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$PM_{2.5}$-AIR POLLUTION: DETERMINING FACTORS OF AIR QUALITY IN PROVINCES ON THE ISLAND OF JAVA

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ABSTRACT
This study focuses on analysing the determining factors of particulate matter ($PM_{2.5}$) air pollution in provinces on the island of Java. Air pollution is a phenomenon of environmental damage that continues to occur in line with human activities which have an impact on humans themselves, including health, global warming, and climate change. $PM_{2.5}$ particulate matter pollution parameters were chosen because these micro particles easily enter through inhalation and pose a big risk to human health. Quantitative research methods were employed to make sense of the available secondary data. Econometric models-Panel Data Regression Analysis were used to examine the sources causing air pollution-$PM_{2.5}$. The results showed that population density and manufacturing industrial production were important factors in increasing air pollution-$PM_{2.5}$. This can be explained by the fact that population density creates complexity in handling garbage and household waste which has the potential to increase emissions, while the manufacturing industry is associated with industrial waste and factory chimney smoke which directly pollutes the air. This research is useful for strengthening control policies and mitigation efforts for air pollution that is harmful to the environment and human health more effectively. Therefore, controlling emission sources and disturbances is necessary to prevent air quality degradation caused by these sectors.
Keywords: *$PM_{2.5}$, Real GRDP, manufacturing industrial production, population density*

1. Introduction

Air pollution is the contamination of the indoor or outdoor environment by various substances, objects and any particles that change the natural characteristics of the atmosphere. The phenomenon of environmental damage occurs every day throughout the world with varying levels of pollution. The root of the problem can be divided into two: natural (disasters, volcanic eruptions, and forest fires) and human activities (industrial production, consumption, transportation and so on). Human activity is believed to be the main cause, both directly and indirectly, of climate change and various threats to the natural environment, including air pollution.

Air pollution is environmental damage that greatly affects human health. The presence of one or more contaminants in the atmosphere such as dust, smoke, gas, mist, odor, smoke, or steam in certain amounts and for a certain duration can endanger human health. The main route of exposure to air pollution is through the respiratory tract. Inhaling pollutants causes inflammation, oxidative stress, immunosuppression, and mutagenicity in the human body which results in impaired function of the lungs, heart, brain, and other organs, as well as causing various diseases that can cause premature death. The World Health Organization report (WHO, 2018) recorded a figure of around 7.3 million premature deaths every year and millions of people are at risk of health due to declining air quality and the effects of greenhouse gases.

Overall, this provides a warning about the importance of carrying out mitigation measures to prevent environmental risks to humans and other life.

This study explains human actions that can mitigate air pollution which is dangerous for humans and life. In various studies on mitigating the risk of environmental damage, factors causing a decrease/increase in ambient air quality CO2, SO2, NO2 gases have received the most attention from researchers (Masito, 2018; Angelia, et.al, 2019; Uniplaita, et.al 2020; Khioron, at .al, 2022; Winatama, et.al, 2023). Different thinking stated that controlling particulate matter is more urgent because particulate matter (PM) has a significant role in increasing the risk of heart disease, lung disease and other respiratory problems (Pope & Dockery, 2006; Greenstone & Fan, 2018). According by Greenstone and Fan (2018), particulate air pollution reduces global life expectancy by almost 2.3 years compared to if particulate concentrations in all locations were at levels considered safe by the World Health Organization (WHO).

The impact of exposure to $PM_{2.5}$ particulates is much more serious for health than some types of disease. Exposure to $PM_{2.5}$ is more serious than infectious diseases such as HIV/AIDS, tobacco and alcohol use behavior that can be stopped, as well as conditions such as malnutrition in children and pregnant women, mental disorders, and others (Greenstone and Fan, 2018). $PM_{2.5}$ is a complex mixture of chemical compositions of various particles with a diameter of less than 2,5 µm ($PM_{2.5}$). With its very small size plus exposure to $PM_{2.5}$ levels exceeding the WHO reference limit guideline of 5 µg/m3 (WHO, 2021), it greatly determines human survival. Even exposure to $PM_{2.5}$ creates an economic burden on health financing, at least the state budget needed reaches IDR 10 trillion to finance population health care per year (Wiratmaja, 2023). Therefore, this study focuses on observing human activities which have a major contribution to the increase in $PM_{2.5}$ particulates.

