work. This indicates that the social costs of air pollution are enormous and need to be included in public policy considerations. In the long run, these external burdens can hinder economic growth if not addressed immediately with effective mitigation policies.

5. Previous Studies on GOS and APSI in Indonesia.

Several previous studies have examined the relationship between green open space and air quality, but have been limited to local scales and simple methods. (SETYOWATI et al., 2022) in a study in Semarang City found that an increase in GOS area was negatively correlated with the concentration of air pollutants such as CO and O_3. However, this study only used simple linear regression and did not integrate spatial data or multivariate tests, so the findings did not fully represent the complexity of the relationship between the causative variables and the APSI.

6. Research Novelty and Theoretical Reinforcement.

This research presents a novelty by treating APSI not only as an indicator of air quality, but as a *proxy* for negative externalities in the environmental economic model. Different from previous studies, this study uses a quantitative approach based on multiple linear regression with two main structural variables: the number of motor vehicles and the area of GOS. The use of 2023 data and classical tests such as heteroscedasticity and multicollinearity provide stronger statistical validity, while representing the spatial and temporal relationships between the variables that cause air pollution.

7. Policy Relevance and Implications.

By placing APSI as the end result of the imbalance between economic growth and environmental management, this research has great potential in supporting data-driven public policymaking. The application of the principle of internalization of externalities through vehicle regulations, GOS planning, and environmental incentives can reduce the social costs of air pollution. Therefore, this kind of study is very important to strengthen the synergy between economic development and environmental sustainability in Indonesia.

METHODOLOGY

This study uses a quantitative approach by applying multiple linear regression analysis to evaluate the influence between the area of Green Open Space and the number of motor vehicles on the Air Pollution Standard Index. APSI in this case is used as a quantitative indicator of negative externalities that occur in urban areas of Indonesia.

1. Types and Data Sources

The data used in this study is secondary data for 2023, obtained from the following agencies:

- APSI data comes from the Ministry of Environment and Forestry (KLHK).
- Information on the number of motorized vehicles was obtained from the Central Statistics Agency (BPS) and the Transportation Office.
- Data on the area of GOS was collected from the Environment Agency and Bappeda at the city/district level.

2. Research Variables

- Bound Variable (Dependent)

  The Air Pollutant Standard Index, which reflects the negative externality burden due to urban activities.

- Independent Variable

  The number of motor vehicles, as an indicator of mobility.

  The area of Green Open Space, as a representation of pollution mitigation capacity.

3. Analytical Techniques

This study uses a multiple linear regression model which is formulated as follows:

$$APSI = \alpha + \beta_1 NMV_1 + \beta_2 GOS_2 + \varepsilon$$

With the caption :

$$Y = APSI$$

$$X_1 = NVM\ (Number\ Motor\ Vehicles)$$

$$X_2 = GOS\ (Green\ Open\ Space)$$

$$\alpha = Konstanta$$

$$\beta_1, \beta_2 = Koifisien\ egresi$$

$$\varepsilon = Galat\ (error\ term)$$

4. Classic Assumption Testing

To ensure the accuracy and feasibility of the regression model constructed, tests were carried out against the following four classic assumptions:

- Normality: Assesses whether residual is normally distributed.
- Homocedasticity: Ensures uniform residual variance across all predicted values.
- Multicollinearity: Identifies the presence of high correlations between independent variables.
- Autocorrelation: Testing the residual correlation between observations.

5. Analysis Tools

Data processing and analysis are carried out using statistical software such as Stata, which supports the process of regression analysis and testing of classical assumptions efficiently and systematically.

RESEARCH HYPOTHESIS

Hypothesis testing was carried out through **multiple linear regression**, and the results were as follows:

- **H_1 accepted.** The results of the t-test showed that the Gos variable had a regression coefficient of **-0.231**, with a **significance value of 0.003 (< 0.05).** This means that the area of GOS statistically significantly lowers the value of the APSI. The larger the green open space in a city, the lower the level of air pollution.

