

**ECONOMIC DYNAMICS UNDER POLLUTED SKIES:
AN ANALYTICAL COMPARISON OF
JAKARTA, SURABAYA, MAKASSAR AND MEDAN**



THESIS

**Submitted as one of the Requirements to obtain Bachelor's Degree in
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Yogyakarta, 2024

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A BACHELOR DEGREE THESIS

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DEDICATION

*In loving memory of my love,
the core of my heart,
the one whose light has guided me through darkness.*

This research is dedicated to her.

*Your life was a blessing,
your memory is a treasure,
you are loved beyond words and missed beyond measure.*

–This work is a heartfelt tribute to someone special whose love has been my
guiding light for the entire of my life journey–

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With perseverance, belief, enthusiasm, hard work, prayers, and support from various parties, the thesis entitled "**Economic Dynamics Under Polluted Skies: An Analytical Comparison of Jakarta, Surabaya, Makassar and Medan**" can be completed. This thesis is a requirement to obtain a Bachelor's Degree (S1) in Economics from the Universitas Islam Indonesia.

During the writing process, the author realized the shortcomings and limitations of his knowledge. Therefore, guidance and assistance from various parties was very helpful in completing this thesis. With humility, the author would like to express his deepest gratitude to:

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ABSTRACT

Air pollution has become a serious environmental concern in Indonesia, especially in heavily populated urban areas such as Jakarta, Surabaya, Makassar, and Medan. The fast urbanization process, along with a rise in personal vehicles and manufacturing growth, has been a significant factor in the rise in pollutant concentrations, particularly fine particulate matter (PM_{2.5}). This research paper aims to analyze the correlation of air pollution to the economy, the number of workers in the manufacturing industry, and the consumption of gasoline in four metropolitan cities in Indonesia. The data used are secondary data analyzed using the Panel Data method. Panel data comprises a comprehensive period and areas covering the years from 2013 to 2023 period in Jakarta, Surabaya, Makassar, and Medan. The analysis was conducted using the EViews 13 software. The results demonstrate that Gross Regional Domestic Product (GRDP), the Proportion of Workers in the Manufacturing Industry and Fuel Consumption have a significant positive relationship with air pollution. The results of this study are expected to provide new insights, enabling policymakers to formulate effective regulations related to air pollution issues.

Keywords: Air Pollution, Economy, Workers, Manufacturing Industry, Fuel Consumption, Metropolitan City.

ABSTRAK

Di Indonesia, polusi udara telah menjadi masalah lingkungan yang serius, terutama di daerah perkotaan yang padat penduduknya seperti Jakarta, Surabaya, Makassar, dan Medan. Proses urbanisasi yang cepat, bersama dengan peningkatan jumlah kendaraan pribadi dan pertumbuhan industri manufaktur, telah menjadi faktor yang menyebabkan peningkatan konsentrasi polutan, terutama partikulat halus (PM_{2.5}). Penelitian ini bertujuan untuk menganalisis hubungan antara polusi udara, ekonomi, jumlah tenaga kerja di industri manufaktur, dan tingkat konsumsi bahan bakar minyak (BBM) di empat kota metropolitan di Indonesia. Pada penelitian ini, panel data yang digunakan terdiri dari periode dan wilayah yang luas, mencakup periode 2013 hingga 2023, termasuk Jakarta, Surabaya, Makassar, dan Medan. Analisis dilakukan dengan menggunakan perangkat lunak *EViews 13*. Hasil penelitian menunjukkan bahwa Produk Regional Domestik Bruto (PDRB), variabel Proporsi Tenaga Kerja di Industri Manufaktur, dan Konsumsi Bahan Bakar Minyak (BBM) memiliki hubungan positif yang signifikan dengan Polusi Udara. Hasil penelitian ini diharapkan dapat memberikan wawasan baru agar para pembuat kebijakan dapat merumuskan peraturan yang efektif terkait isu Polusi Udara.

Kata Kunci: Polusi Udara, Ekonomi, Tenaga Kerja, Industri Manufaktur, Konsumsi Bahan Bakar Minyak, Kota Metropolitan

CHAPTER I

INTRODUCTION

1.1 Background of the Study

Air pollution has become an environmental issue that severely impacts the quality of human life and ecosystems worldwide. Air pollution is contamination of the indoor or outdoor environment by any chemical, physical, or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities, and forest fires are common sources of air pollution. In addition, air pollution is a complex mixture of gases and particles whose source and composition vary by place and time.

According to Government Regulation No. 41 year 1999 concerning Air Pollution Control in Article 1 paragraph 1, air pollution refers to the inhalation of chemicals, energy, and other components into the surrounding air by human activities, resulting in a decrease in the quality of the air to a level where it is unable to perform its intended purpose. In recent decades, rapid industrialization, urbanization, and human mobility have increased emissions of harmful gasses and particles into the atmosphere, increasing air pollution.

According to Government Regulation No. 41 of 1999, Article 1 Paragraph 9, emissions are energy, substances, and other components released

into the atmosphere due to an activity. These components may or may not possess the capacity to function as pollutant elements. As per the provisions outlined in Article 1 Paragraph 11, an emission source is any enterprise or undertaking that produces emissions from a stationary source, a mobile source in particular, or a specific non-moving source. Moreover, as stated in Article 1, Paragraph 12, factors such as the operation of motorized vehicles, forest fires, and waste incineration are constitutive of mobile or non-stationary emission sources. These sources, consequently, contribute to the escalation of air pollution. According to the World Health Organization (2016), 92% of the world's population currently breathes poor air quality (2016). This number is a highly alarming indication of the state of the global environment. Considering the ecosystem's current situation worldwide, the number is not simply statistics; instead, it reflects a significant crisis in both the health and environmental spheres. Poor air quality means that pollutants such as fine particles and noxious gasses are part of air pollution that affects people's health and well-being in their daily lives. Furthermore, the fact that nearly all people exposed to air that fails to meet the safe quality standards set by the World Health Organization demonstrates the severity of air pollution problem. Moreover, the impact of air pollution is very significant, affecting human health, ecosystems, and the global economy.

The effects of air pollution are substantial and far-reaching, impacting human health, environmental quality, and the broader economy. A World Bank

and Institute for Health Metrics and Evaluation (2016) study entitled 'The Cost of Air Pollution: Strengthening the Economic Case for Action' revealed that air pollution causes significant global economic losses. The study estimated that in 2013, 5.5 million premature deaths were associated with outdoor and household air pollution. The economic losses due to these deaths were estimated at US\$225 billion in the form of lost labour income and over US\$5 trillion in terms of welfare losses, demonstrating the substantial economic burden caused by air pollution (World Bank and the Institute for Health Metrics and Evaluation, 2016). Moreover, exposure to air pollution has been linked to an increased risk of developing a range of health problems, including respiratory and cardiovascular diseases, as well as lung cancer. The environment is also adversely affected, with air pollution resulting in damage to ecosystems, the acidification of rainwater, and a reduction in water and soil quality.

The detrimental impact of air pollution on economic growth and development cannot be underestimated, as the phenomenon significantly influences economic growth in many ways. The financial burden of increased healthcare costs associated with respiratory and cardiovascular diseases has a detrimental impact on state and household budgets. Moreover, the financial burden of healthcare costs is borne by individuals and governments, resulting in the diversion of resources from productive investments (OECD, 2016). Concurrently, labour productivity will be reduced due to poor health. This situation not only reduces individual income but also affects firm productivity,

which in turn reduces national economic growth. As a result, economic competitiveness may remain high, but stifling innovation and long-term growth. Tourism also suffers revenue losses as tourists avoid areas with poor air quality. When considered together, these impacts create a vicious cycle that may worsen economic conditions, ultimately obstructing efforts to achieve sustainable economic development.

As a developing country, Indonesia encounters substantial challenges associated with the complex phenomenon of air pollution. Air pollution in Indonesia is measured using the air quality index (AQI). In accordance with the findings of esteemed researchers, the air quality index represents a comprehensive system that converts the measured concentration of air pollutants into a single numerical value for the purpose of reporting air quality and its impact on human health. By category, the air quality index (AQI) is divided into six degrees of concern and colour categories, ranging from good to hazardous level and green to maroon colour, respectively. The higher the concentration of particulate matter (PM 2.5), the more severe its air quality level.

Table 1. 1 Air quality index with corresponding PM2.5 $\mu\text{g}/\text{m}^3$

<i>US AQI Level</i>	<i>Interval Value</i>	<i>PM2.5 ($\mu\text{g}/\text{m}^3$)</i>	<i>Color</i>	<i>Health Recommendation (For 24-hour exposure)</i>
<i>Good</i>	0 – 50	0 – 12.0	<i>Green</i>	Air quality is satisfactory and poses little or no risk.
<i>Moderate</i>	51 – 100	12.1 – 35.4	<i>Yellow</i>	Sensitive individuals should avoid outdoor activities as they may experience respiratory symptoms
<i>Unhealthy for Sensitive Groups</i>	101 – 150	35.5 – 55.4	<i>Orange</i>	The general public and sensitive individuals in particular are at risk of experiencing irritation and respiratory problems.
<i>Unhealthy</i>	151 – 200	55.5 – 150.4	<i>Red</i>	Increased likelihood of adverse effects and aggravation to the heart and lungs among the general public.
<i>Very Unhealthy</i>	201 – 300	150.5 – 250.4	<i>Purple</i>	The general public will noticeably be affected. Sensitive groups should restrict outdoor activities
<i>Hazardous</i>	301+	250.5+	<i>Dark Red (Maroon)</i>	The general public is at high risk of experiencing strong irritations and adverse health effects. Should avoid outdoor activities.

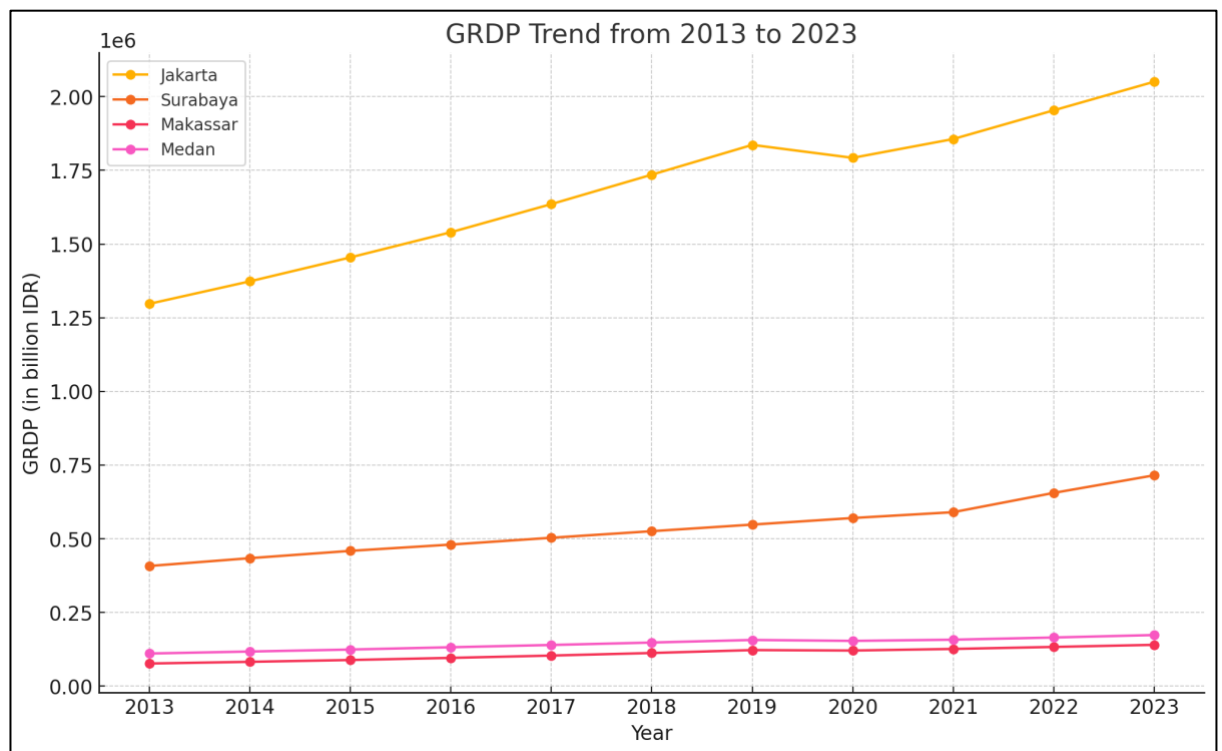
Data Sources: IQAir

According to the data shown in Table 1, when the concentration of PM 2.5 is within the range of 0 - 12.0, with interval values between 0 – 50, this reflects a good air quality level with little or no threat to human health. In addition, if PM 2.5 levels are found to be at a concentration of 250 or more, it indicates that the air quality level is in a dangerous state, and individuals are at a high risk of experiencing the adverse effects of pollution. Along with this, there is a positive correlation between the interval value and the concentration of PM2.5. This is because increases in particulate matter with a diameter of fewer than 2.5 micrometres, commonly referred to as PM2.5, are accompanied by an increase in the interval value.

Air pollution directly impacts the nation's economic landscape, and its impact on the Indonesian economy is undeniable. The rapid economic growth and urbanization have led to an increase in the emission of exhaust gases in several regions, including Jakarta, Indonesia's capital city, and is positioned as the heart of administrative and political activities in the nation, Surabaya, Makassar, and Medan. One important indicator used to measure a region's economic performance is the Gross Regional Domestic Product (GRDP). The GRDP, which evaluates the entire value of products and services generated in an area over a specific period, not only measures economic activities but also gives a broader picture of the society's economic well-being and quality of life. It is known that the complexity of economic issues may increase in the context of rapid globalization, climate change, and emerging technological developments. This is because

globalization has fostered a greater degree of economic integration among nations, bringing new challenges and opportunities.

Figure 1. 1 Trend of Gross Regional Domestic Products



Data Sources: *Central Bureau Statistic*

Figures 1.1 displays a steady upward trend in the Gross Regional Domestic Product (GRDP) of Jakarta, Surabaya, Makassar, and Medan from 2013 to 2023. To begin with, In Jakarta, the capital city of Indonesia, the gross regional domestic product (GRDP) experienced a rise from 18.47 trillion Indonesian rupiah (IDR) in 2013 to 24.64 trillion IDR in 2023, indicating a consistent expansion of the economy. This development was supported by key industries such as services, commerce, manufacturing, and substantial infrastructure investment. Moreover, Surabaya's Gross Regional

Domestic Product (GRDP) consistently increased from 20.53 trillion IDR in 2013 to 26.12 trillion IDR in 2023. The industrial, commerce, and services industries mainly fueled Surabaya's economic development. In addition, the Gross Regional Domestic Product (GRDP) of Makassar showed a consistent upward trajectory, rising from 15.34 trillion IDR in 2013 to 16.03 trillion IDR in 2023, with occasional dips. Lastly, Medan's Gross Regional Domestic Product (GRDP) increased from 13.47 trillion IDR in 2013 to 14.09 trillion IDR in 2023.

Nevertheless, the economic situation worsened in 2020. In those abnormal times, almost all countries worldwide faced the same challenges where their economic condition declined significantly. Humankind was facing a worldwide catastrophe, perhaps one of the biggest crises in human history. What makes the issue particularly challenging is the invisible nature of the virus. While people could not see the appearance of the viruses, society directly experienced the impact of their presence. Therefore, given the 2020 pandemic, the world's economic growth posed a dramatic reduction, including the metropolitan cities in Indonesia.

Like many other nations, Indonesia's economy heavily depends on manufacturing sector. This sector account for a significant portion of the gross regional product (GRDP) and provides many jobs. Given the large number of workers employed in this industry, it is one of the key contributors to the GDP of metropolitan cities. The increase in export value,

economic diversification, and technological innovation demonstrates the sector's contribution to the regional economy. Thus, more than 20% of the workforce in Jakarta is employed in the manufacturing sector, highlighting its importance in boosting economic development.

In this study, the researcher focuses on four major Indonesian cities: Jakarta, Surabaya, Makassar, and Medan. These cities are known for their high degree of economic dominance compared to other urban centres. This condition is because these cities serve as a nexus for many industries, companies, and service sectors, collectively contributing to a significant portion of the gross regional domestic product (GRDP). The high concentration of economic activities in these cities results in a substantial economic output and a notable increase in air pollution concentration. This notion is in line with Stern et al. (1996), who argued that environmental impacts are an inherent aspect of economic development. Thus, the high concentration of industry and transportation in these large cities is the primary source of high levels of pollutant emissions, which have the potential to impact the areas' overall air quality. In addition, the high population density in these cities leads to the use of many transportation vehicles, reflecting the high energy consumption from fuel oil and gas (BBM), further deteriorating the air quality.

Nevertheless, it is essential to acknowledge that although the four cities being investigated are all large metropolitan cities, they also exhibit a range of distinctive characteristics. Such different characteristics will undoubtedly impact economic activities, including the gross regional domestic product (GRDP) level in each city and its correlation with air quality. To illustrate, the cases of DKI Jakarta and Surabaya are cited. As the capital city of Indonesia and the centre of the national economy with the highest GRDP income, Jakarta faces significant challenges related to air pollution. The issue of air pollution in Jakarta has been a concern of the government since the early 1990s and, indeed, a global concern. Based on the World Bank report published in the early 1990s, it was estimated that the health costs associated with air pollution in the Jakarta area in 1989 had reached \$US220 million (World Bank, 1994). In light of these findings, the World Bank urged the Indonesian government to implement concrete measures to control air pollution levels, focusing on the Jakarta case (World Bank, 1997). The issue has become increasingly complex in conjunction with the rapid expansion of economic growth, urbanization, and the exponential growth in the number of motor vehicles.