Apart from that, this study chose location for provinces on the island of Java with various considerations. This is considered because Java Island has dominant economic activity with the Gross Domestic Product contribution of 57.06 percent and the remainder contributed by provinces outside Java (Central Bureau of Statistics, 2022). It is certain that the dominant economic activities are sources of provincial air pollution on the Island of Java which are also relatively high. By examining activity factors, sectoral results, demographic conditions, and residential density using econometric modelling simulation methods, can find factors that cause $PM_{2.5}$ concentrations to occur. This study is useful for strengthening control policies and mitigation measures for air pollution which is dangerous for the environment and human health more effectively.

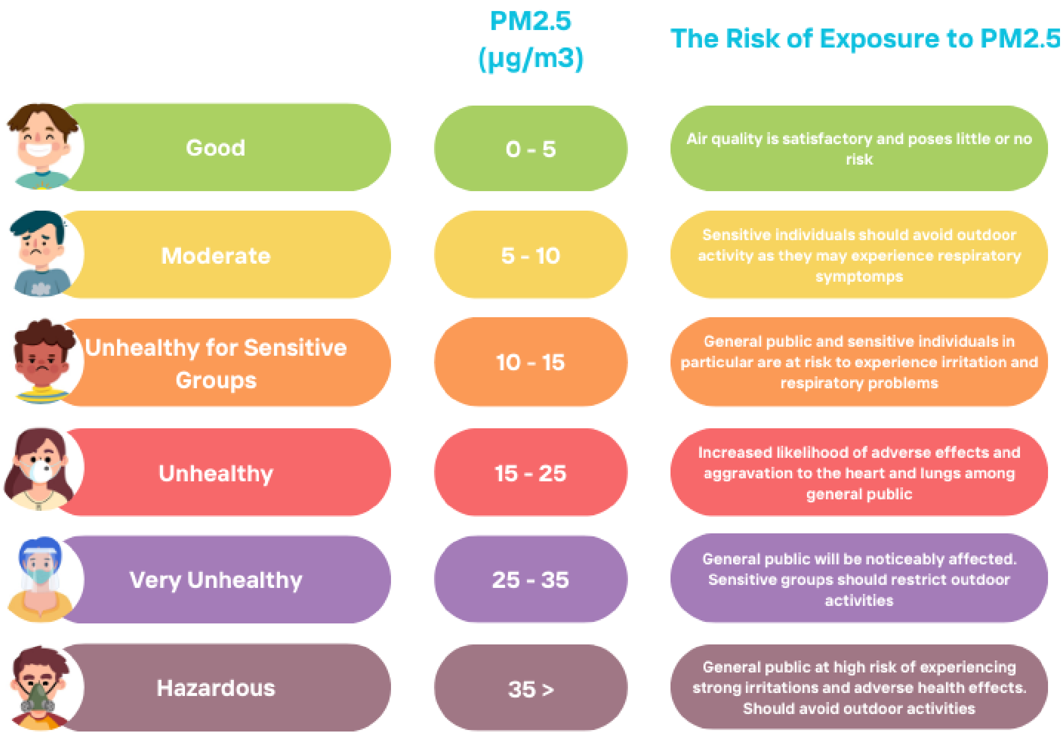
2. Literature Review

2.1 Particulate Matter ($PM_{2.5}$) as Dependent Variable

PM (Particulate Matter) is classified according to the diameter of the particulates. WHO has two PM parameters: particulates less than 2.5 $\mu m/m^3$ ($PM_{2.5}$) as hazardous particles and 10 µm (PM_{10}) which is defined as the long-term average safe level of particulate pollution. The two types of PM are different in size and have different risks related to human health. In the 1980-90s, epidemiological research in the US showed that PM with a diameter of less than 10 µm (PM_{10}) was the focus of health impacts, both acute and chronic. Recent research highlights that small particle, especially $PM_{2.5}$ are more significant in terms of negative impacts on health (Pope & Dockery, 2006). This is because small particles more easily enter the human body through the respiratory tract as the main source.

Air quality criteria are determined by the concentration of $PM_{2.5}$ in the air of area. The air quality index (AQI) ranges from 0 to 500, although air quality can be indexed over 500 if there are higher levels of air pollution. Good air quality ranges from 0 to 50, while measurements above 300 are considered dangerous. $PM_{2.5}$ measurement concentration is a determinant of AQI readings because $PM_{2.5}$ is widely available and is considered the most dangerous pollutant that impacts human health (AQI,2024).