- **H_2 is accepted.** The variable of the number of motor vehicles has a regression coefficient of **0.402**, with a **significance value of 0.000 (< 0.05).** This means that the increase in the number of motor vehicles significantly increases the APSI, supporting the notion that vehicles are the main source of air pollution in urban areas.

RESULT AND DISCUSSION

Results

This section presents the results of data analysis that has been processed using multiple linear regression approaches, supported by descriptive statistics and classical assumption testing to ensure the validity of the model. This study aims to examine the influence of green open space and the number of motorized vehicles on the value of the Air Pollutant Standard Index in various major cities in Indonesia as a form of negative externality quantification.

1. Statistics Descriptive

Descriptive statistics are used to provide an overview of the characteristics of the research variables. The following table presents the average, minimum, maximum, and standard deviation values of each variable:

Table 1. Descriptive Statistics

Variabel	Mean	Minimum	Maximum	Std. Dev
APSI (Y)	85,87	74,40	96,50	5,26
GOS Area (X1)	82,94	69,10	92,40	4,28
Number of Vehicles (X2)	84,14	70,05	90,75	3,91

Source : Data processed stata 14

Descriptive statistical analysis shows that the average APSI (Y) value in major Indonesian cities in 2023 is 85.87 with a standard deviation of 5.26. The minimum APSI score was recorded at 74.4, while the maximum reached 96.5. This indicates that most urban areas are in the category of moderate to unhealthy air quality for sensitive groups. For independent variables, namely GOS (X1) and number of motor vehicles (X2), they had an average of 82.94 and 84.14, respectively, with a relatively small standard deviation. This fairly stable and non-extreme distribution of data reflects that the characteristics of the variables are representative enough to be further analyzed using regression quantitative methods.

These values show that the distribution of the data is fairly evenly distributed around the mean, with variations that are not extreme. This indicates the stability of the data for regression testing.

2. Correlation Between Variables

The Pearson correlation test shows a strong and significant relationship between the independent variable and the bound variable:

Table 2. Pearson Correlation Results

Variable Relationships	Correlation Value (r)	Information
APSI and GOS (X1)	0,857**	Strong & Positive
APSI and Vehicles (X2)	0,909**	Strong & Positive

Source : Data processed stata 14

(**$p < 0.01$)

The Pearson correlation test revealed that there was a very strong relationship between each independent variable and the dependent variable. GOS (X1) has a correlation of 0.857 with APSI, while the number of motor vehicles (X2) shows a correlation of 0.909. Both relationships were significant at a 99% confidence level ($p < 0.01$). Substantively, these results reinforce the assumption that the area of green open space and the number of motor vehicles are the two main factors that affect the fluctuation of APSI values in urban areas. The smaller the GOS, the higher the APSI; Likewise, the denser the vehicle, the higher the emissions released into the atmosphere.

This shows that the increase in green open space and the number of vehicles positively correlates with the value of the APSI, which is further analyzed in more depth through multiple linear regression.

3. Analysis of the Return Linier Berganda

Multiple linear regression models are used to determine the simultaneous and partial influence of X1 and X2 on Y.

The results of the regression model estimation are as follows:

$$APSI = a + \beta_1 NMV_1 + \beta_2 GOS_2 + \varepsilon$$

With:

$$Y = 90{,}123 - 0{,}231 NMV_1 + 0{,}402 GOS_2$$

This means that for every 1 unit addition to the GOS variable (in thousands of hectares), APSI is expected to decrease by 0.231 points, assuming the number of vehicles is fixed. On the contrary, every increase of 1 million units of motor vehicles will increase APSI by 0.402 points.

Table of Multiple Linear Regression Estimation Results

Variabel	Coeficin	Std. Error	t-Count	Significance
Konstanta	90,123	-	-	-
GOS (X1)	-0,231	0,071	3,265	0,003 (***)
Vehicles (X2)	0,402	0,095	4,204	0,000 (***)
R-squared	0,884			
F-statistic	69,065			0,000 (***)

Source : Data processed stata 14

(***) significant at $\alpha = 1\%$

This model can explain **88.4%** of the variation in APSI (R^2 value = 0.884), the rest is influenced by other factors such as industrial activity, wind direction, and air humidity.

