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The Influence of GDP, Coal Exports, and Fossil Energy Consumption On Indonesian Air Pollution Reviewed From CO_2 Emissions

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Abstract. *Air is very vital for the survival of living things, therefore it is important to maintain air quality to avoid pollution. One of the causes of air pollution is high carbon dioxide emissions resulting from economic and industrial activities which are trapped in the atmosphere, causing a greenhouse gas effect. This research aims to determine the influence of GDP, coal exports and fossil energy consumption on air pollution in Indonesia in terms of $CO_{2\ emissions}$. This research also aims to test whether the Environmental Kuznet Curve (EKC) hypothesis applies in Indonesia. The type of data used in this research is secondary data in the form of quantitative data obtained from BPS, World Bank, etc. This research was conducted in all provinces in Indonesia. The data analysis technique used in this research is the Error Correction Model (ECM). The research results show that in the short and long term the variables GDP, coal exports and energy consumption simultaneously have a significant effect on the level of $CO_{2\ emissions}$. GDP in the short term and long term does not partially have a significant effect on the level of $CO_{2\ emissions}$. Meanwhile, GDP squared in the short term partially has no significant effect and in the long term it partially has a positive and significant effect. This shows that the EKC hypothesis does not apply in Indonesia. Coal exports in the short term and long term partially do not have a significant effect. Fossil energy consumption in the short term and long term partially has a positive and significant effect. Considering the importance of air for human life, it is necessary to pay attention to the factors that influence air pollution.*

Keywords *: GDP, Coal Exports, Fossil Energy Consumption, $CO_{2\ Emissions}$*

INTRODUCTION

Environmental quality is a key aspect in human life and the continuity of the earth's ecosystem. The issue of changes in environmental quality has become a complex global problem. Decreased environmental quality not only harms the ecosystem, but also has a direct impact on human health and biodiversity. One form of environmental damage experienced by developing countries such as Indonesia is caused by air pollution (Zuhri, 2014). Air is very vital for the survival of living things. Without air, living creatures would not be able to survive for long because air contains many gases that are needed, especially for breathing, namely oxygen gas. So air is considered a component that is needed at all times. Duki et al. (2003) states that clean air is free from everything that is not needed by humans, whether in the form

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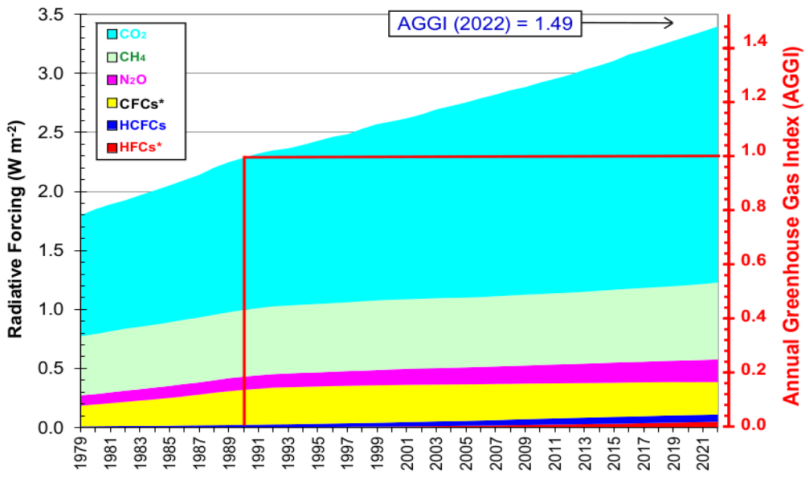
of substances or solid particles such as dust, dirt, or gases that are not needed because they will be harmful such as carbon dioxide, carbon monoxide and gas. -other dangerous gases. When the air that humans breathe is not clean, it can endanger human lung health (Ju, Park et al., 2014). In line with the development of technology and human civilization, air quality has also decreased due to air pollution.

The trend of decreasing air quality in several large cities in Indonesia has been seen in the last few decades as evidenced by monitoring data, especially greenhouse gas emissions which continue to increase. This problem has become a global concern, especially in Indonesia. The increase in air pollution can be caused by the increasing need for transportation and energy in line with the increase in population. Increased use of transportation and energy consumption will increase air pollution, especially carbon dioxide (CO_2) emissions which come from burning fossil fuels which then have an impact on climate and temperature changes.