$PM_{2.5}$ is measured in micrograms per cubic meter (µg/m3). The United States Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) categorized any measurement greater than 9.0 µg/m3 (US AQI 50) as being harmful to human health (Figure 1)



Source: https://www.iqair.com/id/newsroom/what-is-aqi

Figure 1. Categories of $PM_{2.5}$ Values, Air Quality, and Health Implications

The annual $PM_{2.5}$ indicator is used to determine the air quality category each year as follows. Air quality using $PM_{2.5}$ is categorized into 6 clusters. $PM_{2.5}$ value of 0.0-5.0 µm/m3 is in the very good or very healthy category according to WHO provisions, while $PM_{2.5}$ value of 0.51-10.0 µm/m3 is categorized as moderate (healthy). This category may be vulnerable to individuals who are sensitive to pollution and develop respiratory symptoms. At the value of 10.1-25.0 µm/m3, air quality is categorized as somewhat unhealthy. This category requires general discretion and caution in sensitive individuals, as it has the potential to cause respiratory problems and irritation. In the category of $PM_{2.5}$ values above 25.1-35.0 µm/m3 and above 35.1-50.0, the air quality status is unhealthy and very unhealthy. Finally, at a value above 50.0, air quality has entered a condition that is dangerous to health.

The sources that cause $PM_{2.5}$ generation are the focus in this research. By knowing the source of the generation of these dangerous particles, studies can find the policies and mitigation actions needed to prevent a decline in public health status. Previous studies have identified and explained the factors causing $PM_{2.5}$ generation, mainly originating from the following social and economic activities: secondary industry (Yan, et.al, 2020), electricity/energy consumption (Huang, et.al, 2023; Yan, et. .al, 2020), Public Buses/Public Transportation (Yosritzal, et.al; 2023 Yan, et.al, 2020), population or population density (Huang, et.al, 2023; Yan, et.al, 2020; Sarkodie, et.al, 2019), urbanization (Yan, et.al, 2020;

Sarkodie, et.al, 2019; Foreign Direct Investment or FDI (Yan, et.al, 2020); GDP per capita (Huang, et. al, 2023; Yan, et.al, 2020; Sarkodie, et.al, 2019), and meteorological factors (Melinda & Nuryanto, 2023).

By replicating this, this study focused on observing three main factors causing pollution at the level of provinces on the island of Java. This consists of (a) Real Gross Regional Domestic Product (Real GRDP), (b) Population Density (PD) and what has not been studied by previous researchers is Manufacturing Industrial Production (MIP). These factors are explained in the following sections.

2.2 Gross Regional Domestic Product (Real GRDP)

Gross Domestic Product (GDP) reflects the monetary value of all final goods and services produced within a country's territory during a certain period, usually one year (Sukirno, 2004). Economic growth is often used to display economic development which is characterized by an increase in capacity to meet needs. economic goods for society and is measured by the increase in national output or gross domestic product (GDP over time (Todaro, 2000). In the production or business aspect, Real GDP is the result of the added monetary value of goods and services from all sectors in each year with constant prices in the base year. Economic activity sectors covered in GDP include primary sector, secondary/manufacturing sector, and service sector. In the expenditure sector, GDP is expenditure from various institutions in the economy, such as: household consumption, non-government expenditure and government, investment and exports and imports. The aggregation of the monetary value of goods and services divided by the population in a particular region/region is called GDP per capita, which shows how much average economic output is available for everyone.

At the provincial level, provincial/regional output at constant prices is known as Real Gross Regional Domestic Product (Real GRDP). This has the same approach and calculation techniques as the national economy with production coverage and population based on provincial areas. This indicator provides an overview of the average level of welfare of a region and is often used to compare economic levels between different regions. GDP per capita is important because it allows more meaningful comparisons between one region and another with different population sizes.

2.3 Manufacturing Industrial Production

The manufacturing sector provides great opportunities for economic growth in developing countries. Manufacturing is the activity of processing materials or raw materials into finished goods. More precisely, the Central Bureau of Statistics (2020) defines the manufacturing industry as economic activities that change basic goods mechanically, chemically or by hand so that they become semi-finished goods or finished goods, and/or goods of less value into goods of higher value and closer in nature to with end users. In the processing process, activities involve the mobilization of resources (raw materials, human resources, technology, machines, and equipment used to process raw materials. The manufacturing industry is an important sector that produces goods and semi-finished goods en masse (mass production), absorbing labor many, and is the main motor of growth in many countries.