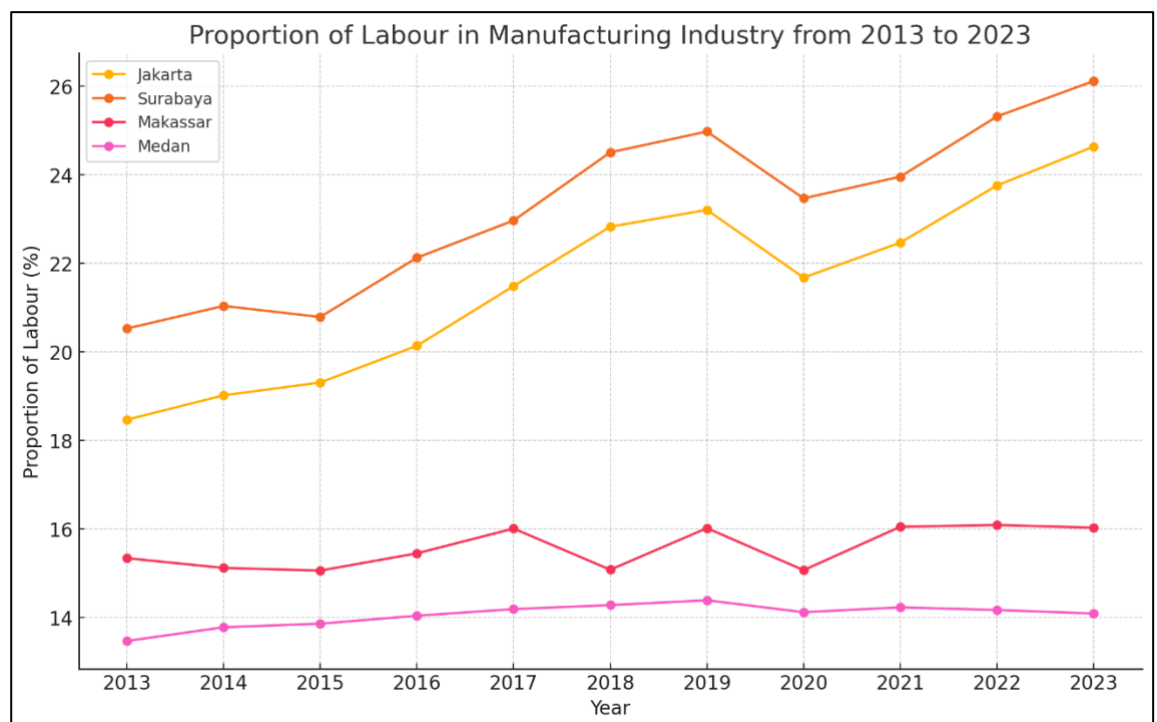
In contrast, Surabaya, despite being classified as a metropolitan area, exhibits a divergent pattern and correlation between economic growth and air pollution levels. Given that its gross regional domestic product is relatively lower than that of Jakarta, Surabaya also confronts a degree of air

pollution comparable to those observed in Jakarta. However, it should be noted that pollution intensity is not distributed evenly; instead, it is concentrated in specific sectors, such as ports and the manufacturing industries.

Another case study may be drawn from eastern and western Indonesia. Makassar, the most populous city and the pawn in eastern Indonesia is similarly afflicted by air pollution, exhibiting levels of contamination comparable to those observed and experienced in Jakarta and Surabaya. However, the distinction lies in the city's characteristics, which are distinct from those of Jakarta, Surabaya, and Medan in that it is not an industrial city. The Central Bureau of Statistics reports that there are only 155 manufacturing industries in Makassar, specifically from the 2023 edition of the Makassar City Manufacturing Industry Directory (Central Bureau of Statistic, 2023). This data indicates that contrary to the common perception, industrial activities do not represent this city's primary source of air pollution. Instead, burning fossil fuels associated with construction activities is a significant contributor to the escalation of pollution in this city. Due to its status as a regional hub in eastern Indonesia, Makassar has undergone an extensive expansion in infrastructural development. This fact has been accompanied by a notable surge in urbanization in this city, which in turn has contributed to the increased air pollution in this pioneer city of eastern Indonesia. The following is a similarly intriguing case study:

Medan. As the most populated city in Sumatra and the largest city in Western Indonesia, the air pollution in Medan is often linked to land and waste burning, given that agricultural-based industrial activities and biomass burning characterize the city's economic growth. These distinct characteristics differentiate air quality and pollution in Medan from those in Jakarta and Surabaya.

Figure 1. 2 Trend Proportion of Workers in Manufacturing Industry



Data source: *Central Bureau Statistic*

This graph clearly shows the changes in the proportion of labour in the manufacturing industry sector in Jakarta, Surabaya, Makassar, and Medan from 2013 to 2023. The labour proportion in Jakarta's manufacturing sector increased from 18.47% in 2013 to 24.64% in 2023. This increase

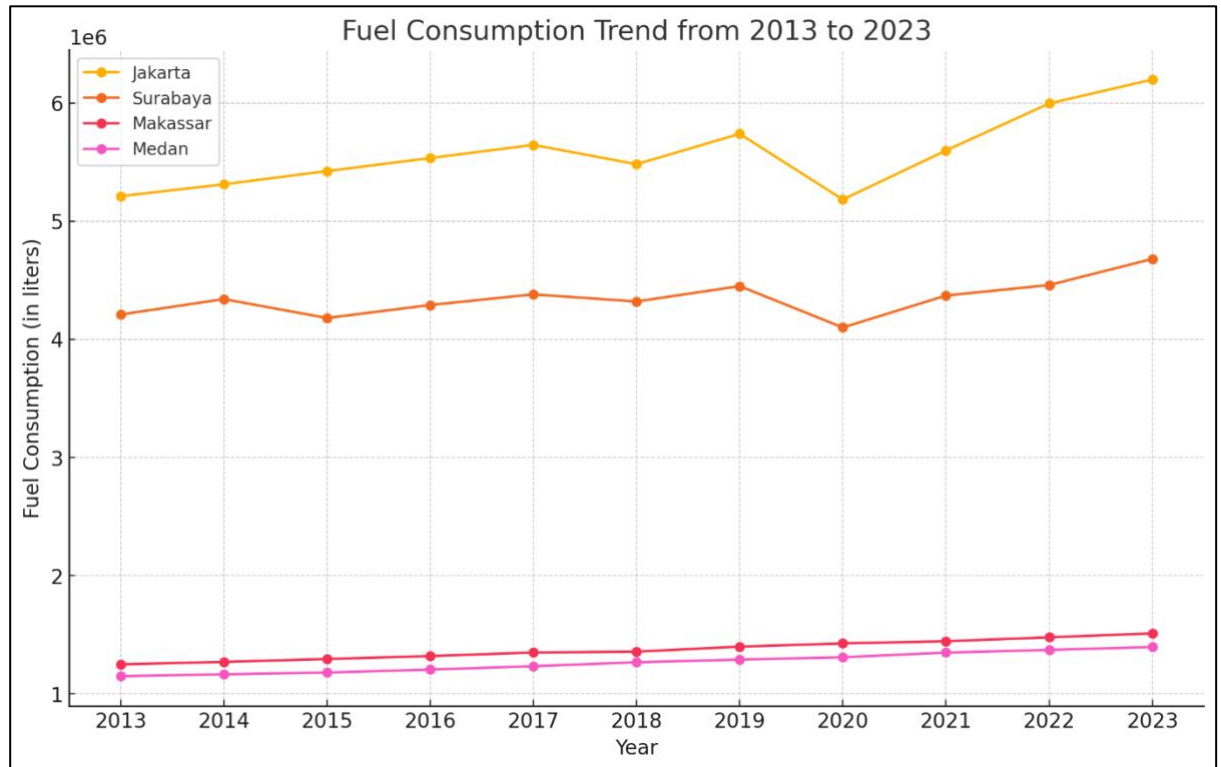
proves that manufacturing is still a significant part of Jakarta's economy despite the city's reputation as a nucleus for services and trade. Furthermore, there is no doubt that Surabaya has shown a notable upward trend, with the proportion of labour in the manufacturing sector increasing from 20.53% in 2013 to 26.12% in 2023. Surabaya is a major industrial city with a robust manufacturing sector driven by investments in new production facilities and technological innovation. The proportion of labour in Makassar's manufacturing sector shows a moderate increase, rising from 15.34% in 2013 to 16.03% in 2023. Medan demonstrates stability with an increase from 13.47% in 2013 to 14.09% in 2023.

In addition, the rapid economic growth in metropolitan cities has led to a rise in energy consumption, including the utilization of fossil fuels. In other words, accumulated emissions from transportation and industrial sectors are one of the main contributors to the presence of harmful substances in the air. Therefore, it is crucial to understand the impact of this air pollution on critical aspects of Jakarta's economy. The industrial sector, for instance, which is the backbone of economic development in Jakarta, Surabaya, and Medan, can be significantly affected. Air pollution possesses the potential to inflict damage on industrial equipment, leading to a decline in production efficiency and an increase in care and maintenance costs.

Additionally, strict emissions and environmental preservation rules may raise business compliance costs, negatively affecting competitiveness. Understanding these dynamics in a global context is crucial, as environmental regulations are becoming more stringent. Moreover, the transportation sector, including cars and motor vehicles, both private and public, produces significant emissions that contaminate the air.

Fuel consumption is a crucial aspect of economic activities, particularly in the transportation and manufacturing industries. The manufacturing and distribution processes rely on fuel as their primary energy source. However, increased air pollution and greenhouse gas emissions are two of the adverse environmental effects caused by excessive fuel usage. The high gasoline usage in major cities like Jakarta, Surabaya, Makassar, and Medan makes sustainable growth a challenging issue that needs more government attention.

Figure 1. 3 Trend of Fuel Consumption



Data source: *Ministry of Eneergy and Mineral Resource*

Fuel consumption has increased due to the growing population in the capital city, Jakarta, and the rising number of road vehicles. Likewise, fuel consumption in Makassar increased from 1,250,450 litres to 1,512,230 litres and in Medan from 1,150,450 litres to 1,396,734 litres over the same time, indicating that the two cities are growing similarly. Consequently, rapid economic development, increased urbanization, and improved community mobility contribute to the four cities' elevated gasoline consumption rates. Eventually, among four metropolitan cities, Jakarta experienced the largest increase, rising from 5,211,987 litres in 2013 to 6,198,732 litres in 2023 (Ministry of Eneergy and Mineral Resource).

In essence, this study aims to elucidate the correlation between economic growth and air pollution levels in four major cities in Indonesia: Jakarta, Surabaya, Makassar, and Medan. This paper defines Indonesia's economic growth based on Gross Domestic Regional Product (GRDP) data from these four cities to ensure a focused analysis. Additionally, to quantify environmental degradation, the researcher limits the analysis to air pollution, represented by Particulate Matter 2.5 (PM2.5) data.

1.2 Problem Formulation

1. Does Gross Regional Domestic Product influence Air Pollution in Jakarta, Surabaya, Makassar, and Medan?
2. Does the Proportion of Workers in the Manufacturing Industry influence Air Pollution in Jakarta, Surabaya, Makassar, and Medan?
3. Does Fuel Consumption influence Air Pollution in Jakarta, Surabaya, Makassar, and Medan?

1.3 Research Objectives

The research paper aims to achieve the following objectives:

- a. To analyze the effect of Gross Regional Domestic Product to the Air Pollution in Jakarta, Surabaya, Makassar, and Medan.
- b. To analyze the effect of the Proportion of Workers in the Manufacturing Industry to the Air Pollution in Jakarta, Surabaya, Makassar, and Medan.

- c. To analyze the effect of the Fuel Consumption to the Air Pollution in Jakarta, Surabaya, Makassar, and Medan.

1.4 Research Contributions

a. Academic Benefits

1. The result of this study is intended to provide an academic discourse and knowledge enhancement for educational purposes and a reference for relevant studies.
2. The result of this study provides insight into air pollution associated with the economy, the proportion of workers in the manufacturing industry, and fuel consumption. Further, it can serve as a foundation for future relevant investigations.
3. It is designed to provide a scientific contribution to the Department of Business and Economics on the relationship between air pollution and the economy, the proportion of workers in the manufacturing industry, and fuel consumption in metropolitan cities such as Jakarta, Surabaya, Makassar, and Medan.

b. Practical Benefits

1. The findings of this study help the government to integrate environmental aspects into economic planning, thereby enabling economic growth to be achieved without adversely affecting the air quality.

2. The research findings may provide a basis for formulating more effective policies in reducing air pollution.
3. The research findings may provide a comprehensive insight into the urgency associated with addressing air pollution.

1.5 Writing Systematics

The writing process of this research is broken down into five chapters;

Chapter I: INTRODUCTION

This chapter serves as the preliminary section of this thesis, comprising the background of the study, problem identification, problem formulation, research objectives, research contribution, and the writing systematics.

Chapter II: LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This section reviews prior studies on this topic and explains the theories and concepts that form the basis of this research. It helps to show what has already been discovered and sets the stage for how this study will build on that knowledge.

Chapter III: RESEARCH METHOD

This chapter provides a complete description of the various forms and sources of data used in this research, as well as the data collection methods. Furthermore, it describes the operational definitions of variables, data-collecting techniques, and analytic

methodologies used to answer the research questions presented in the problem formulation.

Chapter IV: RESEARCH FINDING, DISCUSSION AND IMPLICATIONS

This chapter aims to clarify the process of presenting data and research findings, as well as the results of problem analysis, to achieve the most favourable analytical outcomes.

Chapter V: CONCLUSION AND RECOMMENDATIONS

This chapter presents a comprehensive description of the conclusions and suggestions derived from the analysis carried out.

REFERENCES

The reference or bibliography section comprises the sources used in this research, including journal articles, books, and other relevant sources.

CHAPTER II

LITERATURE REVIEW

2.1 Theoretical Review

This section presents prior studies and literature relevant to the topic being investigated. A few previous studies examining similar topic have been found and described here.

Jiang et al. (2000) examined the interaction between economic growth and air pollution over the 11 years from 2006 to 2016. The research analyzed data from 286 Chinese and 228 South Korean cities. The findings of this research reveal regional disparities in the relationship between air pollution and economic growth in the two countries. In both nations, metropolitan areas had an inverted U-shaped pattern, while non-metropolitan areas exhibited a U-shape. Although pollutant emissions in both nations' urban regions have declined in recent years, a substantial gap exists between China's and South Korea's total emission levels. Furthermore, pollutant emissions in China's urban regions were much greater than in non-metropolitan areas, but the opposite happened in Korea. The eastern and northwest areas in China had an inverted U-shaped connection, while U-shaped interactions prevailed in the southwest, central, and northeast.

The second research by Lee Hsiang-He, Iraqui Oussama, and Wang Chien (2019) investigating the potential effects that various future fuel

consumption patterns may have on the air quality in Southeast Asian regions. This study carefully investigated the impacts on essential air pollutants, including particulate matter (PM_{2.5}), sulphur oxides (SO_x), nitrogen oxides (NO_x), and black carbon. In addition, Jakarta, Bangkok, Hanoi, Singapore, and Kuala Lumpur are the five main cities that are the focus of this study. Indeed, five different fuel consumption scenarios were set in this research.

The findings of this research reveal the results of five different fuel consumption hypothesis scenarios. According to the Coal Scenario, the air quality in the area would worsen due to a dramatic rise in petrol and aerosol emissions. Two other things to consider: Under the gas scenario, switching from coal to natural gas in power generation and industrial sectors might reduce sulfate aerosols by twenty-five percent and result in a considerable reduction in total air pollutants. According to the hypothesis presented in the Modern Scenario, the substitution of natural gas for conventional biofuels in the residential sector might result in a 42 percent reduction in the concentration of black carbon. Last but not least, according to the Shipping Scenario, removing emissions from shipping might significantly reduce fine particulate matter (PM_{2.5}) in Singapore by 69 percent.

The researcher has also analyzed further studies, as shown in Table 2.1 below.

Table 2. 1 Research Review

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
1.	Bo Pieter Johannes Andree, Andres Chamorro, Phoebe Spencer, Eric Koomen, dan Harun Dogo (2019).	<i>Revisting the relation between economic growth and the environment; a global assessment of deforestation, pollution, and carbon emission.</i>	Panel Data Analysis, <i>fixed effect model</i>	Gross Domestic Product, Area of Tree Cover and Tree Cover Loss, Population Density, and Air Pollution Concentration and Carbon Emissions	There is a positive and statistically significant correlation between economic growth and air pollution. This indicates that an increase in economic growth is accompanied by an increase in air pollution. There is a positive and significant correlation between population density and air pollution. Thus, as population density increases, so too does air pollution. Deforestation is positively and significantly correlated with air pollution. Thus, an increase in deforestation is associated with an increase in air pollution.
2.	Sri Indah Nikensari, Sekar Destilawati,	<i>Environmenta l Kuznets Curve Di Asia: Sebelum dan Setelah Millenium</i>	Panel Data Analysis, <i>fixed effect model</i>	Economic Growth, Population, Energy	There is a positive and significant correlation between economic growth and CO ₂ emissions in developing countries. Thus, it can

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
	dan Siti Nurjanah (2019).	<i>Development Goals.</i>		Consumption, And CO2 Emissions.	be concluded that an increase in economic growth is accompanied by an increase in CO ₂ emissions. Conversely, in developed countries, economic growth has a negative and significant effect on CO ₂ emissions. Thus, an increase in economic growth is accompanied by a reduction in CO ₂ emissions. Moreover, population growth has a positive and significant impact on CO ₂ emissions. Thus, an increase in population is associated with an increase in CO ₂ emissions.
3.	Stephen D. Superczynski, dan Sundar A. Christopher (2011)	<i>Exploring land use and land cover effects on air quality in central alabama using gis</i>	Panel Data Analysis, <i>Panel Least Squares</i>	Land Cover, Urbanisation, Industrial Density and Air Pollution.	There is a positive and statistically significant correlation between industrial density and air pollution. Therefore, an increase in industrial density leads to an increase in air pollution.