In the UNFCCC (*United Nations Framework Convention on Climate Change*) conference which was attended by 190 countries, it was also discussed that the main problem of climate and temperature change was caused by high concentrations of Green House Gases (GHG). The EPA report (2017) states that GHGs are gases that are trapped by heat in the atmosphere and can cause an increase in the earth's average temperature resulting in global warming. Greenhouse gases have a function like glass in a greenhouse, namely transmitting sunlight but capturing heat energy from within. The greater the concentration of greenhouse gases in the atmosphere, the greater the heat energy trapped in the earth (Latuconsina, 2010). There are 6 GHG compounds agreed to in the Kyoto Protocol, namely carbon dioxide (CO_2), methane



(CH_4), dinitrogenoxide (N_2O), *chlorofluoro-carbon* (CFC), *hydro-fluoro-carbon* (HFCs), and *sulfur hexafluoride* (SF_6).

Source: *Global Monitoring Laboratory, 2023*

Figure 1. Annual Greenhouse Gas Index for the period 1979-2022

Based on Figure 1, the greenhouse gas that is the largest contributor to the *Annual Greenhouse Gas Index* (AGGI) in terms of quantity and rate of increase is carbon dioxide (CO_2). The direct warming effect of greenhouse gases produced by humans has increased 49% above the *baseline year* with an AGGI value of 1.49 W/m^2 at the end of 2022. This increase was contributed by CO_2 by 80% and was followed by other greenhouse gas compounds. (Greenhouse Gas Bulletin, 2022). So, when quantifying air pollution, it is represented by $CO_{2\ emission\ data}$. In addition, $CO_{2\ emissions}$ are considered to represent aspects of air pollution because the emergence of air pollution is usually characterized by emissions of carbon dioxide gas (CO_2). These emissions can come from industry, transportation, agriculture and forestry (Gupito & Kodoatie, 2013). CO_2 itself is a GHG compound that contributes significantly to the greenhouse effect because of its ability to absorb and emit heat radiation in the atmosphere.

Emissions are the release of various substances, gases, particles and energy into the atmosphere, so $CO_{2\ emissions}$ refer to the process of releasing carbon dioxide (CO2) into the environment which can have serious negative impacts. According to the *Global Carbon Project* report (2023), Indonesia is in 7th position globally as the country producing the highest $CO_{2\ emissions}$ in 2022. The main contribution to the amount of $CO_{2\ emissions}$ in the atmosphere comes from burning fossil fuels, namely oil, coal and gas. earth . Increasing CO_2 emissions are directly related to economic growth and economic development because $CO_{2\ emissions}$ result from industrial development and the level of energy consumption of a country (Hossain, 2012).

CO2 emissions can come from a variety of different sources. The following is a classification of CO2 emission pollutant factors based on the source:

1. Burning Fossil Fuels
   a. Power plants

      The process of burning coal, oil, and natural gas in power plants to produce energy.
   b. Transportation

      Emissions from motorized vehicles (cars, trucks, buses, airplanes, ships) that use fossil fuels such as gasoline and diesel.

c. Industry

The use of fossil fuels in industrial processes such as making steel, cement, chemicals, and others.

2. Non-Energy Industrial Processes:

a. Manufacturing Process

The process of making products from metal, plastic, glass and other materials that uses energy from fossil fuels and produces CO2 as a byproduct.

b. Cement Making

The calcination process of cement clinker (raw material for cement) produces CO2 as a byproduct.

3. Deforestation and Land Use Change

Shrinking forests and changing land use to plantations or fields can release CO2 that was previously stored in biomass.

4. Natural and Anthropogenic Processes

a. Natural Process

Plant and animal respiration processes, as well as the decomposition of organic matter, release CO2 into the atmosphere.

b. Anthropogenic Processes

Forest burning, land use, and solid waste containing organic carbon.

5. Energy Use

a. Household Activities

Use of fossil fuels in households for cooking, heating and electricity.

b. Commercial and Institutional**: Energy use in commercial and institutional buildings for lighting, cooling, and other purposes.

6. Waste Management

Decomposition of organic waste in landfills, including the production of methane (CH4) which is then oxidized to CO2.

7. Volcanism

Volcanic eruptions that release CO2 into the atmosphere.

These factors indicate various sources of CO2 emissions that must be managed and reduced to reduce their impact on global climate change. Handling CO2 emissions requires a comprehensive and integrative approach involving various economic and technological sectors to achieve global emissions reduction targets.