Although the manufacturing industry is important to the economy, it is often associated with high levels of pollution and environmental degradation. The manufacturing industry is also often associated with the use of excess energy for burning, heating, and mixing materials that have negative externalities, such as smoke, dust, hazardous and toxic waste (B3), and rubbish. In fact, the manufacturing industry is a significant contributor to global air pollution, with industrial emissions releasing hazardous waste fumes that pose serious risks to both human health and the environment (Oskouian, 2023). This encourages the importance of government regulations and policies to control industrial areas, pollution, and various technological/technical, ecological, and social requirements to prevent dangers that disrupt the safety of workers, surrounding communities, the environment and excessive use of fossil energy (Hernándes, et.al, 2019).

The condition of the manufacturing industry encourages the importance of a sustainable manufacturing industry development agenda. Sustainable Development Goals (SDGs) place the importance of sustainable manufacturing production. The production system that aims to reduce energy consumption, emissions, disposal, and use of non-recyclable materials (SDGs - 12). An approach that looks at the product, process and life cycle starting from the acquisition of raw materials to the final stage of the product's useful life or end of life (see https://sdgs.bappenas.go.id/metadata-indikator-sdgs/).

2.4 Population Density

Population density is an indicator in many studies, but is often accompanied by only a cursory explanation of the reasons. Population density has various implications for the environment and human health. Population density is the ratio of population to land area. In general, population density is the ratio of the number of residents to the area of land based on a certain unit area. The use of population density variables in research often invites debate. In the case of the Covid-19 pandemic, for example, some researchers point to population density as a predictor of incidence or death rates after exposure to the corona virus, but other studies confirm that this is not the case in many areas with high population density. Population density in an area does not result in high exposure to Covid-19 by showing other factors, so population density needs to be explained more thoroughly. Population density may not necessarily mean higher infection rates by referring to issues of public policy, personal behavior, socioeconomic status, health care, transit, and other factors driving the spread of infection (Greenberg& Scheneider, 2023).

The illustration of the relationship between population density, environment and health above reminds that the relationship between population density and $PM_{2.5}$ generation requires caution. Population density in an area accompanied by the ability to suppress the growth of greenhouse gas emissions may have the opportunity to cause low particulate generation. However, areas that have not succeeded in addressing settlement and housing arrangements, the large number of slum areas, the availability of green open spaces, sanitation and waste handling problems, high energy use, and other real mitigation actions have the potential to produce high exposure to particulates.

2.5. Theoritical Framework

The description above can be depicted in the following theoretical framework diagram (Figure 2). Regarding production, Real Gross Regional Domestic Product (Real GRDP) reflects increased economic activity and has the effect of increasing $PM_{2.5}$ generation. This can be explained by the fact that businesses in various economic, social, and public service sectors that produce goods and services in aggregate have the potential to increase air pollution, especially $PM_{2.5}$.

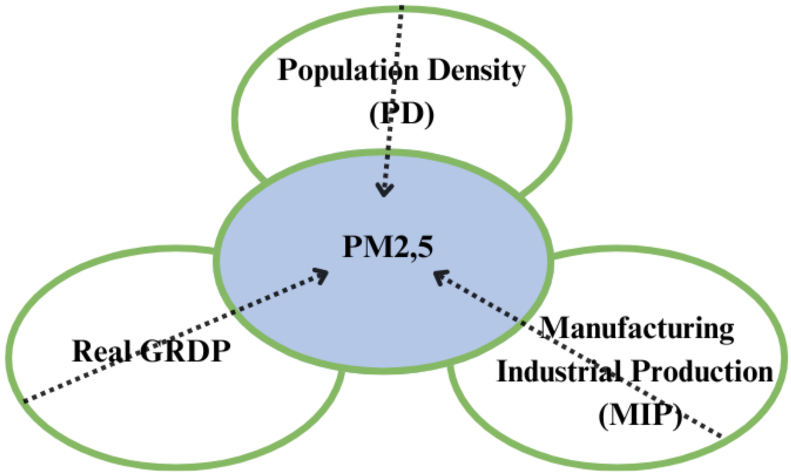


Figure 2: Theoritical Approach (adapted from Yan, et.al, 2020; Sarkodie, et.al, 2019)

In densely populated provincial areas, high population activity has the potential to produce greater emissions such as consumption, transportation, poor sanitation, household waste and garbage, as well as the complexity of handling them in residential areas. Manufacturing industrial production provides great opportunities for economic growth in developing countries but is often associated with high levels of pollution and environmental degradation, including air pollution in the form of $PM_{2.5}$ particles. This can be seen in real terms in manufacturing industrial areas producing pollution through industrial waste, factory chimneys, the use of fossil-based energy and the use of environmentally unfriendly materials such as plastic and fabric.