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
		<i>and remote sensing.</i>			
4.	Katrin Retno Gupito, dan Johanna M. Kodoatie (2013).	<i>Keterkaitan PDRB Perkapita Dari Sektor Industri, Transportasi, Pertanian dan Kehutanan Terhadap Kualitas Lingkungan Diukur Dari Emisi CO2 Di Jawa Tengah.</i>	Panel Data Analysis, <i>Panel Least Squares</i>	The GRDP Of Agricultural, Industrial, Transport, And Forestry Sectors, and CO2 Emissions.	This study examines the relationship between GDP per capita and environmental quality, specifically CO ₂ emissions, in Central Java. It considers the impact of industry, transport, agriculture and forestry sectors on GDP per capita and, in turn, on environmental quality. A positive and statistically significant correlation exists between GRDP in the transport sector and CO ₂ emissions. Thus, an increase in the GRDP of the transportation sector is accompanied by an increase in CO ₂ emissions. Moreover, the GRDP in the forestry sector has a positive and significant effect on CO ₂ emissions. Thus, an increase

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
					in the GRDP of the forestry sector is accompanied by an increase in CO ₂ emissions.
5.	Xiaoju Li, Siti Aslina Hussain, Shafreeza Sobri, dan Mohamad Syazarudin Md Said (2021)	<i>Overviewing the air quality models on air pollution in Sichuan Basin, China</i>	Literature Study	Urbanisation, Motor Vehicles, Industry, and Emissions of SO ₂ , NO ₂ , O ₃ , PM _{2.5} , and PM ₁₀ .	Industry has a positive and significant effect on air pollution. This indicates that the degree of air pollution increases as the quantity of industry increases.
6.	Mehrdad Zarenejad (2012)	<i>Survey relationship between economic growth and environmental effects of energy consumption (case study in Iran with a non-linear approach)</i>	Time Series data, Non-linear Analysis, STAR (Simplify, Transform, Analyze, Refine) method	Economic Growth, Energy Use Intensity, Urban Population, Population Growth Rate, and Carbon	There is a positive and significant correlation between economic growth and carbon dioxide levels and other forms of environmental pollution. Thus, an increase in economic growth leads to a rise in carbon dioxide and other forms of environmental pollution. The urbanization process has a positive

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
				Dioxide Emission	and significant effect on carbon dioxide levels and other forms of environmental pollution. Therefore, the concentration of carbon dioxide and other forms of environmental pollution also increases as urbanization increases. Furthermore, the global population's growth rate positively and significantly impacts carbon dioxide and environmental pollution. This findings indicates an increase in the population growth rate.
7.	Andrew Adewale Alola, Festus Victor Bekun, dan Samuel Asumadu	<i>Dynamic impact of trade policy, economic growth, fertility rate, renewable and non- renewable energy</i>	Panel Data Analysis, <i>Panel Pool Mean Group Autoregressive Distributive</i>	Gross Domestic Product, Non- renewable Energy Consumption, Renewable Energy	Economic growth has a positive and significant effect on environmental degradation. This result indicates that as economic growth increases, so does environmental degradation. Similarly, non-renewable energy

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
	Sarkodie (2019)	<i>consumption on ecological footprint in europe.</i>	<i>Lag (PMG- ARDL)</i>	Consumption, Trade Openess, Fertility Rate and Ecological Footprint.	consumption positively and significantly affects environmental degradation. Consequently, as non- renewable energy consumption rises, so does environmental degradation.
8.	Prima Agung P .S., Djoni Hartono, dan Agni Alam Awirya (2017).	<i>Pengaruh Urbanisasi Terhadap Konsumsi Energi dan Emisi CO2: Analisis Propinsi Di Indonesia.</i>	Panel Data Analysis, <i>Fixed Effect Model</i>	Population, urban population, GRDP, GRDP without oil and gas of manufacturing sector, GRDP without oil and gas of the services sector, energy consumption and energy intensity and	<i>First</i> , urbanization is positively related to energy consumption. A higher level of urbanization will lead to an increase in energy consumption. <i>Second</i> , a positive relationship exists between population growth, energy consumption (fuel, electricity, and total energy), and CO ₂ emissions. Economic growth has a positive and significant relationship with energy (fuel and electricity) and CO ₂ emissions. <i>Third</i> , urbanization does not directly affect the increase

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
				carbon emissions of motor vehicles.	in CO_2 emissions. It is assumed that when per capita income reaches a higher level, consumption behavior reduces CO_2 emissions.
9.	Tri Astuti (2010)	<i>The Role of Manufacturing Industrial Activity in the Environmental Pollution in South Sulawesi</i>	Quantitative approach, Regression Analysis, Input-Output (I-O) tools	Level of Air Pollution: Particulate matter, NOx, Sox, Manufacturing Industry, Production Volume, GDP	The study reveals that the wood processing industry, non-metallic mineral processing, and transport and communication sectors strongly link with upstream and downstream sectors, affecting economic output in South Sulawesi. However, chemical processing, rubber, plastics, primary metals, and metal goods processing were the heaviest polluters in the region.
10.	Hao, Y., Wu, H., Wang, L., & Huang, Z. (2020).	<i>Re-examine environmental Kuznets curve in China: spatial</i>	Panel Data Analysis	Environmental Quality Index, Gross Domestic Product,	Economic growth has Positive and significant relationship to environmental quality. However, after reach turning point, the

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
		<i>estimations using environmental quality index</i>		Urbanization, Population Density, Energi Consumption, Proportion of Industry	environmental quality will gradually improves as the economy grow.
11.	Budy P. Resosudarmo, B. Raksaka Mahi, Ari Kuncoro, and Santi Budi Handayani (2000)	<i>Emisi Polusi Udara dan Air Sungai dalam Struktur Industri Indonesia</i>	Input-Output (I-O) tools	Air Pollution, Pollution of River Water, So ₂ , NO ₂ , Emission Intensity, Processing Industry, Total Suspended Particulates (TSP), Biological Oxygen Demand (BOD) And Total	Industrial activities contribute significantly to air pollution in Indonesia, especially in metropolitan areas such as Jakarta. Industrial discharges also contribute to river pollution, which affects water quality in multiple regions of Indonesia. The analysis highlights the interconnectedness of air and water pollution, arguing that industrial activities contaminate both environmental components.

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
				Suspended Solids (TSS).	
12.	Birdsall, N. & Wheeler, D. (1993).	<i>Trade Policy and Industrial Pollution in Latin America: Where is The Pollution Haven?</i>	Panel Data, Pooled Regression Analysis	Gross Domestic Product, Industrial Output, Tariffs Level, Foreign Direct Investment, Trade	Gross domestic product growth has a significant relationship with air pollution in Latin America, resulting in greater industrial activity that may contribute to higher pollution levels. The research also revealed a link between higher pollution emissions and economic growth, particularly in the secondary sector of manufacturing. FDI increases industrial environmental emissions.
13.	Lou, Y. (2014)	<i>Relationship between Air Pollutants and Economic Development of the Provincial Capital</i>	Panel Data Analysis, Fixed Effect Model	Air Pollutant: PM2.5, SO ₂ , NO ₂ - Gross Domestic Product, Industrial	Economic Development has a positive and significant effect with the higher level of air pollution. The increase in urbanization rates as well as industrial output lead to

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
		<i>Cities in China during the Past Decade.</i>		Output, Urbanization Rate	a higher level of PM2.5, SO ₂ , and NO ₂ .
14.	Lise, W., & Van Montfort, K. (2007)	<i>Energy Consumption and GDP in Turkey: Is There A Co-Integration Relationship?</i>	Time series analysis, <i>Unit Root Test, Error Correction Model</i>	Gross Domestic Product, Energy Consumption,	The findings indicate a significant co-integration relationship of energi consumption to economy.
15.	Jo-Hee Hwang and Seung-Hoon Yoo (2012)	<i>Energy Consumption, CO2 emissions, and economic growth: evidence from Indonesia</i>	Time Series data; <i>Unit Root, Co-integration, and Granger-causality</i> based on an Error-correction Model	Energy Consumption, CO ₂ Emission, and Real Gross Domestic Product	The findings indicate a bidirectional causality between energy consumption and CO ₂ emissions. This finding indicates that increased energy usage directly impacts CO ₂ emissions and that CO ₂ emissions promote even more energy consumption. Furthermore, the results demonstrate the existence of

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
					undirectional causality between economic development, energy consumption, and CO ₂ emissions, with no feedback effects.
16.	Muawya Ahmed Hussein (2007)	<i>Costs of Environmental Degradation, An Analysis in The Middle East and North Africa Region. Emerald, Management of Environmental Quality: An International Journal</i>	Panel Data Analysis, <i>Multiple Regression Amalysis</i>	GDP, Industrial Output, Levels of Pollution, Deforestation Rates, Biodiversity Loss, Population Density, Cost of Environmental Degradation, Urbanization Rates and Education Levels	Environmental degradation caused by pollution (air, water, soil) have a complex and substantial economic cost on the Middle East and North Africa (MENA) region, which lead to a rise in healthcare expenditure and reduce productivity.
17.	I.V . Filimonova,	<i>Influence of economic factors</i>	Panel Data Analysis	Economic Growth, Total	Economic growth has a positive and significant effect on total

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
	I.V . Provornaya, A.V . Komarova, E.A. Zemnukhova, dan M.V . Mishenin (2019)	<i>on the environment in countries with different levels of development.</i>		Population, Energy Intensity, Total of Carbon Dioxide Emission.	carbon dioxide emissions and has an inverted U-shape relationship. In other words, an increase in economic growth leads to an increase in total carbon dioxide emissions, but beyond a certain threshold, an increase in economic growth leads to a decrease in total carbon dioxide emissions. The total population has a positive and significant impact on total carbon dioxide emissions. This finding means that as the population grows, total carbon dioxide emissions also increase. Energy intensity has a positive and significant effect on total carbon dioxide emissions. This finding means that the total carbon dioxide emissions also increase as energy intensity increases.

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
18.	Cropper, M., dan Griff X. C. (1994)	<i>The Interaction of Population Growth and Environmental Quality.</i>	Panel Data Analysis, <i>Fixed Effect Model</i>	Gross Regional Domestic Product, Population Density, Number of Vehicles, CO ₂ Emissions, Environmental Quality Index (EQI), Deforestation rate	Economic growth significantly degrades environmental quality. Economic growth and population density also positively affect CO ₂ emission in Western Europe
19.	Grossman, G. M. & Krueger, A. B. (1991)	<i>Environmental Impact of a North American Free Trade Agreement</i>	Ordinary Least Squares (OLS), Computable General Equilibrium (CGE) Model	Air Pollutant, Gross Domestic Product percapita, Trade Liberalization,	The analysis demonstrates an inverted U-shaped association between economic development and pollution levels. At lower income levels, SO ₂ and smoke concentrations increase with GDP, but fall once GDP exceeds a particular threshold.

No	Researcher (Year)	Title	Research Method	Research Variable	Result and Conclusion
20.	Halkos, George E. and Nickolaos, G. (2011)	<i>Growth and Environmental Pollution: Evidence from China</i>	Panel Data Analysis	Environmental Pollution, Economic Growth, GDP	Economic growth has an adverse impact on environmental quality. This finding demonstrate a strong and positive relationship between economic growth and pollution.
21.	A. Patrick Behrer, Rishabh Choudhary, Dhruv Sharma (2023)	<i>Air Pollution Reduces Economic Activity: Evidence from India</i>	Panel Data Analysis	Gross Domestic Product, Air Pollution: PM 2.5, Inversion: MERRA	The results indicate that higher levels of pollution negatively impact economic activity. This implies that higher levels of pollution result in smaller year-to- year changes in GDP.

The table above compiles several published studies examining the relationship between air pollution and economic growth. One of the most relevant studies to this present research is the research by Santoso, B. K. et al. from Gadjah Mada University, titled ‘Temporal Study of Economic Growth and Air Pollution: Case Study of DKI Jakarta, Semarang, and Surabaya in 2005-2015.’

The main similarity between the two studies lies in the focus of analysis, which includes economic growth and air pollution in three metropolitan

cities, namely DKI Jakarta, Surabaya, and Semarang. However, this present study seeks to expand the scope by examining four metropolitan cities: DKI Jakarta, Surabaya, Makassar, and Medan. The research duration in both studies is ten years; this study covers the period from 2013 to 2023, while the previous study spans 2005 to 2015. Despite some similarities, there are significant differences in the variables used. This study analyses four variables: Gross Regional Domestic Product (GRDP), manufacturing industry, fuel consumption, and air pollution measured using Particulate Matter (PM_{2.5}). In contrast, the study by Santoso et al (2018). only used two variables, GRDP and Aerosol Optical Thickness (AOT). In terms of methodology, this study applies regression analysis using the panel data method, which is also the approach used in the previous study. While there are similarities in some aspects, it is important to note that the differences in variables and scope of analysis provide unique contributions to this study and add to a more comprehensive understanding of the interaction between economic growth and air pollution.

2.2 Theoretical Framework

2.2.1 Air Pollution

1. Definition of Air Pollution

Pollution can be defined as the introduction of harmful materials into the environment. These materials are harmful to the environment and are known as pollutants. Natural processes, such as the emission of volcanic ash

or human activities, including waste disposal and the runoff of industrial and transportation-related substances, can cause pollution. The contamination of air, water, and land is a consequence of such pollution (National Geographic, n.d.).

Another definition of air pollution is the release of pollutants into the air that are detrimental to human health and the planet as a whole. According to Government Regulation No. 41 year 1999 concerning Air Pollution Control in Article 1 Paragraph 1, air pollution refers to the inhalation of chemicals, energy, and other components into the surrounding air by human activities, resulting in a decrease in the quality of the air to the level where can no longer fulfill its intended purpose. Canter (1996) describes air pollution as introducing one or more harmful substances into the atmosphere. The presence of these contaminants in significant quantities over a prolonged period will cause detrimental effects on individuals, wildlife, plants, and materials.

According to the World Health Organization (2017), air pollution is often caused by household combustion devices, motor vehicles, industrial operations, and forest fires. The pollutants that pose significant risks to human health include particulate matter, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide. Both outdoor and indoor air pollution contribute to respiratory and other illnesses and are significant factors in causing sickness and death.

2. Sources of Air Pollution

The air pollutant sources can be classified based on the type of source, frequency of occurrence, spatial distribution and type of emissions. In general, there are two distinct categories of factors that contribute to air pollution:

a) By Nature

- a. The release of methane gas (CH_4) into the atmosphere as a result of the decomposition of organic waste
- b. Wind-driven dust
- c. Ash or gases generated by volcanic eruptions along with volcanic gases

b) Anthropogenic

- a. Fossil-fuels combustion
- b. Dust as a result of industrial activities
- c. Illegal forest-fires
- d. Chemical release to the atmosphere

3. Types of Air Pollution

Farida (2004) classified air pollution into two categories based on its movement.

a. Stationary Sources

The Government Regulation number 41 Article 1, Paragraphs 14 and 15 of 1999 define stationary sources and specific stationary sources. By

definition, stationary sources are emission sources that do not move from their location, while specific stationary sources are fixed emission sources from forest fires and rubbish burning. Stationary sources include industries, settlements, and power plants, contributing to the emission of various pollutants into the atmosphere, including but not limited to nitrogen oxides, methyl mercaptan (CH_3SH), NH_3 , hydrogen sulfide, flour, lead, acid gases, zinc, mercury, cadmium, arsenic, antimony, radionuclides, and smoke.

b. Mobile Sources

Mobile sources are emissions from trains, aircraft, ships, and other big vehicles. To put it another way, mobile sources refer to emission sources that are in motion or not static and are also known as emission sources that originate from motorized vehicles. The Government Regulation number 41 Article 1, Paragraphs 12 and 13 of 1999, define two similar types of mobile sources which are mobile and specific mobile sources. Mobile sources, such as motor vehicles, are emission sources that are not static and may move. Furthermore, specific mobile sources are emission sources that are not static and may move from trains, aircraft, and other huge vehicles.

On the other hand, according to Sunu (2001), the types of pollution can be identified based on shape, geography, chemical composition, effects on health, and origin.

4. The measurement of Air Quality

The Air Quality Index (AQI) is an indicator developed by government agencies to inform the public about how polluted the air is at the moment or how polluted it is expected to be in the future.

Table 2. 2 Air Quality Standard based on *EU Directives*

Air Quality	(I_{EU})
EU Standards are exceeded by one pollutant or more	>1
EU Standards are fulfilled on average	1
The situation is better than the norms requirements on average	<1

Sources: Ministry of Environment and Forestry (2019)

The methodology for calculating the air quality index is based on the standards set by the European Union Directives program, which the European Regional Development Fund funds under the auspices of the Regional Initiative Project, specifically the Common Information to European Ai (CiteairII) initiative. The index is calculated by comparing the annual average value with the standard of the European Union (EU) Directives. A value of >1 indicates that the air quality exceeds the EU standard, whereas a value of ≤ 1 signifies that the air quality meets the EU standard. Currently, the EU Directives on air quality standards continue to serve as the foundation for quality standards established by the World Health Organization (WHO). The index is calculated for hourly, daily, and annual average data (Ministry of Environment and Forestry, 2019).

2.2.2 Gross Regional Domestic Product

1. Definition of gross regional domestic product

GRDP is the final value of goods and services produced by a region over a certain period. The calculation of GRDP can be classified into two approaches applied in Indonesia: the expenditure approach and the value-added production approach. The function of GRDP is to represent how a region produces goods and services in a certain period by looking at various sectors of the GRDP itself, such as the agricultural sector, manufacturing sector, service sector, and others. Regarding expenditure, the components of GRDP include Household Consumption, Corporate Investment, Government Expenditure, and Net Exports. Thus,

The concept of GRDP is the same as GDP. According to Mankiw (2018), Gross Domestic Product is the total final output of a country's goods and services in a certain period. Sidik (2017) provides another definition of GRDP. GRDP is the net value of final goods and services produced by various regional economic activities over a certain period. GRDP's value illustrates a region's ability to manage its natural resources. Therefore, the natural resources or factors of production available in a region determine the magnitude of the GRDP generated. Thus, the limitations of natural resources in a region lead to differences in GRDP values between regions. Each factor of production in a country's economy will depend on another

factor of production. Both raw materials and the final product require the cooperation of production factors.

Gross Regional Domestic Product (GRDP), according to the definition of the Central Statistics Agency quoted from Sukirno (2011), is the added value generated by a business unit or the sum of the total value of final goods and services produced by all economic activities in a region. GRDP is one of the essential indicators of economic growth in a region and within a certain period (one year) generated by all economic activities in a country or region.

2. Methods of Presenting GRDP

a. GRDP at constant prices

Using the prices of goods in a specific year as the base year, GRDP at constant prices calculates the added value of goods and services to determine real economic growth from year to year.

b. GRDP at current prices

At current prices, the Gross Regional Domestic Product (GRDP) calculates the value added of goods and services based on the current market price, and it serves as a tool to assess the capacity of economic resources and the composition of a region's economy.

In addition, the Central Bureau of Statistics has revised the base year for the Gross Regional Domestic Product calculation, moving from

2000 to 2010. This alteration was implemented in response to significant global and local developments over the past decade, which have subsequently influenced the national economy.

3. Calculation of Gross Regional Domestic Product

The gross regional domestic product calculation can be performed in two different ways: the direct and indirect methods.

a. Direct Method

I. Production Approach

GRDP is the sum of the added value of final goods and services minus the intermediate costs of each total gross production of each sub-sector or sector activity within a certain period (one year). The units of production are grouped into nine sectors or business fields, namely:

- 1) Processing Industry
- 2) Quarrying and Mining
- 3) Agriculture
- 4) Trade, Hotels and Restaurants
- 5) Electricity, Gas, and Water
- 6) Construction
- 7) Transportation and Communication
- 8) Finance, Rental, and Corporate services
- 9) Services

II. Income Approach

The Gross Regional Domestic Product refers to the total income received by the factors of production for their services in the production process within a region over one year. These services receive compensation through wages, salaries, profits, and rental fees. All calculations are made before deductions for income taxes and other taxes.