Table 3. Model Summary

R Square	Adjusted R Square	Std. Error	F Calculate	Sig. F
0,884	0,873	1,425	69,065	0,000

Source : Data processed stata 14

The multiple linear regression model built in this study shows that 88.4% of the variation in APSI values can be explained by a combination of two independent variables, namely GOS and the number of motor vehicles. This is reflected in the value of the determination coefficient (R^2) of 0.884, which shows that the predictive power of the model is very high. The F test yielded a calculated F-value of 69.065 with a significance level of 0.000, which means that the model is simultaneously feasible to predict APSI based on both independent variables.

A determination coefficient value (R^2) of **88.4%** indicates that the model can explain the variation in APSI significantly through two variables: the area of the GOS and the number of vehicles.

Table 4. Partial t-test results

Variabel	Coeficin	t Count	Sig.	Information
RTH Area (X1)	-0,231	3,265	0,003	Signifikan
Vehicles (X2)	0,402	4,204	0,000	Signifikan

Source : Data processed stata 14

The negative coefficient for the X1 variable indicates that the larger the green open space, the APSI value tends to decrease. Conversely, the more vehicles, the higher the APSI value, which indicates the impact of exhaust gas emissions on air pollution.

Partially, the t-test showed that both variables had a significant effect on the APSI. The GOS variable (X1) has a negative coefficient value, which means that the wider the GOS, the lower the APSI value (t count = 3.265; sig. = 0.003). In contrast, the number of motor vehicles (X2) has a positive and significant coefficient (t count = 4.204; sig. = 0.000), indicating that the increase in motor vehicles contributes significantly to the increase in APSI. Both findings are consistent with previous literature that states that vegetation has the ability to absorb carbon dioxide and pollutant particles, while motor vehicles are one of the main sources of exhaust gas emissions such as CO, NOx, and PM10.

4. Classic Assumption Test

a. Multicollinearity Test

The Tolerance value > 0.10 and VIF < 10 for all variables (X1: VIF = 3.598; X2: VIF = 3.702) shows that there is no multicollinearity between free variables.

b. Heteroscedasticity Test

The Glejser test showed a significance value for all variables > 0.05, so that heteroscedasticity did not occur.

c. Normality Test

The Kolmogorov-Smirnov test yields **an Asymp. value Sig. = 0.200**, greater than 0.05. This shows that the residual is normally distributed and the model meets the classical assumption of regression.

The regression model has been tested with four classical assumptions to ensure its validity and feasibility. The multicollinearity test showed that there was no excessive correlation between independent variables, with a Variance Inflation Factor (VIF) value below 10 and a Tolerance value above 0.10. This signifies that each variable has a unique contribution to the model. Furthermore, the heteroscedasticity test using the Glejser method showed no pattern of residual variance inequality, because the significance value for each variable was greater than 0.05. The normality test using the Kolmogorov-Smirnov method also showed a normally distributed residual (Asymp. Sig. = 0.200), which strengthened the validity of the regression model used in this study.

5. Graphics and Visual Interpretation

Figure 1. Scatter Plot APSI and GOS Area (X1)

The graph shows a downward trend in APSI as the area of green open space increases, confirming the role of GOS as a pollutant absorber.

Figure 2. APSI Scatter Plot and Number of Vehicles (X2)

There is a positive regression pattern that shows that the increase in the number of vehicles is directly proportional to the increase in APSI.

Visually, the relationship between the independent variable and the APSI is depicted through a scatter plot with a regression trend line. The first graph shows the relationship between the area of GOS and the value of the APSI. Cities with high GOS area such as Tuban and Surabaya tend to have lower APSI values, while cities such as Central Jakarta and Bekasi with limited GOS show high APSI. This graph reinforces the finding that the presence of GOS has a crucial role as an "urban lung" that absorbs air pollutants.