3. Research Methods

Quantitative model research methods with panel data regression analysis were used in this research. This study analysed the relationship between real GRDP (GRDPit), manufacturing industrial production (MIPit), and population density (KPit) on air pollution ($PM_{2.5}$). The data used is cross section data for 6 provinces on the island of Java (Banten Province, DKI Jakarta, West Java, Central Java, DI Yogyakarta, and East Java) for the 2012-2021 data series (10 years). The panel data regression model used is as follows.

$$LnPM_{2.5it} = \beta_0 + \beta_1 LnPDB_{it} + \beta_2 LnPIM_{it} + \beta_3 LnKP_{it} + e_{it}$$

$PM_{2.5}$	=	Particulate Matter measures 2.5 µm/m3 in each province of the Java Island
β_0	=	Constant
$\beta_1 \beta_2 \beta_3$	=	Independent variable coefficient
GRDP	=	Gross Domestic Product in each province of Java Island, often called Gross Regional Domestic Product (GRDP). In this study it is often used interchangeably to refer to the meaning of GDP at the provincial level.
MIP	=	Manufacturing Industry Production in every province of the Java Island
PD	=	Population Density in every province of the Java Island

i = *Cross section*

t = *Time series*

Panel data regression modeling was estimated to ensure the best model between the common effect model (CEM), fixed effect model (FEM), and random effect model or REM (see figure 3)

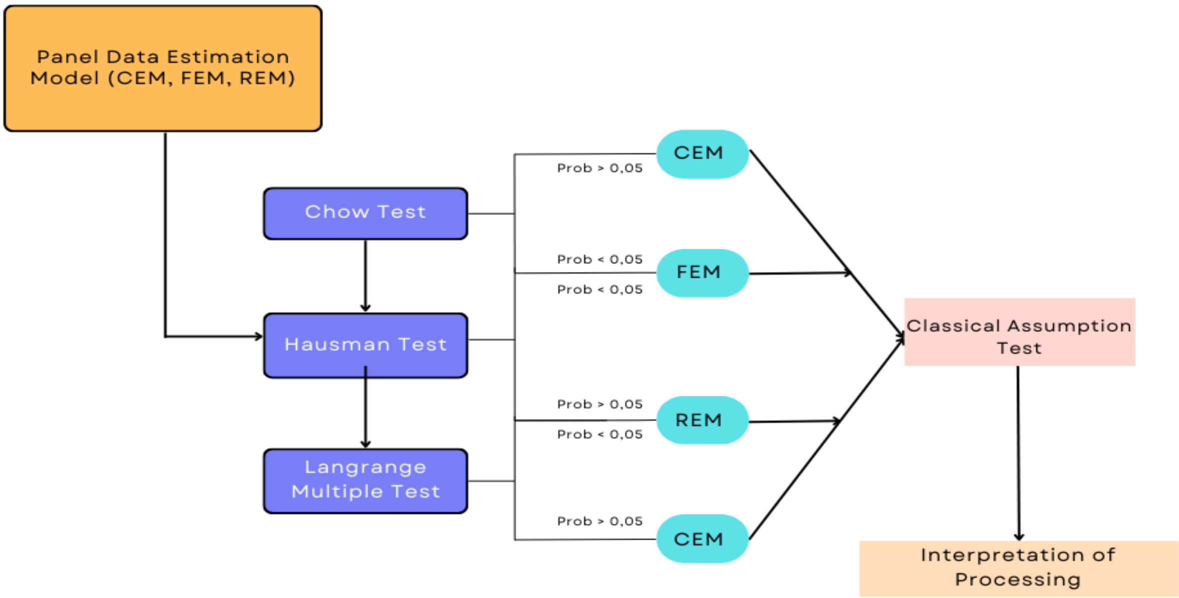


Figure 3: Flowchart of data processing steps

Futhermore, the Chow test, Hausman test, and LM test were carried out to determine the most appropriate model. The classical assumption test is carried out according to the selected model. The process of panel data regression analysis, including model selection, and significance testing of individual effects and combined effects (via t-statistics and F-statistics, with $\alpha = p = 0.05$) was also carried out. The final section carried out data analysis and interpretation.