III. Expenditure Approach

GRDP is the number of services received by production factors that participate in a region's production process within a certain period (one year). According to the Central Statistics Agency (Syahrullah, 2014), Gross Regional Domestic Product is the sum of the added value of final goods and services produced by various regional production units.

b. Indirect Approach

The indirect method involves allocating district GRDP to provincial GRDP or vice versa. It is achieved by utilizing a range of production indicators and other appropriate indicators as allocators, with the process beginning at the district or city GRDP level and proceeding to the provincial level.

2.2.3 The Proportion of Labour in Manufacturing Industry

1. Definition Labour

The term "labour" describes a group of working-age individuals who possess the capacity to engage in productive activities, whether in the production of goods or the provision of services, to fulfill their own needs and the needs of broader society. By the provisions outlined in Law No. 13 of 2003, Article 1 Paragraph 2, concerning Manpower, the term labour encompasses all individuals capable of engaging in productive work, whether for personal or community-oriented purposes and in pursuit of producing goods and services. The significance of labour in the production process is contingent upon its capacity to serve as a propelling force for the factors of production, employing distinctive competencies to generate the final goods and services.

Following the Central Statistics Agency (BPS), the labour population can be classified into two distinct categories: the labour force and the non-labour force. The term 'labour force' describes the population aged 15 years and above who are currently engaged in employment or have a job but may be in a period of unemployment or underemployment. The non-labour force population comprises individuals aged 15 and above who are engaged in activities other than working, including those pursuing education, managing households, or not actively seeking employment.

2. Definition of Manufacturing Industry

Manufacturing is a substantial economic sector transforming raw materials into finished products. A variety of procedures, equipment, and workforce enable this transformation. The sector involves several operations, including assembling, processing, and refining raw materials to create final goods for distribution.

3. Definition of Proportion of Labour in Manufacturing Industry

The proportion of labour in the manufacturing industry is an important indicator that demonstrates the percentage of workers employed in the manufacturing sector compared to the total labour force in a region or country. From an economic standpoint, it offers a transparent representation of the distribution of labour across diverse industrial sectors and the extent to which the manufacturing sector plays a pivotal role in absorbing labour. Understanding these proportions allows for better analysis of a region's economic structure and the identification of sectors that contribute significantly to employment.

2.2.4 Fuel Consumption

Petroleum or crude oil is a natural resource extracted from the earth in liquid form, that can be used as a raw material for industry or as fuel (Department of Energy and Mineral Resources, 2009). Petroleum is a complex chemical compound comprising primarily hydrogen (H) and carbon (C) atoms. Thus, it is also known as a hydrocarbon compound, labeled

explicitly as C_xH_y . The specific gravity of oil is measured in degrees API. A higher °API value indicates a less dense oil. The °API value is used to classify oil based on its density, allowing for the distinction between light oil, heavy oil, and condensate (gas).

In the meantime, fuel consumption can be defined as the total amount of fuel used by various sectors, including transportation, industry, and households, within a specific region or country. Factors that influence fuel consumption include economic growth, which usually leads to higher fuel usage due to increased economic activity; population growth, which generates greater demand for fuel for transportation and household needs; and infrastructure, such as the construction of roads, ports, and airports, which facilitates and accelerates the movement of goods and people, thereby increasing fuel consumption.

2.3 Relationship between Dependent Variable and Independent Variable

2.3.1 Relationship between Regional Gross Domestic Product and Air Quality Index

The gross regional domestic product (GRDP) represents a significant indicator of regional economic activity. The relationship between gross regional domestic product (GRDP) and air pollution is a complex phenomenon, and a deeper investigation is required to fully understand it. The gross regional domestic product (GRDP) measures the total value of goods and services produced within a region. It is commonly

used as an indicator to evaluate a region's economic activity and prosperity. An increase in a region's GRDP indicates a simultaneous rise in economic growth. Expansion or acceleration generally follows rapid economic growth in the industrial and transportation sectors. The rising number of motor vehicles clearly reflects growth in the transportation sector.

Moreover, in the industrial sector, increased demand for products will lead to the expansion of growth in production capacity by companies, which in turn, will result in higher emissions from factories that utilize fossil fuels and chemical processes, ultimately causing environmental pollution, including air pollution. Recognizing that the rising demand for energy and raw materials often coincides with GRDP growth, necessitating the burning of fossil fuels, is crucial. From an economic standpoint, this activity can result in increased production of goods and services. However, from an environmental perspective, it may lead to a deterioration of air quality, which in turn may cause the formation of pollutants such as fine particulate matter (PM_{2.5}), carbon monoxide (CO), and sulfur dioxide (SO₂). These pollutants have the potential to exert a deleterious effect on the quality of the air. Cole, Elliott, and Strobl (2008) identified a positive correlation between the gross domestic product (GDP) and levels of air pollution in a previous study. It can, therefore, be assumed that economic expansion has the potential to increase air pollution.

2.3.2 Relationship between Proportion of Workers in Manufacturing Industry and Air Quality Index

The proportion of labour in the manufacturing sector is inextricably linked to the contribution of this sector to a region's economy. This reflects the sector's significance to a region's economy. The manufacturing industry plays a pivotal role in the economy, particularly, industries that rely on raw materials and large-scale production, which are often primary sources of pollutant emissions. This is because the manufacturing industry can generate a significant number of employment opportunities, which contribute considerably to gross domestic product (GDP). The existence of this industry, however, can also impact the level of air quality and the surrounding environment. Moreover, the effects caused by the existence of these industries are quite significant, with demonstrably negative consequences.

The manufacturing industry, particularly on a large scale, typically implements highly intensive production processes. Moreover, industrial activities and production depend on various raw materials and energy sources. In this context, the manufacturing industry relies on energy derived from fossil fuels, including coal, oil, and natural gas, which are burned in industrial processes to boost production activities. The combustion of these fuels during industrial processes generates harmful gas emissions, including carbon dioxide (CO₂), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and particulate matter (PM 2.5), which can subsequently impact the surrounding environment.

In the meantime, the correlation between the proportion of workers in the manufacturing sector and air quality is that an increase in the number of individuals working in the manufacturing industry signifies a heightened level of production activities within the sector. In short, an increase in the proportion of labour in this sector indicates an intensification of manufacturing activities. This elevated production intensity will ultimately result in greater environmental degradation and adverse effects on human health. This relationship has been strengthened by Tian et al. (2015), which demonstrates that areas with a high concentration of manufacturing labour tend to have worse air quality indexes than regions that are more focused on agriculture or services.

2.3.3 Relationship between Fuel Consumption and Air Quality Index

Fuel consumption has a direct correlation with air quality. Fuel combustion, particularly in the transportation and industrial sectors, represents a significant source of pollutant emissions, including nitrogen dioxide (NO₂), carbon monoxide (CO), and fine particulate matter (PM_{2.5}). Fuel consumption for energy derived from fuels such as petrol, diesel, coal, and the like can cause adverse environmental impacts due to the release of pollutants into the surrounding environment. For example, nitrogen dioxide (NO₂) can cause acid rain that damages soil and water. It is harmful as it plays a role in forming ozone, which is a damaging atmospheric constituent. The second is carbon monoxide (CO), a direct consequence of fuel combustion.

In addition to polluting the air, it also harms the human respiratory system, reducing the body's capacity to transport oxygen in the blood.

In addition, fuel combustion also produces fine particulate matter (PM_{2.5}), which represents the primary focus of this paper. PM_{2.5} is a direct consequence of fuel combustion and is similarly detrimental to both the environment and human health. These small particles can penetrate deeply into the respiratory tract and even enter human skin. This indicates that the effects of PM_{2.5} are not limited to internal health issues, such as those affecting the respiratory tract, but also extend to external health concerns, such as skin conditions. Poor air quality is associated with increased disease cases, as previously discussed. Eventually, this will place a burden on the country in terms of healthcare costs.

Fuel consumption deals with vehicles and industrial activities. Therefore, an increase in fuel consumption, whether due to an increase in the number of vehicles or the intensity of industrial activities, significantly impacts the concentration of pollutants in the air. It can, therefore, be argued that the volume of fuel used affects both the quantity and the concentration of pollutants released into the atmosphere. Consequently, this dynamic affects not only the environment and human health but for the country's economic well-being. A direct association has been found between the amount of gasoline used and the level of air pollutants on air, as established by Schifter et al. (2005). This correlation suggests that air pollutants harm both public health and the environment.

2.4 Research Framework

The research hypotheses can be formulated as follows, based on the framework and the research objectives that have been described:

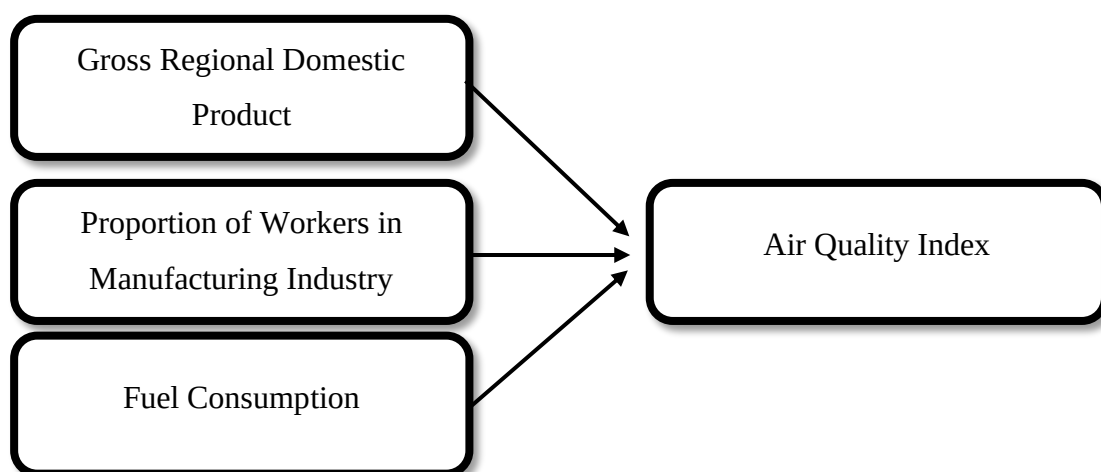


Figure 2. 1 Research Framework

This research employs a conceptual framework that explains the dependent variable (Air Quality Index) and the independent variables (Regional Gross Domestic Product, Proportion of Workers in the Manufacturing Industry, and Fuel Consumption). From Figure 2.1, this research aims to determine the extent to which the independent variables affect the dependent variable in four metropolitan areas.

2.5 Hypothesis Formulation

In research, hypotheses are speculative statements that elucidate the correlation between variables, which must be empirically tested through data

collection and analysis. The purpose of a hypothesis is to determine whether the evidence supports the suggested correlation. Within the context of this research entitled “Economic Dynamics under Polluted Skies: an Analytical Comparison of Jakarta, Surabaya, Makassar, and Medan”, a few hypotheses are proposed:

1. It is hypothesized that the variable Gross Regional Domestic Product has a positive and significant effect on the Air Quality Index in Jakarta, Surabaya, Makassar and Medan
2. It is hypothesized that the variable of the Proportion of Workers in the Manufacturing Industry has a positive and significant effect on the Air Quality Index in Jakarta, Surabaya, Makassar, and Medan
3. It is hypothesized that the variable of Fuel Consumption has a positive and significant effect on the Air Quality Index in Jakarta, Surabaya, Makassar, and Medan.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Method

This research employs a quantitative approach to examine the effect of the independent variables - the economy, the proportion of workers in the manufacturing industry, and fuel consumption in four metropolises: Jakarta, Surabaya, Makassar, and Medan on the dependent variable – air quality index. . Therefore, this research uses secondary data as its primary source of information.

According to Sugiyono (2015), secondary data consists of information collected indirectly by data collectors, including data from publications, websites, dams, or other instruments. In this research, the data were obtained from The Central Bureau of Statistics (*Badan Pusat Statistik*), Ministry of Environment and Forestry (*Kementerian Lingkungan Hidup dan Kehutanan*), Indonesian Agency for Meteorology, Climatology and Geophysics (*Badan Meteorologi, Klimatologi, dan Geofisika*), and Ministry of Energy and Mineral Resources (*Kementerian Energi dan Sumber Daya Mineral Republik Indonesia*). Books and internet media sources were also used as references to support this research.

The data employed in this study is Panel Data, a combination of Time Series and Cross-sectional data. The time series data in this study consist of

annual data collected over the observation period from 2013 to 2023, covering 11 years. The cross-section data is derived from four metropolitan cities in Indonesia: Jakarta, Surabaya, Makassar, and Medan.

In relation to research variables, this research study has one dependent and three independent variables. The Air Quality Index (AQI) is the dependent variable in this study and the independent variables are Gross Regional Domestic Product (GRDP), Proportion of Workers in the Manufacturing Industry, and Fuel Consumption.

3.2 Definition of Operational Variables

In a scientific study, operational variables are defined and quantified using specific, measurable terms. This process enables the transformation of abstract concepts into concrete measurements, thus ensuring clarity and consistency in data collection and analysis. In this study, the dependent variable is the Air Quality Index, while the independent variables include the Gross Regional Domestic Product (GRDP), Proportion of Workers in the Manufacturing Industry, and Fuel Consumption.

Table 3.1 presents the list of variables used in this research. The researcher classifies the variables into two categories: dependent and independent.

Table 3. 1 Data and Sources of Data

Variable Name	Variable Code	Unit Measurement	Data Sources
Air Quality Index (AQI)	Y	Percentage	Ministry of Environment and Forestry & Indonesian Agency for Meteorology, Climatology and Geophys
Gross Regional Domestic Product (GRDP)	X1	Billion IDR	The Central Bureau of Statistics
Proportion of Workers in the Manufacturing Industry	X2	Percentage	The Central Bureau of Statistics
Fuel Consumption	X3	Kiloliters	Ministry of Energy and Mineral Resources

3.2.1 Dependent Variable

The dependent variable is the variable that is influenced or assessed in the study to observe its impact on the independent variable. After implementing changes or modifying the independent variable, the researcher assesses the dependent variable (Bandura et al., 1961).

3.2.1.1 Air Quality Index (AQI)

The air quality index, also known as AQI, is a measure of air quality indicating the level of pollution. The calculation of the air

quality is done by comparing the yearly average value with the European Union (EU) standard directives. If the index value is more than 1, the air quality exceeds the European Union standard and cannot be used as a benchmark to see an air pollution level in an area or region. In contrast, if the index value is less than 1, the air quality meets the European Union (EU) standard and can be used as a benchmark to see the level of air pollution in that area. Moreover, the European Union Directives standard is still considered a benchmark or the basis for determining quality standards by the World Health Organization (WHO). The value of air quality is within the interval of 0-300+; a higher air quality represents a lower level of air pollution in the area. On the contrary, a higher air quality index represents a significant level of air pollution in that area (Ministry of Environment and Forestry, 2019). The data utilized in this research study is sourced from the Ministry of Environment and Forestry (KLHK): Laporan Akhir Kegiatan Pemantauan Kualitas Udara and Indonesian Agency for Meteorology, Climatology and Geophys from 2013 to 2023.

3.2.2 Independent Variable

The independent variable is the variable that researchers intentionally modify or alter in order to examine its impact on the dependent variable. This

variable is considered the causal or influential element that affects the dependent variable (Bandura et al., 1961).

3.2.2.1 Gross Regional Domestic Product (GRDP)

The term "Gross Regional Domestic Product" (GRDP) describes the aggregate value of all final goods and services generated by all economic units within a certain state or area of a country. It measures the total value contributed to the product by all manufacturing units in the region. Starting in 2013 and continuing through 2023, the data collection was provided by The Central Bureau of Statistics and is represented in billions of rupiah.

3.2.2.2 Proportion of Workers in the Manufacturing Industry

The term "Proportion of Workers in the Manufacturing Industry" can be defined as the percentage of labour working in the manufacturing industry sector compared to the total labour force in a region or country. The manufacturing sector includes various types of employment involved in producing goods, from raw materials to finished products. Starting in 2013 and continuing until 2023, the data collection was provided by The Central Bureau of Statistics and is represented in percentages.

3.2.2.3 Fuel Consumption

The term “Fuel Consumption” refers to the quantity of fuel oil used during a certain period by various sectors, including but not limited to transportation, industry, homes, and other sectors. Starting in 2013 and continuing until 2023, the data collection was provided by the Ministry of Energy and Mineral Resources (*Kementerian Energi dan Sumber Daya Mineral Republik Indonesia*). It is represented in Kiloliters (kL).

3.3 Data Analysis Methods

Data refers to information translated into an efficient form for movement or processing (Vaughan, 2019). Similarly, data analysis can be defined as the systematic application of statistical techniques to describe and illustrate data, condense and recapitulate data, as well as evaluate it. Furthermore, the researcher conducted descriptive statistical analysis to classify the data. The initial step in the data analysis is distinguishing between complete and usable data. Subsequently, the data was analyzed using the methods aligning with the desired outcomes to solve the research questions. This study employs a quantitative model based on Panel Data Analysis, with data processing conducted using the Eviews 13 program. The study utilizes time series data spanning from 2018 to 2023.

Panel data, also referred to as longitudinal data or cross-sectional time-series data, is a type of data that tracks and measures multiple units of observation, such as a city or firm, over time. This research implements multiple regression models as the statistical technique to determine the overall pattern of relationships between variables.

3.4 Regression Analysis Methods

Regression analysis measures the effects of the dependent variable - the air quality index, on the independent variables - gross regional domestic product, the proportion of workers in the manufacturing industry, and fuel consumption in four metropolitan cities from 2013 to 2023. The model of the panel data regression equation is as follows:

$$AQI_{it} = \beta_0 + \beta_1 \ln GRDP_{it} + \beta_2 \ln PWMI_{it} + \beta_3 \ln FC_{it} + \varepsilon_{it}$$

Where,

AQI_{it} = Air Quality Index ($\mu\text{g}/\text{m}^3$)

β_0 = Intercept

$\beta_0 \beta_1 \beta_2 \beta_3$ = Coefficient Regression

$GRDP_{it}$ = Gross Regional Domestic Product

$PWMI_{it}$ = Proportion of Workers in the Manufacturing Industry

FC_{it} = Fuel Consumption

i = Cross-section (City)

t = Time Series (2013 – 2023)

ε_{it} = error term or residual

Several methods are commonly employed in estimating regression models with panel data. These include the common effect model, the fixed effect model, and the random effect model. Panel data combines cross-sectional and time series data (Kuncoro, 2003).