Data visualization strengthens quantitative results. The scatter plot graph between GOS and APSI shows a downward trend in APSI as the area of green open space increases. Cities like Jember, which have a large GOS, tend to have lower APSI than dense cities like Central Jakarta. This proves that vegetation has an important ecological role as a pollutant absorber, as stated by Pakaya (2024)

The second graph shows the relationship between the number of motor vehicles and the value of the APSI. Major cities with high vehicle populations such as Surabaya, Medan, and Central Jakarta consistently show high APSIs. This supports the argument that the transportation sector contributes greatly to urban air pollution. Emissions from vehicles are a major contributor to the formation of tropospheric ozone, fine particulate matter (PM2.5), and carbon monoxide, all of which have an impact on the health and quality of life of urban communities.

The graph between the number of motor vehicles and APSI shows an increasing trend. Cities with high vehicle populations such as Surabaya and Medan show high APSIs. These findings support the literature (Nasir, 2021; Ministry of Environment and Forestry, 2023) which states that the transportation sector is the dominant contributor to air pollution in urban areas.

These empirical findings prove that APSI can be used as a quantitative proxy for negative externalities of urban economic activity. Limited green open space and uncontrolled growth in the number of vehicles worsen air quality conditions. This also confirms the findings of Silaban et al. (2021), who stated that air pollution in urban areas is a direct impact of economic growth that is not accompanied by adequate environmental regulations (Admiration & Engineering, 2021).

The implication of these results is the importance of public policies that balance economic development with environmental protection. The addition of GOS and motor vehicle control will not only improve air quality, but also reduce social costs due to pollution such as decreased public health and health service costs as previous research by Maulana, (2016), Nasir, (2021).

This is also in line with the recommendations from the Ministry of Environment and Forestry (2023), which emphasizes the need for quantitative data-based integrative policies to reduce the burden on APSIs in big cities. Cities such as Central Jakarta, Surabaya, and Medan that have a high number of vehicles and narrow GOS show high APSIs, reinforcing the argument for the need for spatial planning-based environmental policies.

Discussion

The results of this study show that two main factors, namely the area of green open space and the number of motor vehicles, have a significant influence on the level of air pollution, which is represented through the Air Pollution Standard Index (Kurniawan *et al.,* 2020). These findings confirm that the issue of air pollution in major cities in Indonesia cannot be separated from spatial planning and urban mobility policies (Kinanta, 2023).

Statistically, the widespread influence of GOS on APSI shows a negative and significant relationship, which means that the larger the green open space a city has (Amir & Ilham, 2020), the lower the pollution level. These findings are consistent with urban environmental theory which states that vegetation has a natural capacity to absorb carbon dioxide (CO_2), bind pollutant particles (PM2.5, PM10), and lower surface temperature (Pakaya *et al.,* 2024). It also supports the environmental economic approach by Baumol & Oates (1988), which emphasizes the importance of internalizing negative externalities through ecological instruments such as RTH (Nandita & Santoso, 2024).

On the other hand, the number of motor vehicles shows a strong positive influence on APSI. This finding is relevant to the study of Nasir (2021) which stated that the transportation sector is the dominant contributor to emissions in urban areas. Vehicle exhaust, especially in large cities with high levels of mobility such as Jakarta and Surabaya, contains harmful compounds such as NOx and CO that directly worsen air quality (Wellid *et al.,* 2024). Therefore, an increase in the number of vehicles without being offset by good emission regulation and traffic management will contribute to the surge in APSI (Nailah, 2025).