4. Research Findings and Discussion

4.1 Descriptive Analysis

As an initial illustration of the study results, the average $PM_{2.5}$ values and determining factors for air quality are stated in Table 1 and Table 2 below. The overall average of the data shows that $PM_{2.5}$ has approached a diameter of 2.5 µg/m3 per cubic meter with an average of 22.79 µg/m3 for the entire island of Java. This reflects unhealthy air quality conditions. This is worrying because residents live, work and carry out activities in polluted areas, and cannot do much to avoid particulate pollution and continue to breathe unhealthy air. Therefore, regulations and policies accompanied by real mitigation, supervision and control actions must continue to be implemented.

Table 1: $PM_{2.5}$ Values and Air Quality Determinants for 2012-2021

Variabel	Unit	Max	Min	Mean	Std. Deviasi
$PM_{2.5}$	$\mu g/m^3$	37.53	11.32	22.79	6.16
Real GRDP	Thousand trillion rupiahs	1,856.00	71.70	941.39	565.37
MIP	Percent	43.72	10.85	28.08	11.78
PD	People/Km^2	15,978	797	3,524.23	5,410.24

Source: Eviews 12 (processed) 2024

Economic and social factors can be explained. Regional income reflected through Provincial Gross Domestic Product has an average for a decade of IDR 941.39 thousand trillion or around US$ 58.64 billion at an exchange rate of 1 US$ = 16.055 (https://www.bi.go.id/id/statistics/information-kurs/transaksi-bi/default.aspx, accessed May 11, 2024, 15.00). There are high differences in income between provinces which are reflected in the standard deviation. The average contribution of the manufacturing industry reaches 28.08 percent of the total provincial GDP. Population density reached an average of 3,524.23 people/km2.

Table 2: Average $PM_{2.5}$ Values and Air Quality Determinants by Province in 2012-2021

Provinces	$PM_{2.5}$	Real GRDP	MIP	PD
Banten	26.02	394.97	36.03	1,247.4
DKI Jakarta	31.96	1,574.22	12.41	15,509.8
West Java	25.25	1,296.94	43.12	1,337.6
Central Java	19.65	862.77	34.56	1,052.1
DI Yogyakarta	14.01	90.19	12.77	1,176.2
East Java	19.85	1,429.27	29.62	822.3

Source: Processed with Eviews, 2024

Based on region, provinces have a variety of $PM_{2.5}$ pollutants in the somewhat unhealthy and unhealthy categories. This can be seen in the very unhealthy category experienced by the provinces of DKI Jakarta, Banten and West Java. These three areas are concentrations of economic growth due to the expansion of capital and metropolitan development. The somewhat unhealthy category occurs in the provinces of Central Java, East Java and DI Yogyakarta.

4.2 Panel Data Regression Analisis

4.2.1. Model CEM, FEM, and REM

Table 3 shows the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM). The constant can be negative and positive and can be accounted for theoretically, because the relationship between $PM_{2.5}$ and its determining factors has a positive slope, so the constant can be above or below the zero point. Negative and positive constants can be used as long as the regression model being tested meets the assumptions (for example normality) or other classic assumptions for multiple regression (Dougherty, 2002).

Table 3. The Estimation Result of Demand with Common, Fixed and Random Effect

Variabel	Common Effect Model (CEM)	Fixed Effect Model (FEM)	Random Effect Model (REM)
Constant (C)	-0.6685	4.776	-0.2228
Ln $GRDP_{it}$	-0.0155	-0.4502	-0.0403
Ln MIP_{it}	0.4962	-0.3663	0.4990
Ln PD_{it}	0.3318	1.1589	0.1349
R-Squared	0.8353	0.9019	0.3384
Adj R-Squared	0.8264	0.8866	0.3030
F-Statistic	94.6543	58.6551	9.5499

Source: Preceded with Eviews, 2024

The model that best suits the research objectives will be selected from the three models that have been estimated. The three estimation models are the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM) (see Table 3). Model selection is carried out with two types of tests which are used as a means to select a panel data regression model (CEM, FEM or REM) based on the characteristics of the data; namely the F Test (Chow Test) and Hausmann Test.

4.2.2. Model Selection Test

Based on Table 4, it can be seen that the best model selected is the Random Effect Model (REM). For the t and F test results, we will use the calculation results from the Random Effect Model (REM). ***The Selection CEM vs FEM Model.*** Decision making in the Chow test is based on the Probability F value of Prob. F 0.0001 < 0.05 then H_0 will be rejected and H_1 accepted.Thus, it can be concluded that the Chow test, Fixed Effect Model (FEM) was selected.