3.4.1 Common Effect Model (CEM)

The Common Effect Model (CEM) is a regression method in panel data analysis that assumes a homogeneity of observation units and periods. In this model, all units and periods are considered to have the same intercept. Thus, only one regression line is employed for the entirety of the data set. The CEM is a relatively simple model that does not consider the specific effects of individual units or changes over time. Consequently, the model may need more accuracy regarding units' heterogeneity or significant temporal changes. This model is appropriate when the panel data set comprises homogeneous units, or the objective is to present a comprehensive overview without delving into individual or temporal variations (Wooldridge, 2010). This systematic model combines time series data and cross-section data into panel data. Due to the different units of variables utilized in this research, it is essential to use logarithmic transformations in order to standardize the units.

3.4.2 Fixed Effect Model (FEM)

The Fixed Effect Model (FEM) analyzes panel data by taking into account specific differences between units that stay constant throughout the analyzed period. In this model, each unit has its intercept that captures the unit's unique characteristics that remain constant across time. Researchers often use the Hausman test to choose between the Fixed Effects Model (FEM) and Random Effects Model (REM), and prefer the fixed effect model when a connection exists between the fixed effects and the independent variables.

3.4.3 Random Effect Model (REM)

The Random Effect Model (REM) is a regression method in panel data analysis that assumes that the differences between units are random and uncorrelated with the independent variables. This model incorporates the specific effect of each unit into the error term (Greene, 2012). Random effect models allow for more information from the data by assuming that the variation between units is part of a random distribution. This model excels in scenarios where the units of observation serve as samples from a larger population, and there is no correlation between the random effects and the independent variables.

3.5 Selection of Estimation Model

Three statistical tests - the Chow test, the Hausman test, and the Lagrange multiplier test, commonly called the LM test, must be conducted before determining the optimal model selection.

Testing	Result	Decision
Chow Test	Prob. > 0.05	CEM
	Prob. < 0.05	FEM
Hausman Test	Prob. > 0.05	REM
	Prob. < 0.05	FEM
Legrange Multiplier	Prob. > 0.05	CEM
	Prob. < 0.05	REM

3.5.1 Chow Test

The Chow test aims to determine which model to choose, between the common effect model and the fixed effect model. The hypothesis for selecting the panel data regression model states that the fixed effects will be used if the cross-section chi-square value is less than 0.1. However, if the cross-section chi-square value exceeds 0.1, the common effects will be used and the need for the Hausman test is eliminated (Rosinta, 2018).

H₀: The common effect model is superior to the fixed effect model.

H_a: The fixed effect model is superior to the common effect model.

3.5.2 Hausman Test

The Hausman test aims to determine which model to choose, between the random effect model and the fixed effect model. The hypothesis for selecting the panel data regression model states that the fixed effects will be used if the cross-section chi-square value is less than 0.1. However, if the cross-section chi-square value exceeds 0.1, the random effect will be used and the need for the Hausman test is eliminated (Rosinta, 2018).

H₀: The random effect model is superior to the fixed effect model.

H_a: The fixed effect model is superior to the random effect model.

3.5.3 Lagrange Multiplier (LM)

The Lagrange Multiplier aims to determine which model to choose, between the common effect model and the random effect model. The hypothesis for selecting the panel data regression model states that the random effects will be used if the cross-section chi-square value is less than 0.1. However, if the cross-section chi-square value exceeds 0.1, the common effect will be used and eliminate the need for the Hausman test is eliminated.

H₀: The common effect model is superior to the random effect model.

H_a: The random effect model is superior to the common effect model.

3.6 Classical Assumption Test

3.6.1 Multicollinearity Test

The purpose multicollinearity test is to ascertain the presence of a strong relationship between the independent variables in the regression model. This examination is conducted by assessing the tolerance value and VIF (Variance Inflating Factor) value. The criteria for determining the possibility of multicollinearity are as follows (Ghozali, 2016):

1. If the VIF value < 10 or the Tolerance value > 0.01 , indicating there is no multicollinearity.
2. If the VIF value > 10 or the Tolerance value < 0.01 , indicating that multicollinearity exists.

If the Correlation Coefficient of each Independent variable > 0.85 , it indicates that multicollinearity exists. However if the Correlation Coefficient of each Independent variable < 0.85 , it indicates that multicollinearity does not exist.

3.6.2 Heteroscedasticity Test

To ensure that the estimation remains the best linear unbiased estimation (BLUE), the regression model must meet the OLS requirement of constant variance. The term "heteroscedasticity" refers to the model's non-constant variance. A model with a non-constant variance may still exhibit linear behaviour. This study requires the regression model to obtain BLUE using the Heteroscedasticity Test.

3.6.3 Autocorrelation Test

Autocorrelation analysis determines whether a linear regression model shows a relationship between the residual errors in a given period (t) and those in the previous period (t-1). If this correlation exists, it will be referred to as an autocorrelation condition. Autocorrelation exists because observations are sequential and related (Ghozali, 2016).

Therefore, to determine whether autocorrelation is present in this research, the LM test (Lagrange Multiplier) will be employed to acquire the chi-squared (X^2) value. Autocorrelation can be identified using the following methods:

1. If the calculated X^2 value > critical table X^2 , it may be inferred that it indicates autocorrelation.
2. If the calculated X^2 value < critical table X^2 , it may be inferred that it does not indicate autocorrelation.

3.7 Statistical Testing

In this study, statistical tests are performed to ascertain the acquired regression result. When performing hypotheses testing, three distinct types of analysis are employed: the T-test for individual parameter significance, the F-test for simultaneous significance, and the coefficient of determination (R^2) (Kim, 2013).

3.7.1 Coefficient of Determination (R^2)

R-squared (R^2) is a statistical measure representing the proportion of the variance for a dependent variable explained by an independent variable in a regression model (Ejiro, 2023). The coefficient determination, denoted as R^2 , is a numerical value between 0 and 1. A higher value of R^2 indicates a strong link between the dependent variable and one or more independent variables.

Table 3. 2 The Coefficient of Determination (R^2)

<i>Interval Value</i>	Level of Closeness
<i>0.001 – 0.200</i>	Very Weak
<i>0.201 – 0.400</i>	Weak
<i>0.401 – 0.600</i>	Moderately Strong
<i>0.601 – 0.800</i>	Strong
<i>0.801 – 1.000</i>	Very Strong

Source: Prawira (2006)

3.7.2 F-test

The F-test is utilized to ascertain whether the independent variables significantly affect the dependent variable (Gujarati, 2012). Hypothesis testing is simultaneously using F-test at a 95% confidence level with

degrees of freedom ($df_1 = (k-1)$) and ($df_2 = (n-k)$). Here are the testing formulations:

$H_0 : \beta_{1...n} < 0$ Implies that all independent variables do not have a significant effect on Air Quality Index

$H_a : \beta_{1...n} > 0$ Implies that all independent variables significantly affect the Air Quality Index

Here are the testing criteria:

- H_0 rejected and H_a accepted if Computed F-value > Critical F-value
- H_0 accepted and H_a rejected if Computed F-value < Critical F-value

3.7.3 T-test

Gujarati (2012) defines the T-statistical test as examining the correlation or impact of each independent variable on the dependent variable. Hypothesis testing is conducted on regression coefficients by doing individual parameter significance tests (T-test) at a 95% confidence level with degrees of freedom ($df = (n-k)$). Here are the testing criteria:

- H_0 rejected, and H_a accepted if Computed T-value > Critical T-value
- H_0 accepted, and H_a rejected if Computed T-value < Critical T-value

The Null hypothesis (H_0) is rejected, and the Alternative hypothesis (H_a) is accepted when the calculated t-value is greater than the critical t-value from the t-table. In contrast, the Null hypothesis (H_0) is accepted, and the Alternative hypothesis (H_a) is rejected if the calculated t-value is less than the critical t-value from the t-table. Furthermore, rejecting H_0 indicates that the tested independent variable significantly and negatively influences the dependent variable. On the other hand, when the null hypothesis is accepted, it indicates that the independent variable being tested has a statistically significant and positive impact on the dependent variable.

CHAPTER IV

DATA ANALYSIS AND DESCRIPTION

4.1 Descriptive Statistics of Research Variables

Descriptive statistical analysis provides a comprehensive summary of each research variable's characteristics, including the sum of data, maximum value, minimum value, average (mean), standard deviation, and variance. The analysis was conducted using the software EViews 13.

The average data used in this study were collected over a period of 11 years, from 2013 to 2023. This study analyzes gross regional domestic product, the proportion of workers in the manufacturing industry, and fuel consumption.

Table 4. 1 Descriptive Statistical Analysis

<i>Variable</i>	<i>N</i>	<i>Mean</i>	<i>Maximum</i>	<i>Minimum</i>	<i>Std. Dev.</i>
<i>Air Quality Index</i>	44	34.077	72.800	18.200	11.143
<i>Gross Regional Domestic Product</i>	44	618120.2	2050456	76907.4	657489.7
<i>Proportion of Workers in Manufacturing Industry</i>	44	18.690	26.120	13.470	4.104
<i>Fuel Consumption</i>	44	3139752	6198732	1150450	1901760

Data Source: Data processed using *EViews 13*

Based on Table 4.1, it can be inferred that the average value, standard deviation value, maximum value, and minimum value of each variable are used in this study from the period 2013 to 2023.

The mean value for the Air Quality Index (AQI) is 34.077, which serves as the dependent variable in this analysis. The majority of observations cluster around this mean value, indicating the central tendency of the AQI data distribution. The maximum value is 72.80. In contrast, the lowest recorded value for the variable AQI is 18.200. Furthermore, the standard deviation for variable AQI is 11.143. The relatively large standard deviation value indicates a significant degree of variation around the mean.

The Gross Regional Domestic Product (GRDP) has a mean value of 618120.2. This value implies that GRDP data is generally within this average range. The highest value observed in the existing data set is 2050456, representing the maximum value attained by variable GRDP. In contrast, the dataset's lowest value is 76907.4, representing the minimum value of variable GRDP. The standard deviation of the GRDP variable is 657489.7, which indicates the extent of dispersion from the mean value. Such high standard deviation indicates a considerable degree of variation in the data set.

The mean value for the proportion of workers in the manufacturing industry (PWMI) is 18.690. The majority of observations in the PWMI data distribution

cluster around this mean value, indicating its central tendency. It offers an overview of the position of the data on a broader numerical scale. 26.120 is the maximum value. In contrast, the lowest recorded value for PWMI is 13.470. Furthermore, the standard deviation for the variable PWMI is 4.104. The relatively high standard deviation value indicates a notable degree of variation around the mean. It indicates that the PWMI data is not only concentrated around the mean but also distributed across a broader range.

The mean value for fuel consumption (FC) is 3139752. This average indicates that the data on fuel consumption generally falls within this range. The highest value observed in the existing data set is 6198732, representing the maximum value attained by the variable FC. In contrast, the lowest value observed in the dataset is 1150450, which represents the variable FC's minimum value. The FC variable has a standard deviation of 1901760, indicating the degree of data dispersion from its mean value. Such high standard deviation indicates a significant degree of variation in the data's values.

4.2 Manufacture Industry and Fuel Consumption

a. The manufacturing industries in Jakarta, Surabaya, Makassar, and Medan

The manufacturing industry is an economic activity that transforms raw materials into finished or semi-finished goods. This process may entail mechanical, chemical, or manual modification to increase the value of the

goods produced and align them more closely with the needs and expectations of the end consumers. The following are the 2020 Standard Classification of Indonesian Business Field (KLBI):

Table 4. 2 Types of Manufacture Industry

Standard Classification of Indonesian Business Field (KLBI)
<i>Manufacture of food products</i>
<i>Manufacture of beverages</i>
<i>Manufacture of tobacco products</i>
<i>Manufacture of textiles</i>
<i>Manufacture of wearing apparels</i>
<i>Manufacture of leather and related products and footwear</i>
<i>Manufacture of wood and of products of wood and cork</i>
<i>Manufacture of articles of straw and plaiting materials, bamboo, rattan, and the like</i>
<i>Manufacture of paper and paper products</i>
<i>Printing and reproduction of recorded media</i>
<i>Manufacture of coke and refined petroleum products</i>
<i>Manufacture of chemical products</i>
<i>Manufacture of pharmaceuticals medicinal chemicals and botanical products</i>
<i>Manufacture of rubber and plastic products</i>
<i>Manufacture of other non-metallic mineral products</i>
<i>Manufacture of basic metals</i>
<i>Manufacture of fabricated metal products except machinery and equipment</i>

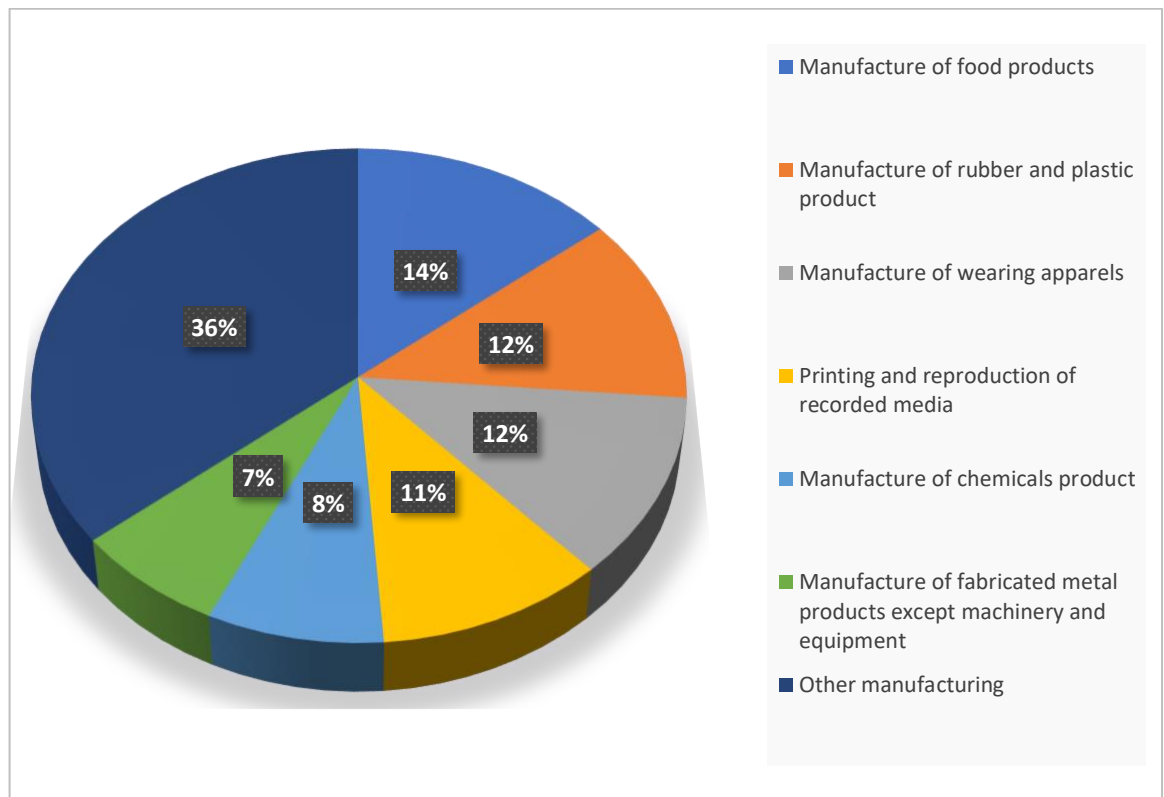
<i>Manufacture of computers, electronic and optical products</i>
<i>Manufacture of electrical equipment</i>
<i>Manufacture of machinery and equipment n.e.c</i>
<i>Manufacture of motor vehicles, trailers, and semi trailers</i>
<i>Manufacture of other transport equipment</i>
<i>Manufacture of furniture</i>
<i>Other manufacturing</i>
<i>Repair and installation of machinery and equipment</i>

Source: *Central Bureau of Statistics (BPS)*

According to the data shown in Table 4.2, there are about 24 different kinds of manufacturing industries classified, with different distributions of large—and medium-scale industries for each city across Indonesia.

Jakarta is home to many large and medium-scale manufacturing industries, with 1,680 business units/companies spread across five city areas and one district. The figure below shows the distribution of these industries according to the Standard Classification of Indonesian Business Field or KLBI (*Klasifikasi Baku Lapangan Usaha Indonesia*), which collectively reflects the diversification of the city's manufacturing sector.

Figure 4. 1 Distribution of Manufacturing Industry in Jakarta



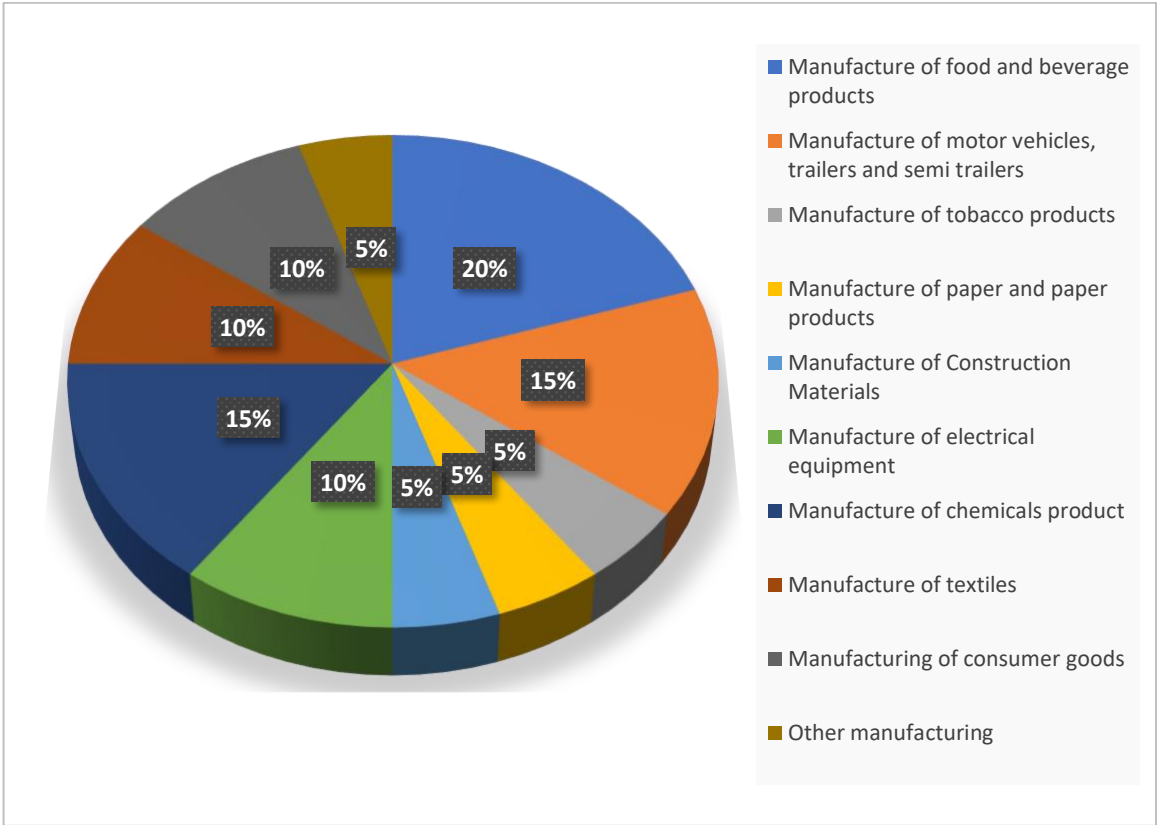
Source: *Central Bureau of Statistics (BPS)*

The composition of the manufacturing industry in this area demonstrates that the other manufacturing sector is the predominant force, representing 36% of the total, followed by the manufacture of food products (14%), the rubber and plastic products industry, and the wearing apparel industry (12% each), printing and reproduction of recorded media (11%), the chemical products industry (8%), and the fabricated metal products industry except machinery and equipment (7%).