Year	CO2 emissions (tons)	Percentage	GDP Per Capita (US$)	Percentage
2012	515954180	-	3668.212	-
2013	489055100	-5.21%	3602.886	-1.78%
2014	487889950	-0.24%	3476.625	-3.50%
2015	539149250	10.51%	3322,582	-4.43%
2016	540085600	0.17%	3558.819	7.11%
2017	556944200	3.12%	3839.785	7.89%
2018	594101400	6.67%	3902.662	1.64%
2019	650905900	9.56%	4151.228	6.37%
2020	605984600	-6.90%	3895.618	-6.16%
2021	615923400	1.64%	4334.216	11.26%
2022	728883260	18.34%	4787,999	10.47%

Table 1. CO2 Emissions and GDP Per Capita in Indonesia 2012-2022

Source: *World Bank and Central Statistics Agency (data processed),* 2023

In table 1, from 2012 to 2022, the level of $CO_{2\ emissions}$ in Indonesia experienced fluctuations which tended to show an increasing trend, which was also followed by the level of GDP per capita in Indonesia. When the pandemic took place, namely in 2020, the *Covid-19 pandemic* had driven a decrease in carbon dioxide (CO_2) emissions by 6.90% and this decrease was followed by Indonesia's GDP per capita level which decreased by 6.16% in 2020. Then during the pandemic Covid-19 has subsided and the economy has improved again, causing Indonesia's GDP per capita to increase to 10.47% in 2022. This increase was also followed by $CO_{2\ emission\ levels}$ which increased by quite a large figure, namely 18.34% in the same year.

The significant influence between GDP and $CO_{2\ emissions}$ is possible because along with economic growth through Gross Domestic Product (GDP), industrial activity and consumption will increase, which then produces more $CO_{2\ emissions}$. Economic development increases industrial activity, domestic transportation, and can even cause forest fires in the dry season which have exceeded the environmental carrying capacity and can no longer be neutralized and can pollute the surrounding nature, resulting in a decline in environmental quality (Princiotta,

FT, 1991). The decline in environmental quality in question is a decline in environmental quality due to air pollution caused by carbon dioxide emissions ($CO_{2\ emissions}$) which continue to increase. The increase in CO2 emissions is driven by increasingly large production processes. The more the industry uses machines that do not have environmentally friendly technology, the more the industry will become the biggest contributor to the decline in environmental quality (Hutabarat, 2010). This means that increasing industrialization can cause pollution in the country to increase. This statement is supported by research results from Karimi et al. (2022) which shows that GDP and industry have a significant and positive long-term relationship with $CO_{2\ emissions}$ in Indonesia. This means that increasing GDP and industrial activities will also increase the level of $CO_{2\ emissions}$ which will then have an impact on air pollution. As development increases, various externalities emerge, such as industries that use chemicals for the combustion process, environmentally unfriendly technology, etc. which will ultimately impact poor air quality and environmental damage. (Kurniarahma et al., 2020)

Various business sectors that build Indonesia's GDP have both direct and indirect impacts on the environment. Apart from the industrial sector, transportation has a direct relationship to air pollution because there is *residue* or waste that goes directly into the air and has the potential to pollute the environment. The increasing number of transportation services will cause the number of vehicles to increase very rapidly, especially in urban areas, which has an impact on increasing environmental pollution, especially air pollution (Helda et al., 2018). The relationship between economic growth and $CO_{2\ emissions}$ is known as *the Environmental Kuznets Curve* (EKC), where significant environmental degradation occurs in developing countries with low per capita income. Because the large growth of industrialization focuses on advancing the economy and absorbing the workforce. This theory states that the level of environmental damage will increase along with economic development and at a certain point (*turning point*) the level of environmental damage will decrease along with increasing economic growth which is characterized by an inverted U-curve (Yustisia, 2014). This means that increasing economic growth can cause pollution in developing countries to increase.

The Environmental Kuznet Curve (EKC) hypothesis was first proposed by Kuznet in 1955. In the EKC hypothesis, it is explained that there is a relationship between per capita income and environmental damage. In the initial stage, per capita income was accompanied by environmental damage. Then, this increase reaches a certain point or turning point, where environmental damage is at its highest and does not increase, while per capita income continues

to increase. Then in the final stage there is an increase in environmental quality where there is a reduction in environmental damage and an increase in per capita income (Arifin et al., 2023).

Good economic growth must be supported by the foreign trade sector, both exports and imports. Exports play an important role in a country's economic activities because they will generate foreign exchange which can be used to finance imports of raw materials and capital goods needed in the production process which can later form added value. The aggregate added value produced by all production units in the economy is the value of Gross Domestic Product (GDP). Therefore, exports can be added value to increase a country's economic growth (Nurmawaddah, 2019). However, higher export activities will lead to increased economic growth which will ultimately increase carbon dioxide (CO_2) emissions as a result of production and transportation activities (Rahman Mohammad Mafizur, 2017). Exporting countries experience a greater impact of environmental pollution due to exploiting resources for export activities because exploitation by exporting countries will result in depletion of natural resources and environmental damage (Suparmoko, 2002).