Table 4: Model Selection Test

Model Test	Prob	Result Model
Test Chow	0.0001	Fixed Effect Model (FEM)
Test Hausman	0.0748	Random Effect Model (REM)
Test Langrange Multiplier	0.0001	Random Effect Model (REM)

Source: Preceded with Eviews, 2024

The Selection of FEM vs REM Model. The basis for decision making in the Hausman test is also based on Probability F. In the output value Prob. F=0.0748 > 0.05 then H_0 will be accepted and H_1 rejected. It can be concluded that the Random Effect Model (REM) was chosen.

The Selection of REM vs CEM Model. The basis for decision making in the Langrange multiplier test is also based on Probability F. In the output value Prob. F 0,0001 < 0.05 then H_0 will be accepted and H_1 rejected. It can be concluded that the Random Effect Model (REM) was chosen.

4.2.3. Classical Assumption Test

4.2.3.1 Multicollinearity Test

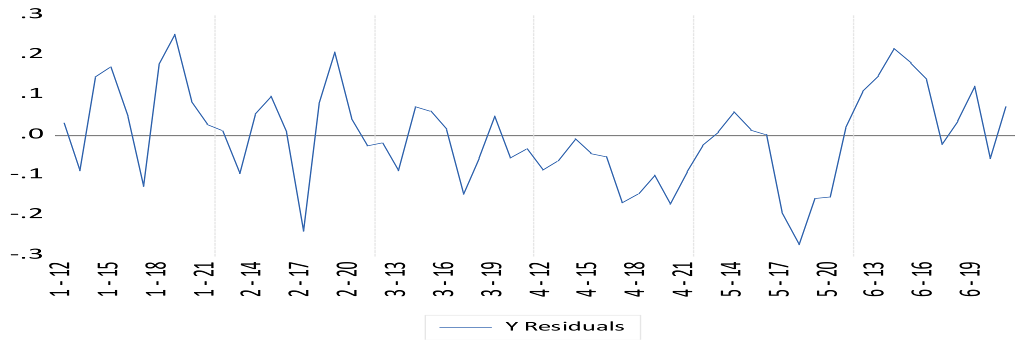
If we look at Table 5, the correlation coefficient for GRDPit and MIPit is 0.3605 < 0.85, GRDPit and PDit is 0.3255 < 0.85, MIPit and PDit is -0.6109 < 0.85, it can be stated that multicollinearity does not occur.

Table 5: Multicollinearity Test

	Ln $GRDP_{it}$	Ln MIP_{it}	Ln PD_{it}
Ln $GRDP_{it}$	1	0.3605	0.3255
Ln MIP_{it}	0.3605	1	-0.6109
Ln PD_{it}	0.3255	-0.6109	1

Source: Preceded with Eviews, 2024

4.2.3.2 Heteroscedasticity Test



Source: Processed with Eviews, 2024

Figure 4: Multicollinearity Test

Based on the image above, the residual graph does not exceed the limits (500 and -500), meaning that the residual variance is the same, so that the data does not experience symptoms of heteroscedasticity (Napitupulu et al., 2021).

4.3 Hypothesis Test

Table 6. T-test on Random Effect Model (REM)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant (C)	-0.222810	0.844061	-0.263974	0.7928
Ln $GRDP_{it}$	-0.040309	0.053083	-0.759364	0.4508
Ln MIP_{it}	+0.499018	0.134945	3.697929	0.0005
Ln PD_{it}	+0.338370	0.072124	4.691491	0.0000

Source: Preceded with Eviews, 2024

The REM model equation model can be stated as follows.

$Ln\ (PM_{2.5})_{it} = -\ 0.2228 - 0.040\ Ln\ GRDP_{it} + 0.4990\ Ln\ MIP_{it} + 0.3384\ Ln\ PD_{it} + \varepsilon_{it},\ R^2 = 0.3384$

4.3.1. R2-Test

The coefficient of determination shows the extent to which the contribution of the independent variable in the regression model is able to explain variations in the dependent variable. This equation has a determination coefficient R2 of 0.3384. This figure shows that the independent variables in the model are only able to explain 33.84 percent of the dependent variable as explained by Ghozali (2016). This still requires a further identification process regarding the determining factors of $PM_{2.5}$.