Similar to Jakarta, Surabaya is also a motherland to many large and medium-scale manufacturing industries, with 940 business units/companies

distributed across the region. Most manufacturing industries in Surabaya produce food products and rubber and plastic products. 122 and 95 companies, respectively, are involved in these two sectors. The lowest number of companies in Surabaya is marked in the manufacture of coke and refined petroleum products, with a mere three companies.

Figure 4. 2 Distribution of Manufacturing Industry in Surabaya



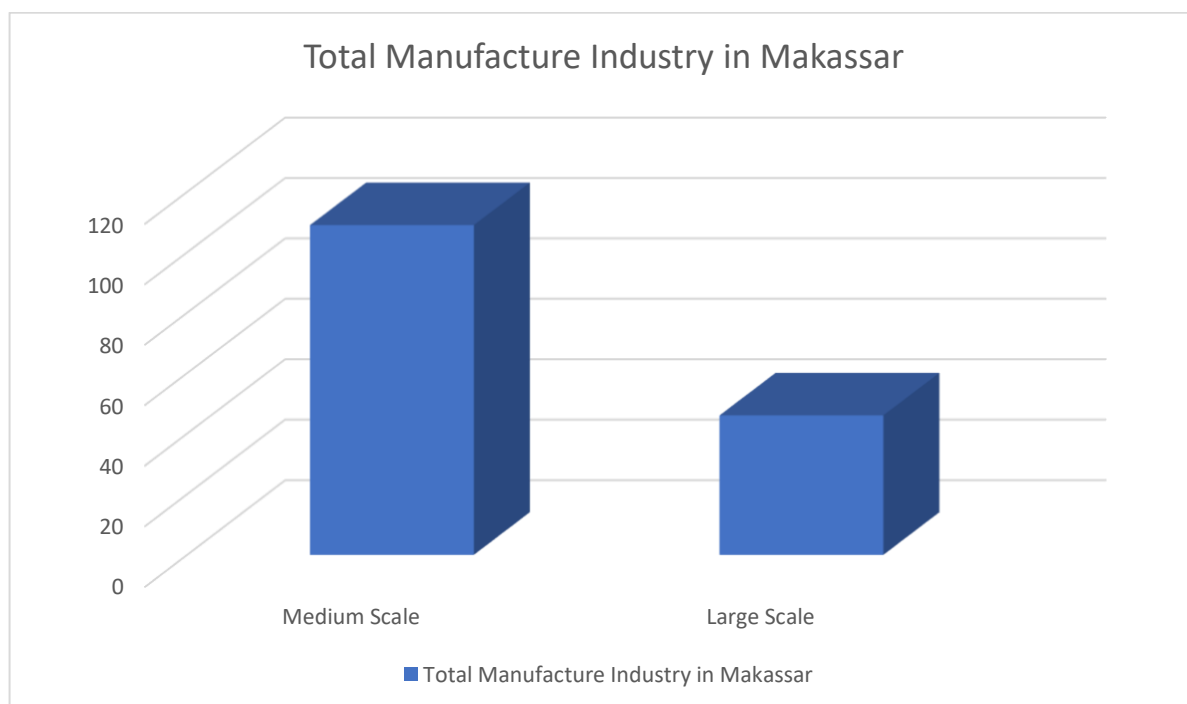
Source: *Central Bureau of Statistics (BPS)*

The composition of the manufacturing industry in Surabaya demonstrates that the manufacturing sector of food and beverage is the predominant force, representing 20% of the total, followed by the manufacture of motor vehicles,

trailers, and semi-trailers and the manufacture of chemical products (15% each), the electrical equipment, textiles and consumer goods industry (10% each), and manufacture of construction materials, tobacco, paper products and other manufacturing (5% each).

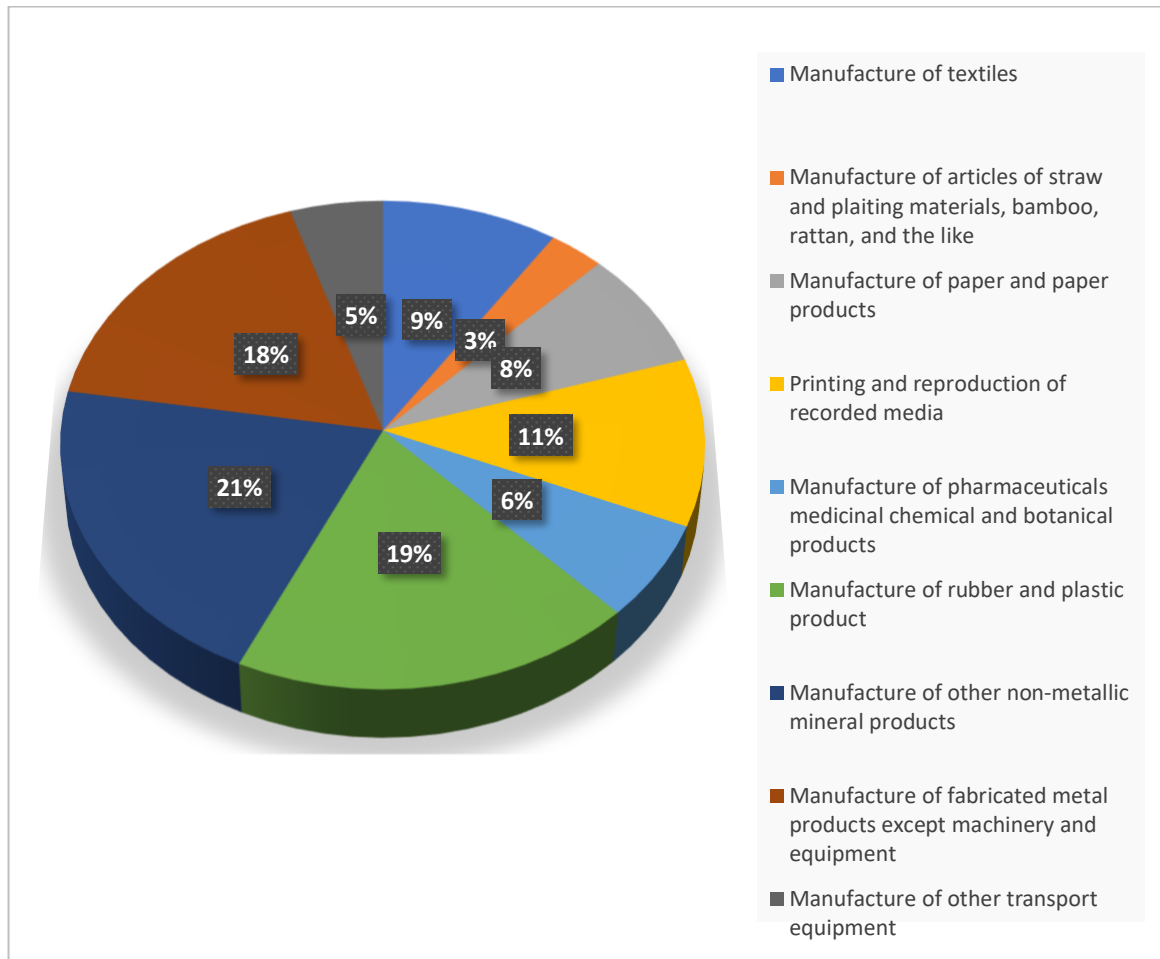
Makassar, the capital of South Sulawesi province, is also one of the largest cities in eastern Indonesia. However, it has fewer manufacturing industries than the two previous metropolitan cities, Jakarta and Surabaya. In Makassar, the total number of manufacturing industries is 155, with the majority (85 companies) producing food and beverage products. Furthermore, the region is home to 46 large-scale companies, representing 29% of the total manufacturing companies. The remaining 109 companies are classified as medium-scale.

Figure 4. 3 The Manufacturing Industry in Makassar



Source: *Central Bureau of Statistics (BPS)*

Figure 4. 4 Distribution of Manufacturing Industry in Makassar

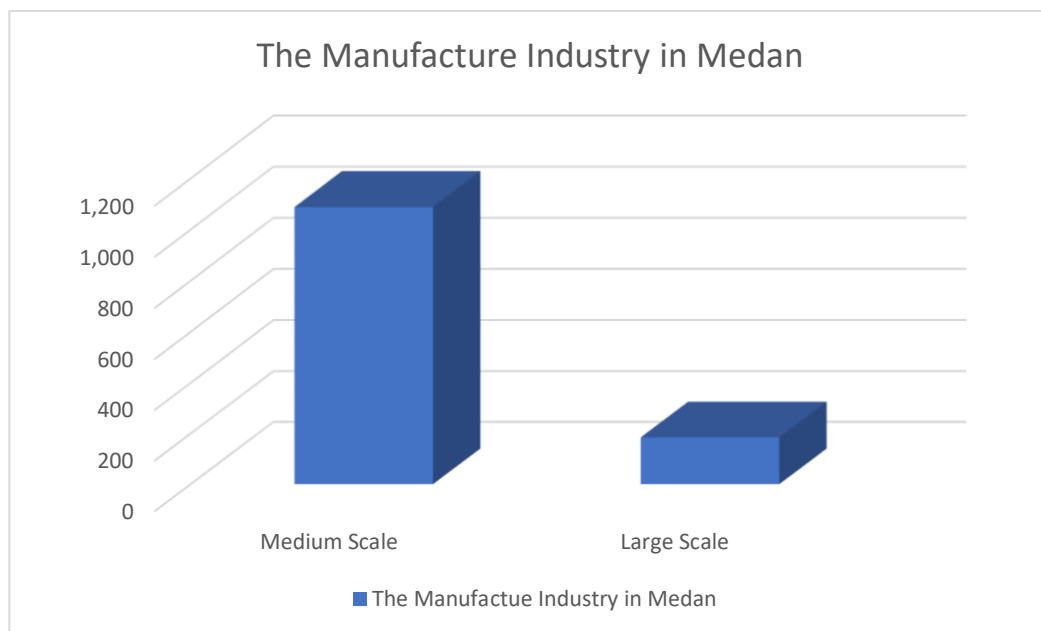


Source: *Central Bureau of Statistics (BPS)*

In contrast to Makassar, which represents a relatively limited number of manufacturing industries, Medan has a significantly more expansive industrial landscape, containing a larger number and range of manufacturing activities. In Medan, there are 1,273 manufacturing firms, of which 1,088 are medium-sized firms, reflecting a significant diversification of the medium-sized industrial sector.

Furthermore, Medan is home to 185 large-scale manufacturing enterprises, demonstrating the city's capacity as a major economic centre in North Sumatra with a significant contribution to national industrial production. Such a large number of companies demonstrates that Medan is one of Indonesia's most important industrial centres.

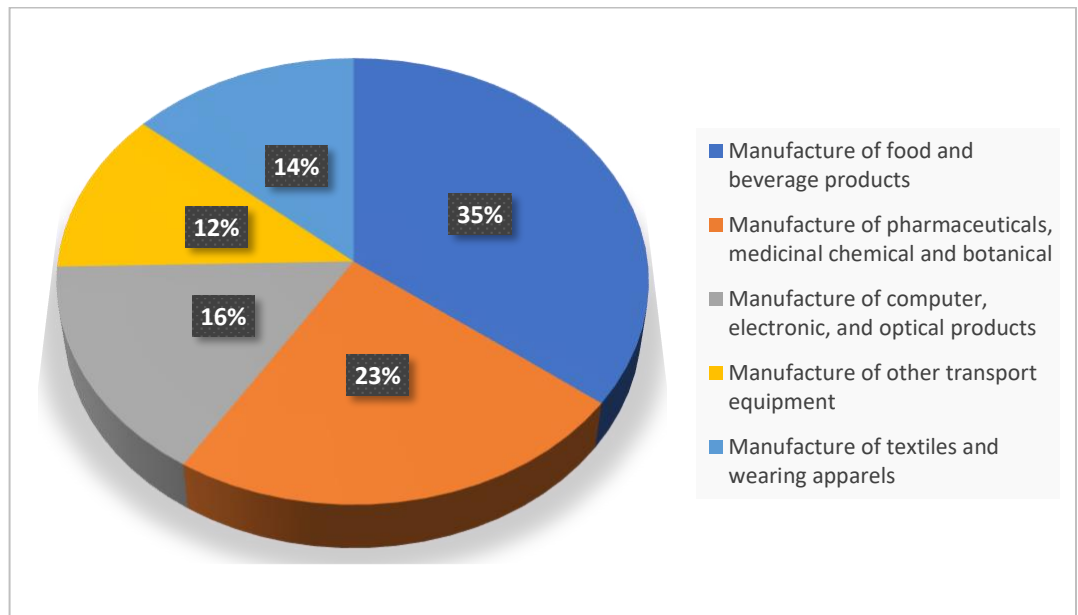
Figure 4. 5 The Manufacturing Industry in Medan



Source: *Central Bureau of Statistics (BPS)*

As with the metropolitan cities previously discussed, the dominant manufacturing industry in this city is food and beverage products. There are 450 companies in this sector, followed by the chemical manufacturing industry, which comprises 300 pharmaceutical companies. Other industries are textiles, the metal industry, electronics, and many more.

Figure 4. 6 Distribution of Manufacturing Industry in Medan



Source: *Central Bureau of Statistics (BPS)*

b. Vehicle Types and Fuel Usage

Table 4. 3 Number of Motor Vehicles and Cars

City	Car	Motor Vehicle	Bus	Cargo Vehicle	Special-purpose Vehicle
Jakarta	4.354.155	19.016.898	876.637	44.352	64.611
Surabaya	564.973	2.991.442	3.838	174. 381	428
Makassar	340.257	1.587.659	2.956	97.515	403
Medan	508.783	2.886.824	5.741	166.566	1.814

Source: Ministry of Negry and Mineral Resource

Four-wheeled vehicles, specifically cars, account for approximately 70% of general fuel use in Indonesia. In contrast, two-wheeled vehicles, namely motorbikes, account for approximately 30%. Additionally, Pertalite (RON 90) is the most consumed type of petrol in numerous cities in Indonesia. Pertalite consumption in Indonesia accounts for approximately 79% of the total

consumption of other petrol varieties such as Pertamina (RON 92), Pertamina Turbo (RON 98), Solar, or Dexlite (Ministry of Energy and Mineral Resource).

4.3 Estimation of Panel Data Regression

The regression of panel data is conducted using three methods: the Common Effect Method (CEM), the Fixed Effect Method (FEM), and the Random Effect Method (REM). One of these three methods will be selected as the most appropriate for data analysis.

4.3.1 Common Effect Model (CEM)

The common effect method integrates time series and cross-sectional data into a unified panel data set. This method does not take into account the individual and temporal aspects. It can, therefore, be concluded that the data behaviour between districts/cities is consistent. The following are the results of the Common Effect Model analysis for the variables gross regional domestic product, proportion of workers in the manufacturing industry, and fuel consumption in Jakarta, Surabaya, Makassar, and Medan from 2013 to 2023. Table 4.2 illustrates the regression estimation outcomes for the common effect model.

Table 4. 4 Common Effect Model Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
<i>C</i>	188.4656	62.33685	3.023341	0.0043
<i>Gross Regional Domestic Product (GRDP)</i>	21.50627	3.953153	5.440282	0.0000
<i>Proportion of Workers in Manufacturing Industry (PWMI)</i>	48.70269	14.96396	3.254666	0.0023
<i>Fuel Consumption (FC)</i>	-38.63317	9.667191	-3.996319	0.0003
<i>R-squared</i>	0.638290			
<i>F-statistic</i>	25.52860			
<i>Prob. (F-statistic)</i>	0.000000			

Data Source: Data processed using *EViews 13*

4.3.2 Fixed Effect Model (FEM)

The following are the results of the Fixed-Effect Model analysis for the variables gross regional domestic product, proportion of workers in the manufacturing industry, and fuel consumption in Jakarta, Surabaya, Makassar, and Medan from 2013 to 2023. Table 4.3 displays the regression estimation outcomes for the fixed-effect model.

Table 4. 5 Fixed Effect Model Result

Variable	Coefficient	Std. Error	t-Statistic	Prob.
<i>C</i>	-1326.623	322.8722	-4.108817	0.0002
<i>Gross Regional Domestic Product (GRDP)</i>	-22.84771	12.61114	-1.811708	0.0782
<i>Proportion of Workers in Manufacturing Industry (PWMI)</i>	86.95988	21.38842	4.065746	0.0002
<i>Fuel Consumption (FC)</i>	94.86417	28.71138	3.304062	0.0021
<i>R-squared</i>	0.792623			
<i>F-statistic</i>	23.56990			
<i>Prob. (F-statistic)</i>	0.000000			

Data Source: Data processed using *EViews 13*

4.3.3 Random Effect Model (REM)

The following are the results of the Random Effect Model analysis for the variables gross regional domestic product, proportion of workers in the manufacturing industry, and fuel consumption in Jakarta, Surabaya, Makassar, and Medan from 2013 to 2023. Table 4.4 illustrates the regression estimation outcomes for the random effect model.