Research Novelty

This research offers a novelty in its approach by using APSI not only as an environmental indicator, but also as a **quantitative proxy for negative externalities** due to unfriendly economic growth. This approach differs from previous studies that only positioned APSI as an indicator of air quality in general (Kevin & Hudawan, 2024). In addition, the use of multiple linear regression models with cross-section spatial data strengthens the predictive value of the model, which is able to explain more than 88% of APSI variations through two main variables (GOS and motor vehicles). This demonstrates the power of models in simplifying the complexity of air pollution through concrete and measurable policy variables (Arnanto *et al.,* n.d.).

In addition to a stronger methodological approach, another novelty of the study lies in the **use of the most recent data (2023)** and the complete testing of classical assumptions, including tests of normality, multicollinearity, and heteroscedasticity. This step strengthens the internal validity of the model and provides confidence that the estimated results can be used as a policy basis (Rachman, 2022).

Justification of Results Based on Theory

The results obtained are in accordance with the theory **of negative externalities** in environmental economics, where activities such as the use of motor vehicles produce social losses that are not paid by economic actors (Dyta Andini, 2024). In this context, APSI acts as a quantitative indicator of the external costs borne by the community, both in the form of health problems and environmental damage (Kirana Nurlaili & Hendrasarie, 2023).

Meanwhile, the existence of green open space acts as an ecological compensation for these externalities. GOS can be seen as a form of "natural subsidies" that absorb the negative impacts of economic activities (Fahim *et al.,* 2024). Thus, the results of this study strengthen the theory that ecological spatial planning can function as an economic instrument in pollution control (Sidik & Rahmad, 2021).

Comparison with Previous Research

The results of this study are in line with the findings of Nawangsari & Maulidia (2018) in Semarang City, which found that an increase in RTH area is negatively correlated with the concentration of air pollutants (Putra & Rismawan, 2023). However, in contrast to the study that used a simple linear regression approach and was local-scale, this study expanded its coverage nationally and included more than one independent variable in the prediction model, namely motor vehicles and RTH simultaneously (Fauziah *et al.*, 2017).

A study by Liputo et al. (2015) in Jakarta stated that although GOS is nominally quite high, vegetation structure and location are not effective in reducing pollution (Susrama & Diyasa, 2024). This study refines these findings by showing that not only the quantity, but the distribution and functionality of GOS in relation to vehicles are crucial (Hariyadi *et al.,* 2023).

Compared to global studies such as Silaban *et al.* (2021), which highlights urban economic growth that is not accompanied by adequate environmental policies, the results of this study confirm that the same problem also occurs in Indonesia. However, this study provides more measurable empirical and quantitative evidence on this issue, so that it can be the basis for data-based policy formulation (Analya *et al.,* 2003).

CONCLUSION

The results of this study have analyzed the influence of the area of Green Open Space and the number of motor vehicles on the Air Pollution Standard Index as a representation of negative externalities in Indonesia's major cities. Based on multiple linear regression analysis, it was found that both independent variables had a significant effect on APSI. The GOS regression coefficient is negative (-0.231), indicating that increasing the area of GOS is able to reduce air pollution levels (Damayanti & Handriyono, 2022). In contrast, the number of motor vehicles showed a positive influence (0.402) on APSI, which means that the growth of vehicles is a major contributor to air pollution (Sajiwo *et al.,* 2024).

The regression model used had an R^2 value of 0.884, which showed that 88.4% of ISPU variations could be explained by GOS and vehicle variables. The classical assumption test also showed that the model is free of multicollinearity, heteroscedasticity, and normally distributed residual (Rona & Hudawan, 2024).

Based on these results, the recommended policies include: (1) increasing and optimizing GOS in urban areas as an absorber of air pollutants, (2) restricting motor vehicles through quota systems, toll roads, and electric vehicle incentives, and (3) strengthening environmentally friendly public transportation. This policy must be integrated with environment-based urban spatial planning (Kartikasari, 2020).

For further research, it is recommended to involve additional variables such as industrial emission levels, wind direction, surface temperature, and panel spatial data covering longer time periods. Spatial approaches or non-linear modeling can also be used to dynamically strengthen the analysis of the relationship between environmental factors and APSI (Kurniawan *et al.,* 2020).

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