4.3.2 F-Test

The F test is carried out to see the influence of all independent variables together on the dependent variable. To determine that all independent variables have the ability to explain the dependent variable in the Random Effect Model (REM), the calculated F value of 9.5499 in the model is compared with the statistical F value (α, df1, df2). With α = 5% and degrees of freedom for df_1=k-1=3, and df_2=n-k-1= 55, the F value (5%,3.55) in the F distribution table is 2.773. Comparison of calculated F and F (5%, 3.55) in the table confirms that the test rejects H_o and accepts H_a where all independent variables have a significant influence on the dependent/dependent variable.

4.4. Analysis of the selected REM Model

4.4.1. The effect of real GRDP on $PM_{2.5}$

In the REM model above, GRDP does not significantly influence the generation of $PM_{2.5}$ concentrations. This can be seen from the probability value of this variable being more than 0.05. This is in line with research by Zhu, et.al (2022) that there is an insignificant negative relationship between real GRDP and $PM_{2.5}$ concentrations. There are symptoms that show that the higher the provincial GDP, the higher the concentration of $PM_{2.5}$ in the region, but this relationship does not have a significant effect throughout the year. In other words, the incidence of high concentrations of $PM_{2.5}$ in large cities is seasonal or does not occur on all days of the year, and is determined by factors outside the model such as: climate and meterology in the area, such as: wind speed, humidity, rainfall and others.

4.4.2 The Effect of Manufacturing Industry Production on $PM_{2.5}$

Manufacturing industrial production has a significant effect on the formation of $PM_{2.5}$ particulates. Statistically, significance is shown by the probability value of less than 0.05. This is in line with research by Zhu et.al (2022) where the stochastic impacts by regression on population influence and technology of pollutant- $PM_{2.5}$ model has been used to examine the importance of socio-economic factors on $PM_{2.5}$ pollution and the findings show that the industrial sector secondary has the greatest impact. This shows that the existence of manufacturing industries in big cities such as Jakarta, West Java and Banten has the potential for the formation of $PM_{2.5}$ and has implications for health. In contrast, DI Jogjakarta, which does not have many large manufacturing industries, has relatively the lowest $PM_{2.5}$.

4.4.3. The Effect of Population Density on $PM_{2.5}$

Population density (PD) on REM model has a significant influence on the concentration of pollutant- $PM_{2.5}$. This is tested from a probability value of less than 0.05, which means PD has a significant effect on $PM_{2.5}$. Panuju & Usman (2023) found that areas with high population density tend to have higher $PM_{2.5}$ concentrations compared to areas with low population density. This cannot be overgeneralized, because population density accompanied by good settlement and housing arrangements, adequate green open space, settlement of slums, excellent management of rubbish, waste and sanitation, use of low-carbon energy and other concrete actions can correct the relationship of KP and $PM_{2.5}$. However, most provinces on the Java Island have various settlement and housing conditions that are not yet sustainable, so population density is still a challenge that must be solved, especially the contribution of dense settlements to the formation of high $PM_{2.5}$ concentrations. This indication can be stated that the top three positions in $PM_{2.5}$ particulate concentrations are in provinces that have high population density.

5. Conclusion and Recommendation

This study found that provinces on the island of Java have high air quality and concentrations of $PM_{2.5}$ particulates. This showed that air quality is in the moderate, somewhat unhealthy, and not healthy categories. The REM model confirms that the factors that determine the formation of $PM_{2.5}$ are manufacturing industrial production activities and population density.

Manufacturing Industrial Production and population density are stated to be the main sources of $PM_{2.5}$ pollutants. This is related to the activity of using excess energy for burning, heating, and mixing materials that have negative externalities, such as factory chimney smoke, dust, hazardous and toxic waste (B3), and other industrial waste (including plastic). Regarding population density, it needs to be examined carefully, because in areas of provinces or big cities in the world that have succeeded in arranging housing/housing, adequacy of green open space, handling rubbish and waste, as well as good sanitation systems, the use of low-carbon energy can have the potential to reduce emissions. and particulate concentration- $PM_{2.5}$. However, this research confirmed that provinces on the island of Java that have not yet scheduled mitigation actions and concrete steps been at great risk of producing high levels of $PM_{2.5}$.

This study recommends the importance of regulations and policies to control and supervise increasingly resilient manufacturing industry activities, as well as further strengthening the action agenda and concrete steps to mitigate emissions, including $PM_{2.5}$. The same thing related to the aspect of population density requires hard work and real action to reduce emissions, especially sanitation and waste management, as well as handling household waste which still haunts cities on the Java Island.

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