Table 4. 6 Random Effect Model Result

Variable	Coefficient	Std. Error	t-Statistic	Prob.
<i>C</i>	173.2874	73.47366	2.358497	0.0233
<i>Gross Regional Domestic Product (GRDP)</i>	20.42248	4.955945	4.120804	0.0002
<i>Proportion of Workers in Manufacturing Industry (PWMI)</i>	51.51108	15.44955	3.334148	0.0019
<i>Fuel Consumption (FC)</i>	-37.22110	10.37947	-3.586030	0.0009
<i>R-squared</i>	0.515922			
<i>F-statistic</i>	14.21045			
<i>Prob. (F-statistic)</i>	0.000002			

Data Source: Data processed using *EViews 13*

4.4 Selection of the Estimation Model

4.4.1 Chow-Test

Table 4. 7 Result of Chow-Test

Effect Test	Statistic	d.f.	Prob.
<i>Cross-section F</i>	9.178700	(3,37)	0.0001
<i>Cross-section Chi-square</i>	24.477501	3	0.0000

Data Source: Data processed using *EViews 13*

Based on the results of the Chow test, the probability value obtained is 0.0001, which is below 0.05. This value indicates that the Fixed Effect Model (FEM) is more appropriate than other models, such as the Random Effect model. By choosing FEM, the unobserved fixed effects can be controlled that may affect

the dependent variable in panel data. After confirming that FEM is the right model through the Chow test, the next step is to conduct the Hausman test. The Hausman test is important to evaluate whether the assumption about the correlation between fixed effects and independent variables is valid, ensuring the consistency and efficiency of the estimates used in the model.

4.4.2 Hausman Test

Table 4. 8 Result of Hausman Test

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	42.420904	3	0.0000

Data Source: Data processed using *EViews 13*

The results of the Hausman test indicate a probability value of 0.0000 (<0.05), which is significantly smaller than the probability of 0.05. This probability value indicates a significant correlation between the fixed effects and the independent variables, thereby confirming that the fixed effects model (FEM) is the best option for this panel data analysis.

The Chow and Hausman tests consistently indicate that the fixed-effect model is the most appropriate, so the Lagrange Multiplier test (LM-Test) is unnecessary.

4.5 Classical Assumption

The selected model is the fixed effects model (FEM). Therefore, a classical assumption test must be carried out. The classical assumption tests employed include the presence or absence of multicollinearity and heteroscedasticity (Basuki & Yuliadi, 2014; Napitupulu et al., 2021).

4.5.1 Multicollinearity Test Result

The multicollinearity test in this research aims to determine whether there is a deviation of the linear relationship between independent variables in the regression model.

Table 4. 9 Multicollinearity Test Result

	<i>Gross Regional Domestic Product</i>	<i>Proportion of Workers in Manufacturing Industry</i>	<i>Fuel Consumption</i>
<i>Gross Regional Domestic Product</i>	1	0.8157	0.9570
<i>Proportion of Workers in</i>	0.8157	1	0.9197

<i>Manufacturing Industry</i>			
<i>Fuel Consumption</i>	0.9570	0.9197	1

Data Source: Data processed using *EViews 13*

Based on the multicollinearity test results in Table 4.7, the correlation coefficient value of Gross Regional Domestic Product (GRDP) to the proportion of labour in the manufacturing industry is 0.8157, the value of GRDP to fuel consumption is 0.9570, and the correlation coefficient value of the proportion of workers in the manufacturing industry to fuel consumption is 0.9197.

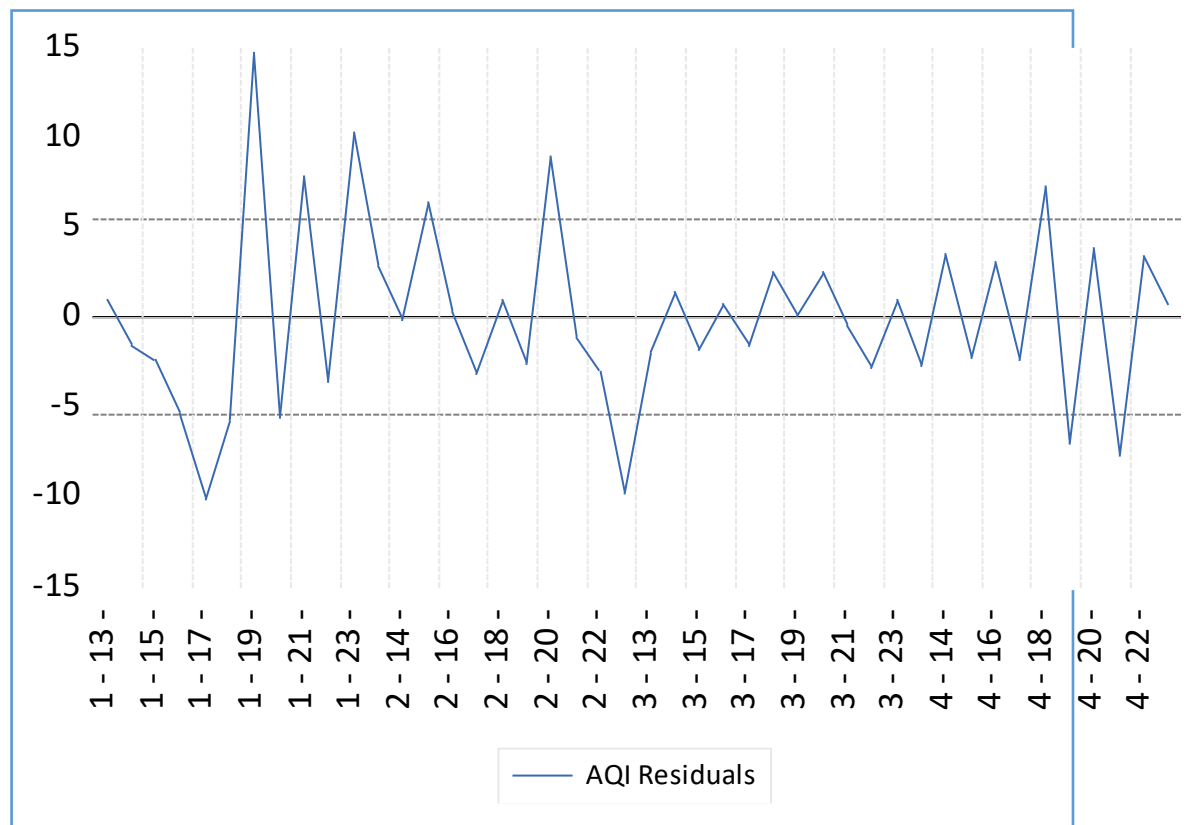
The results of the multicollinearity test calculation demonstrate that there are indications of multicollinearity for some variables. This is shown by the correlation coefficient value between the independent variables of GRDP and fuel consumption and the proportion of workers in the manufacturing industry to fuel consumption, which is more significant than 0.85. Nevertheless, this condition does not cause significant problems in model estimation because the resulting estimator is still BLUE (Best Linear Unbiased Estimator). In this case, the assumption of no correlation between independent variables is unnecessary. Multicollinearity has more impact on increasing the standard error of the estimator, which can make it challenging

to obtain an estimator with a small standard error. Therefore, regression analysis models can still be performed despite multicollinearity without causing significant problems.

4.5.2 Heteroscedasticity Test Result

The heteroscedasticity test in this research aims to determine whether there is heteroscedasticity in the regression model's residuals across different observations.

Figure 4. 7 Heteroscedasticity: Residual Graph



Data Source: Data processed using *EViews 13*

From the analysis of the residual graph, it is evident that the residual line does not exceed the predetermined limit, which is between ± 500 . This limit indicates residual values must fall within the specified range to avoid heteroscedasticity issues. The results demonstrate that the residual values are confined to a narrower range, between +15 and -15. This number indicates that the residual values are significantly below the specified limit, providing substantial evidence that there are no indications of heteroscedasticity in this model. Therefore, it can be concluded that this model passes the heteroscedasticity test, indicating that the residual variance remains constant and is not influenced by the independent variable values.

4.6 Regression Analysis

This analysis method determines the extent of the independent variable's impact on the dependent variable. The fixed effect model has been identified as the most optimal of the three tests conducted. Consequently, regression analysis can be performed using the fixed effect model (FEM). After that, the following regression can be derived:

Table 4. 10 Panel Regression result of Fixed Effect Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
<i>C</i>	-1326.623	322.8722	-4.108817	0.0002
<i>Gross Regional Domestic Product (GRDP)</i>	-22.84771	12.61114	-1.811708	0.0782
<i>Proportion of Workers in Manufacturing Industry (PWMI)</i>	86.95988	21.38842	4.065746	0.0002
<i>Fuel Consumption (FC)</i>	94.86417	28.71138	3.304062	0.0021
<i>R-squared</i>	0.792623			
<i>F-statistic</i>	23.56990			
<i>Prob. (F-statistic)</i>	0.000000			

Data Source: Data processed using *EViews 13*

$$\text{AQI} = -1326.622 - 22.847 \cdot \text{LogGRDP} + 86.959 \cdot \text{LogPWMI} + 94.864 \cdot \text{LogFC}$$

- c. The value of the constant is 1326.623. If it is assumed that all independent variables, namely gross regional domestic product (GRDP), the proportion of workers in the manufacturing industry (PWMI), and fuel consumption (FC) have a constant value or if the value is equal to zero, the air quality index is 1326.622.
- d. The coefficient for the variable gross regional domestic product (GRDP) is 22.847. This number indicates that an increase in the gross regional domestic product will reduce the dependent variable by 22.847, assuming that the other variables remain constant.
- e. The coefficient for the variable proportion of workers in manufacturing industry (PWMI) is 86.959. This number implies that

a one-unit increase in the proportion of workers in the manufacturing industry will result in an 86.959 increase in the dependent variable, assuming that the other variables remain constant.

- f. The coefficient for the variable fuel consumption (FC) is 94.864. This number implies that a one-unit increase in fuel consumption will result in a 94.864 increase in the dependent variable, assuming that the other variables remain constant.

4.7 Statistical Testing

This analysis requires performing three statistical tests: the R-squared, t-test, and F-test. These tests evaluate the regression model, measure the strength of the relationship between variables, and assess the statistical significance of the overall model.

4.7.1 Coefficient of Determination (R^2)

The Adjusted R-squared value in this research is 0.7926, which indicates that the independent variables "Gross Regional Domestic Product, the proportion of workers in the manufacturing industry, and fuel consumption" collectively influence the dependent variable "Air Quality Index " by 79.26%. The remaining 20.74% of the influence on the dependent variable is caused by variables excluded in this study.

4.7.2 F-test

The F test is a statistical method for determining whether variables from two or more categories belong to the same population.

Table 4. 11 F-test Result

F-statistic	Prob(F-statistic)
23.5699	0.0000

Data Source: Data processed using *EViews 13*

The calculated F value obtained in this study is 23.5699 based on the statistical calculation results shown in Table 4.9. The calculated F value of $23.5699 > F_{table}$, which is 5.33261. This value is associated with a probability (p-value) of 0.0000 for the F-statistic. The value of $\text{sig. } 0.0000 < 0.05$, this result is highly significant, as indicated by the low p-value, much lower than the widely accepted significance criterion of 0.05. Hence, H_0 is rejected, and H_a is accepted, meaning that the variables of gross regional domestic product, the proportion of manufacturing industry labour, and fuel consumption affect the air quality index in Jakarta, Surabaya, Makassar, and Medan.

4.7.3 T-test

A statistical test (T-test) is a method of analysis used to demonstrate the influence of an independent variable on a dependent variable. Examining

the p-value allows us to determine the statistical significance of the relationship between the two variables.

Table 4. 12 T-test result

Variable	Significance (Sig.) Value	T-Count Value
<i>Gross Regional Domestic Product</i>	0.0782	-1.8117
<i>Proportion of workers in the manufacturing industry</i>	0.0002	4.0657
<i>Fuel Consumption</i>	0.0021	3.3040

Data Source: Data processed using *EViews 13*

The impact of the independent variable on the dependent variable can be described as follows:

- a. Gross Regional Domestic Product (GRDP): The t-test results show that the t-count value of 1.8117 is smaller than the t-table of 3.0975, with a significance value (sig.) of 0.0782, greater than 0.05 but less than alpha 0.1. Therefore, the null hypothesis (Ho) is rejected, and the alternative hypothesis (Ha) is accepted. This result means that the GRDP variable significantly affects air pollution in four metropolitan cities in Indonesia: Jakarta, Surabaya, Makassar, and Medan.

b. Proportion of workers in the manufacturing industry: The t-test results show that the t-count value of 4.0657 is greater than the t-table of 3.0975, with a significance value (sig.) of 0.0002, which is smaller than 0.05. Therefore, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_a) is accepted. This result means that the variable proportion of labour in the manufacturing industry sector significantly affects air pollution in four metropolitan cities in Indonesia: Jakarta, Surabaya, Makassar, and Medan.

c. Fuel Consumption: The t-test results show that the t-count value of 3.3040 is greater than the t-table of 3.0975, with a significance value (sig.) of 0.0021, smaller than 0.05. Therefore, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_a) is accepted. This result means that the variable of fuel consumption significantly affects air pollution in four metropolitan cities in Indonesia: Jakarta, Surabaya, Makassar, and Medan.

4.8 Discussion

4.8.1 Analyzing the Relationship of Gross Regional Domestic Product and Air Quality Index

The results of the multiple regression analysis indicate that there is a positive relationship between the Gross Regional Domestic Product variable and the Air Quality Index (AQI) variable in the cities of Jakarta, Surabaya, Makassar, and Medan with an AQI value of -1.811708.

The probability value is 0.0782, which is significant at the alpha level of 10%, suggesting that the variable of GRDP is statistically significant. This implies that the GRDP has an influence on the air quality level in those cities.

DKI Jakarta and Surabaya, Indonesia's most significant economic centres, demonstrate a clear correlation between economic growth and air pollution levels. DKI Jakarta serves as both the capital city and the centre of business, trade and government activities, which makes it one of the most polluted regions in Indonesia. An increase in gross regional domestic product (GRDP) in Jakarta is frequently accompanied by an expansion in the number of motorised vehicles, which constitute the primary mode of transportation for residents of the city. The transport sector is one of the many challenges faced by Jakarta. The industrial sector also has a significant impact on air quality. While some large industrial estates are located in the suburbs, such as in Bekasi and Tangerang, the emissions generated from this sector still affect Jakarta's air quality. The growth of Jakarta's GRDP, which signifies an increase in production and consumption, has also led to an increase in industrial activity and energy consumption. As a result, these growing economic sectors continue to drive increased pollutant emissions.

Furthermore, the increase in GRDP in Surabaya is driven by the industrial and trade sectors, where port activities and heavy industry are integral to the city's economy. Fossil fuel consumption in Surabaya is rising as a result, with industrial and transport purposes accounting for the majority

of this consumption. This is leading to a spike in greenhouse gas emissions and other pollutants that are directly impacting air quality.

The relationship between GRDP and air pollution is clear: as one increases, the other does too. This is evident in Makassar and Medan. As a distribution centre for eastern Indonesia, the increase in economic activity in Makassar is followed by a surge in the number of private and logistics vehicles transporting goods to various eastern regions of Indonesia. This results in a significant contribution to the deterioration of air quality in the city from exhaust emissions from these vehicles. Furthermore, the rapidly growing construction sector in Makassar also contributes harmful particles that pollute the air, such as PM10 and PM2.5. Moreover, Medan's economic growth, characterised by an increase in GRDP, also indicates high industrial activity, especially in the processing of plantation products such as palm oil, rubber, and coffee. Processing industries in Medan often use fossil-based fuels.

Although the four cities demonstrate comparable trends in the impact of gross domestic product (GDP) on air pollution, notable discrepancies exist in their economic characteristics and the primary sources of pollution within each region. In Jakarta and Surabaya, which are economic centres in Java, air pollution is primarily generated by the transport sector and labour-intensive industries. Conversely, in Makassar and Medan, which are economic centres

outside Java, the surge in pollution is predominantly attributed to the transport logistics sector and the crop processing industry. The rapid urbanisation observed in cities outside Java, as seen in Makassar and Medan, has resulted in a notable reduction in green land that can naturally absorb pollutants, thereby worsening the air quality in these cities.

Furthermore, the output level coefficient of -22.84771 in these four regions indicates that an increase in the gross regional domestic product by one percent will reduce the air quality index by 22.84771. Consequently, it can be concluded that the relationship between gross regional domestic product and the air quality index is inelastic. The results of the analysis demonstrate a positive relationship between GRDP and the air quality index, which aligns with the theories previously validated by empirical evidence and previous research.

This finding is consistent with the study by Bashir et al. (2021) titled *Revisiting the Relation between Economic Growth and the Environment: A Global Assessment of Deforestation, pollution, and Carbon Emission* by Bo Pieter Johannes Andree, Andres Chamorro, Phoebe Spencer, Eric Koomen, dan Harun Dogo (2019) found that there is a positive and statistically significant correlation between economic growth and air pollution. It implies that a rise in economic growth is correlated with a rise in air pollution. Moreover, this research found a positive and significant correlation between

population density and air pollution. An increase in deforestation is also associated with increased air pollution. Another research conducted by Andrew Adewale, Alola, Festus, VictorBekun, and Samuel Asumadu Sarkodie (2019), entitled *Dynamic Impact of Trade Policy, Economic Growth, Fertility Rate, renewable and Non-renewable Energy Consumption on Ecological Footprint in Europe*, found that economic growth has a positive influence and significant towards environmental degradation.

Contrary to the results of this study, research titled *The Relationship between Air Pollution, Economic Growth, and Life Expectancy: Empirical Evidence from Indonesia*. This study identified a correlation between air pollution and economic growth. The research employed analytical techniques, including Granger causality and ARDL, and utilized time series data from 1985 to 2019. The findings indicate that while a notable long-term relationship exists between economic growth and air pollution, the short-term impact may fluctuate, potentially leading to inconsequential results in specific circumstances.

4.8.2 Analyzing the Relationship of Proportion of Workers in Manufacturing Industry and Air Quality Index

The results of the multiple regression analysis indicate that there is a positive relationship between the Proportion of Workers in the Manufacturing Industry variable and the Air Quality Index (AQI) variable in the cities of

Jakarta, Surabaya, Makassar, and Medan with an AQI value of 4.065746. The probability value is 0.0002, which, at the alpha level of 5%, suggests that the variable is statistically significant. It implies that the proportion of workers in manufacturing industries influences the Air Quality Index in those cities. The output level coefficient of 86.95988 indicates that an increase in the proportion of workers in manufacturing industries by one percent will increase the air quality level by 86.95988. Consequently, it can be concluded that the relationship between the proportion of labour in manufacturing industries and the air quality index is elastic and positive.

The findings of this study demonstrate a clear correlation between the proportion of workers in the manufacturing industry and the level of air pollution in the areas under study. The high proportion of workers indicates high production intensity within the manufacturing industry. It would seem that industrial activities may significantly and directly impact the increase in pollutant emissions in the four cities. This is happening because the production process requires a considerable amount of energy. Furthermore, increasing production intensity and volume would also increase energy demand. It is worth considering that the large number of industries that use fossil fuels such as coal and petroleum as energy may potentially harm air quality in these regions. The findings of this study demonstrate that as the proportion of workers in the manufacturing industry rises, so too does the level of air pollution in the cities under investigation. The high proportion of

workers indicates high production intensity within the manufacturing industry. This industrial activities significantly and directly contribute to the observed increase in pollutant emissions in the four areas. This issue is because the production process itself requires a considerable amount of energy.

Furthermore, an increase in production intensity and volume indicates a corresponding rise in energy demand. The intensity of industries that utilise fossil fuels, such as coal and petroleum, as energy sources further deteriorates the air quality in these regions. The high number of manufacturing industries and the proportion of labour in these industries in Jakarta and Surabaya, for instance, is directly proportional to the high level of air pollution in these two areas. Despite introducing policies promoting environmentally friendly renewable technologies and fuels in both regions and several companies adopting such technologies, the implementation of these policies needs to be improved. In fact, not all industries have adopted environmentally sustainable technologies that do not contribute to air pollution. Although these industries are still developing in regions outside Java, Makassar, and Medan, their contribution to adverse environmental impact persists.

Eventually, the analysis demonstrates a positive relationship between the proportion of workers in manufacturing industries and the air quality index, which aligns with the theories previously validated by empirical

evidence and previous research. Hao, Wu, Wang, and Huang, the authors of the study *"Re-examine environmental Kuznets curve in China: spatial estimations using the environmental quality index,"* show that more industrial activities, such as manufacturing, are linked to higher levels of pollutants like PM2.5, which in turn changes the AQI. The study employed spatial data to examine the correlation between energy intensity in the manufacturing sector and environmental quality.

On the other hand, research by the National Bureau of Economic Research titled *"Why Is Pollution From U.S. Manufacturing Declining? The Roles Of Environmental Regulation, Productivity, And Trade"* found the opposite. The analysis disclosed that while industrial output rose overall, pollutant emissions per production unit significantly decreased. This decrease may be due to the implementation of more stringent environmental regulations and improvements in production methods. Eventually, the data suggests an inverse correlation between the percentage of workers in the manufacturing sector and air pollution.

4.8.3. Analyzing the Relationship of Fuel Consumption and Air Quality Index

The results of the multiple regression analysis indicate that there is a positive relationship between the Fuel Consumption variable and the Air Quality Index (AQI) variable in the cities of Jakarta, Surabaya, Makassar, and Medan, with an AQI value of 3.304062. The probability value is 0.0021,

which suggests that the variable is statistically significant at the alpha level of 5%. This number implies that the consumption of fuel has an influence on the Air Quality Index in those cities. The output level coefficient of 94.86417 indicates that an increase in fuel consumption by one percent will increase the air quality level by 94.86417. Consequently, it can be concluded that the relationship between fuel consumption and the air quality index is elastic.

Furthermore, the use of fuel oil is directly linked to the level of air pollution in the four regions studied, namely Jakarta, Surabaya, Makassar, and Medan. It demonstrates that increased fuel consumption will inevitably lead to a rise in air pollution levels, which will have a detrimental impact on the environment, human health, and the economy. This is because fuel combustion for energy use produces harmful pollutant emissions, such as carbon dioxide. This is because fuel combustion contains particles that harm the environment and humans, including particulate matter 10 (PM10) and particulate matter 2.5 (PM2.5), which are much smaller and can quickly enter the human respiratory tract. PM2.5 is a pollutant that has undoubtedly contributed to the decline in air quality levels in several areas in Indonesia, including Jakarta, Surabaya, Makassar, and Medan. Jakarta is, in fact, one of the most polluted metropolises in the world. This is unsurprising considering the number of vehicles in the city. The region has approximately 19 million motorbike units, the highest number compared to other regions, including Surabaya with around 3 million motorbike units, Makassar with 1.5 million, and Medan with about 2.8 million. Furthermore, it should be noted that the

use of fuel oil is not limited to the transport sector. It is also employed as the primary fuel source for production and logistics operations in industrial facilities in the areas, contributing to air quality deterioration.

The data clearly shows that the amount of fuel oil used directly affects the level of air quality in the four regions despite their different characteristics. It has proven that air pollution problems still arise even though these regions have different economic, social, and community characteristics. With the highest number of vehicles and the largest population in Indonesia, Jakarta is a city characterized by a society heavily dependent on private vehicles. This fact often leads to traffic congestion that increase pollution levels by emitting more pollutants. Surabaya faces the same issue as Jakarta: many private vehicle users are causing traffic congestion. Even though many companies are now producing electric vehicles to transition away from fossil fuels, the number of consumers interested in them still needs to be increased. It indicates that many people still prefer gasoline-powered vehicles. Additionally, fuel oil is crucial for the operation of construction vehicles in infrastructure development. It can be reasonably asserted that, in addition to transport and industry, the extensive construction in these four regions, namely Jakarta, Surabaya, Makassar, and Medan, contributes to air quality.

The results of the analysis demonstrate a positive relationship between fuel consumption and the air quality index, which aligns with the theories

previously validated by empirical evidence and previous research. In the study "*Energy Consumption, CO2 Emissions, and Economic Growth: Evidence from Indonesia*," published in 2014, Hwang and Yoo found that increased energy consumption from fossil fuels contributed significantly to increased CO2 emissions, which had a detrimental impact on air quality in Indonesia. The researchers employed panel data analysis to examine the interrelationship between the country's energy consumption, CO2 emissions, and economic growth.

CHAPTER V

CONCLUSION

Based on the research findings and discussion, the following conclusions can be drawn.

5.1 Conclusion

- 1) The study findings indicate that, from the period 2013 to 2023, a positive correlation was identified between air pollution and gross regional domestic product in the four cities being investigated. This implies that an increase in gross regional domestic product significantly affect the level of air quality. This finding supports the initial hypothesis which states that gross regional domestic product positively affects the air quality index.
- 2) The study findings indicate that, from the period 2013 to 2023, a positive correlation was identified between air pollution and the proportion of workers in the manufacturing industry in the four cities being studied. It indicates that an increase in the number of workers in the manufacturing sector correlates with an increase in the air quality index in the cities. This finding supports the second hypothesis, which states that the proportion of manufacturing workers has a positive relationship with AQI. It suggests that the manufacturing sector significantly contributes to the elevated levels of air pollutants.
- 3) The study findings indicate that, from the period 2013 to 2023, a positive correlation was also identified between air pollution and fuel consumption

in the four cities being investigated. It indicates that an increase in fuel consumption correlates with an increase in the air quality index in the cities. This finding supports the third hypothesis, which states that fuel consumption positively correlates with the air quality index. High fuel consumption, especially in the transportation and industrial sectors, can increase the emission of pollutants such as carbon monoxide, nitrogen oxides, and fine particles that damage air quality.

5.2 Suggestions

- 1) The government should incorporate environmental policies into regional economic development plans, to be implemented comprehensively nationally. An effective strategy would be to enforce more stringent emission regulations for industry and transportation while boosting financial support initiatives for renewable energy and electric vehicles. The government may also encourage the establishment of green industrial estates, which emphasize using low-emission technology and environmentally friendly industry practices. Consequently, it is possible to generate a higher gross regional domestic product (GRDP) without harming the air quality, which is a step toward the long-term objective of making a healthier and more sustainable environment for society.
- 2) The government needs to implement stricter regulations and improve the monitoring of emissions from the manufacturing sector. An effective

measure would be to implement more stringent emission regulations for industrial facilities and enhance the requirements for environmental permits. Furthermore, the government should offer fiscal incentives, such as tax refunds or subsidies, to encourage enterprises to adopt environmentally friendly technology, such as air filtration systems and energy-efficient machinery, for industrial use. Promoting the establishment of eco-friendly industrial zones where enterprises must adhere to strict environmental regulations and utilize sustainable energy sources is also needed.

- 3) Infrastructure development for electric vehicles, such as charging stations, and increased tax incentives for the purchase of electric vehicles can reduce emissions from the transportation sector, thereby addressing the rise in air pollution caused by fuel use. In addition, policymakers in Jakarta, Surabaya, Makassar, and Medan should consider strategies to enhance and integrate a variety of public transportation modes. The objective is to encourage more people to shift from private vehicles to public transportation. Moreover, it is also necessary to broaden the scope of the odd-even policy in those cities. This measure would effectively decrease the volume of vehicles on the streets and mitigate the detrimental effects of air pollution

5.3 Limitations

A notable limitation of the present research is the lack of studies that examine the relationship between air pollution, economic growth, the proportion of manufacturing labour, and fuel consumption in Indonesia.

Most studies have been conducted in developed countries, where economic conditions and regional characteristics differ significantly from those in Indonesia. Furthermore, comparisons of economic characteristics and policies between regions within and outside Java Island have not been widely explored, creating a gap in understanding regional variations.

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APPENDICES

Appendix 1

Research Data Employed

CROSS SECTION		PERIODE	AQI	GRDP	PWMI	FC
			Y	X1	X2	X3
JAKARTA	JKT	2013	32.5	1297195	18.47	5211987
		2014	33	1373389	19.02	5312345
		2015	34.2	1454564	19.31	5423876
		2016	35.5	1539917	20.14	5534234
		2017	36.8	1635359	21.49	5645678
		2018	42.42	1735208	22.83	5482342
		2019	67.2	1836241	23.21	5739274
		2020	31.95	1792291	21.68	5183729
		2021	55	1856076	22.47	5598219
		2022	53.8	1953456	23.76	5996124
		2023	72.8	2050456	24.64	6198732
SURABAYA	SUB	2013	30.47	407725.8	20.53	4210560
		2014	31.02	434268.3	21.04	4340780
		2015	31.76	459030.7	20.79	4180930
		2016	32.54	480345.7	22.13	4290860
		2017	33.23	503456.8	22.97	4380970
		2018	40.6	525789.1	24.51	4320500
		2019	40.6	548123.5	24.98	4450700

CROSS SECTION		PERIODE	AQI	GRDP	PWMI	FC
			Y	X1	X2	X3
		2020	38	570456.8	23.47	4100600
		2021	35	590227.1	23.96	4370800
		2022	37.5	655616.2	25.32	4459901
		2023	36	715294.7	26.12	4680751
MAKASSAR	UPG	2013	18.02	76907.4	15.34	1250450
		2014	20.01	82592.8	15.12	1270890
		2015	19.08	88828.1	15.06	1295670
		2016	21.05	95957.4	15.45	1320233
		2017	22.07	103826.1	16.01	1350560
		2018	24.3	112568.4	15.08	1357780
		2019	25	122465.8	16.02	1400123
		2020	26.8	120905.7	15.07	1427340
		2021	28.4	126312.8	16.05	1445620
		2022	29.1	133132.6	16.09	1478950
		2023	30.6	140197.9	16.03	1512230
MEDAN	MDN	2013	22.34	110795.4	13.47	1150450
		2014	30.48	117525	13.78	1165890
		2015	25.22	124269.9	13.86	1181230
		2016	32.13	132062.86	14.04	1205670
		2017	28.67	139739.3	14.19	1234560

CROSS SECTION		PERIODE	AQI	GRDP	PWMI	FC
			Y	X1	X2	X3
		2018	40	148007.14	14.28	1267890
		2019	26.74	156780.5	14.39	1290450
		2020	37.91	153669.9	14.12	1310340
		2021	29.32	157689.3	14.23	1349680
		2022	40.45	165120	14.17	1372450
		2023	37.76	173445.6	14.09	1396734

Appendix 2

Descriptive Statistic

	AQI	GRDP	PWMI	FC
Mean	34.07750	618120.2	18.69045	3139752.
Median	32.31500	290585.7	17.68500	2806415.
Maximum	72.80000	2050456.	26.12000	6198732.
Minimum	18.20000	76907.40	13.47000	1150450.
Std. Dev.	11.14352	657489.7	4.104288	1901760.
Skewness	1.605065	1.038044	0.270139	0.180069
Kurtosis	6.238498	2.486771	1.547648	1.264604
Jarque-Bera	38.12014	8.384826	4.402247	5.759046
Probability	0.000000	0.015110	0.110679	0.056162
Sum	1499.410	27197287	822.3800	1.38E+08
Sum Sq. Dev.	5339.656	1.86E+13	724.3428	1.56E+14
Observations	44	44	44	44

Appendix 3

Common Effect Model (CEM)

Dependent Variable: AQI
Method: Panel Least Squares
Date: 07/29/24 Time: 02:42
Sample: 2013 2023
Periods included: 11
Cross-sections included: 4
Total panel (balanced) observations: 44

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	188.4656	62.33685	3.023341	0.0043
LOGGRDP	21.50627	3.953153	5.440282	0.0000
LOGPWMI	48.70269	14.96396	3.254666	0.0023
LOGFC	-38.63317	9.667191	-3.996319	0.0003
R-squared	0.638290	Mean dependent var		34.07750
Adjusted R-squared	0.611162	S.D. dependent var		11.14352
S.E. of regression	6.948754	Akaike info criterion		6.801510
Sum squared resid	1931.407	Schwarz criterion		6.963709
Log likelihood	-145.6332	Hannan-Quinn criter.		6.861661
F-statistic	23.52860	Durbin-Watson stat		2.019966
Prob(F-statistic)	0.000000			

Appendix 4

Fixed Effect Model (FEM)

Dependent Variable: AQI
Method: Panel Least Squares
Date: 07/29/24 Time: 02:43
Sample: 2013 2023
Periods included: 11
Cross-sections included: 4
Total panel (balanced) observations: 44

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1326.623	322.8722	-4.108817	0.0002
LOGGRDP	-22.84771	12.61114	-1.811708	0.0782
LOGPWMI	86.95988	21.38842	4.065746	0.0002
LOGFC	94.86417	28.71138	3.304062	0.0021

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.792623	Mean dependent var	34.07750
Adjusted R-squared	0.758995	S.D. dependent var	11.14352
S.E. of regression	5.470608	Akaike info criterion	6.381567
Sum squared resid	1107.319	Schwarz criterion	6.665415
Log likelihood	-133.3945	Hannan-Quinn criter.	6.486831
F-statistic	23.56990	Durbin-Watson stat	2.602275
Prob(F-statistic)	0.000000		

Appendix 5

Random Effect Model (REM)

Dependent Variable: AQI
Method: Panel EGLS (Cross-section random effects)
Date: 07/30/24 Time: 00:53
Sample: 2013 2023
Periods included: 11
Cross-sections included: 4
Total panel (balanced) observations: 44
Wallace and Hussain estimator of component variances

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	173.2874	73.47366	2.358497	0.0233
LOGGRDP	20.42248	4.955945	4.120804	0.0002
LOGPWTI	51.51108	15.44955	3.334148	0.0019
LOGFC	-37.22110	10.37947	-3.586030	0.0009
Effects Specification				
			S.D.	Rho
Cross-section random			2.632050	0.1301
Idiosyncratic random			6.806155	0.8699
Weighted Statistics				
R-squared	0.515922	Mean dependent var		20.95325
Adjusted R-squared	0.479616	S.D. dependent var		9.422029
S.E. of regression	6.796827	Sum squared resid		1847.874
F-statistic	14.21045	Durbin-Watson stat		2.093086
Prob(F-statistic)	0.000002			
Unweighted Statistics				
R-squared	0.635027	Mean dependent var		34.07750
Sum squared resid	1948.831	Durbin-Watson stat		1.984657

Appendix 6

Chow Test

Redundant Fixed Effects Tests

Equation: Untitled

Test cross-section fixed effects

Effects Test	Statistic	d.f.	Prob.
Cross-section F	9.178700	(3,37)	0.0001
Cross-section Chi-square	24.477501	3	0.0000

Cross-section fixed effects test equation:

Dependent Variable: AQI

Method: Panel Least Squares

Date: 07/30/24 Time: 00:44

Sample: 2013 2023

Periods included: 11

Cross-sections included: 4

Total panel (balanced) observations: 44

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	188.4656	62.33685	3.023341	0.0043
LOGGRDP	21.50627	3.953153	5.440282	0.0000
LOGPWT	48.70269	14.96396	3.254666	0.0023
LOGFC	-38.63317	9.667191	-3.996319	0.0003
R-squared	0.638290	Mean dependent var		34.07750
Adjusted R-squared	0.611162	S.D. dependent var		11.14352
S.E. of regression	6.948754	Akaike info criterion		6.801510
Sum squared resid	1931.407	Schwarz criterion		6.963709
Log likelihood	-145.6332	Hannan-Quinn criter.		6.861661
F-statistic	23.52860	Durbin-Watson stat		2.019966
Prob(F-statistic)	0.000000			

Appendix 7

Hausman Test

Correlated Random Effects - Hausman Test

Equation: Untitled

Test cross-section random effects

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	42.420904	3	0.0000

Cross-section random effects test comparisons:

Variable	Fixed	Random	Var(Diff.)	Prob.
LOGGRDP	0.000023	0.000018	0.000000	0.7204
LOGPWMI	0.097491	1.797858	1.368839	0.1461
LOGFC	0.000022	-0.000005	0.000000	0.0000

Cross-section random effects test equation:

Dependent Variable: AQI

Method: Panel Least Squares

Date: 07/30/24 Time: 00:58

Sample: 2013 2023

Periods included: 11

Cross-sections included: 4

Total panel (balanced) observations: 44

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-51.61308	20.71663	-2.491384	0.0173
LOGGRDP	2.32E-05	1.41E-05	1.650637	0.1073
LOGPWMI	0.097491	1.274238	0.076509	0.9394
LOGFC	2.21E-05	6.88E-06	3.217288	0.0027

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.805810	Mean dependent var	34.07750
Adjusted R-squared	0.774320	S.D. dependent var	11.14352
S.E. of regression	5.293823	Akaike info criterion	6.315869
Sum squared resid	1036.909	Schwarz criterion	6.599717
Log likelihood	-131.9491	Hannan-Quinn criter.	6.421133
F-statistic	25.58914	Durbin-Watson stat	2.455242
Prob(F-statistic)	0.000000		

Appendix 8

Multicollinearity Test

	LOGGRDP	LOGPWMI	LOGFC
LOGGRDP	1	0.8157448538671362	0.9570203154958604
LOGPWMI	0.8157448538671362	1	0.9197028141708988
LOGFC	0.9570203154958604	0.9197028141708988	1

Appendix 9

Heteroscedasticity Test