Table 2 . Oil and Gas and Non-Oil and Gas Sectors 2017-2022

Year	2017	2018	2019	2020	2021	2022
Oil and Gas	15,744.4	17,171.7	11,789.3	8,251.1	12,247.4	15,998.2
Non Oil and Gas	153,083.8	162,841.0	155,893.7	154,940.7	219,362.1	275,906.1

From BPS data, the dominance of Indonesia's exports in the last 5 years was contributed by non-oil and gas, amounting to 94.51% of Indonesia's total exports. One of the main non-oil and gas export commodities is coal. Until 2020, coal has become the main foreign exchange earner from the mining sub-sector with a value of US$ 14 billion (Azizah & Soelistyo, 2022). Most of Indonesia's coal production is aimed at the export market, making coal one of Indonesia's leading export commodities. The results of a joint study conducted by the Ministry of Finance (Kemenkeu) and the Indonesia Eximbank Institute (2019) placed coal in first position of Indonesia's ten leading commodities. In fact, in 2019, according to the IEA, Indonesia was in first place as the world's largest coal exporter.

Total export volume rock Indonesian coal in 2022 will reach 473 million tons, consisting of from rock coals thermal / lignite 469 million tons and rock coals metallurgy 4 million tons. Rock coals thermal And lignite generally used as source energy generator

electricity , meanwhile rock coals metallurgy For material standard make steel . Coal exports can encourage more intensive mining activities in exporting countries. The coal mining process and related activities, such as clearing mining land, can cause deforestation and changes in land use. This can result in the release of carbon from forests and soil, which can also increase CO 2 emissions in exporting countries. The process of transporting coal from an exporting country to a receiving country involves the use of fuel for ships, trucks or trains. This transportation can also produce additional CO 2 emissions . Coal loading at ports can also involve the use of machinery and equipment that uses fossil fuels, which will contribute to CO 2 emissions .

Coal mining activities also cause air pollution, because this is caused by the coal burning process. T he level of coal production in Indonesia is in line with the level of CO 2 emissions , which means that increasing the amount of coal produced will increase the level of CO 2 emissions in Indonesia. This is because the coal mining process produces gas that looks brown in the air and pollution that forms and causes acid rain and other types of pollution that can make the air in the sky dirty. Apart from that, the dust resulting from the coal removal process is also very dangerous for health. Because it can cause respiratory problems, respiratory infections, and if you continue to breathe this air in the long term it will cause lung cancer.

Activities that can damage the environment due to coal mining activities also occur during the extraction or exploitation of coal which has an impact on air pollution due to coal dust particles, and can even cause erosion, heavy metal pollution, river shallowing and the formation of acid mine water (AT). The temporary storage process of coal can also trigger air, water and soil pollution. Meanwhile, the process of burning coal which is used as an energy source causes the release of harmful substances into the air in the form of CO, As, Se, Hg and Nox, CO2 and SO2 gases. This kind of condition will have an impact on environmental damage and can also endanger health (Setiawan, et al., 2018).

In the industrial sector in Indonesia, coal is one of the main sources of fuel, but the use of coal fuel can also affect air pollution because the use of coal fuel can produce emissions. According to *Greenpeace* research , worrying air conditions are caused by the presence of coal-fired power plants (PLTU) as a factor that contributes to the air pollution problem (Ruhiat et al., 2019). PLTUs feel free because of weak regulations and implementation of emission standards for main pollutants, which is indicated by the fact that PLTUs in Indonesia are allowed to emit very high SO2 emissions compared to China and India (Ruhiat, et al., 2019). Apart from the effects of the PLTU, research conducted by Santoso, et al. shows that Jakarta and Semarang are examples of areas affected by air pollution due to economic growth from

industrial activities. Research in these two regions shows that there is a correlation between economic parameters, namely the Gross Regional Domestic Product (GRDP) variable and Aerosol Optical Thickness (AOT) as a pollution parameter. Where industrial areas in DKI Jakarta are experiencing spatial expansion and Semarang is experiencing a fairly rapid expansion of industrial areas (Santoso, et al., 2018). Currently there are dozens of Coal Steam Power Plants (PLTU) scattered and operating in Indonesia, releasing millions of tons of pollution every year and coal is used as the main fuel in steam power plants (PLTU). In 2021, the volume of coal used for PLTU will reach 112.13 million tons, while in 2020 it will reach 104.83 million tons. From time to time, the PLTU pollutes the air with toxic pollutants, including mercury, lead, arsenic, cadmium and fine but toxic particles such as ozone and heavy metals, which can infiltrate people's lungs. These fine particles penetrate into the lungs and bloodstream, causing various health problems. Apart from PLTU, the smelting or metallurgical industry and the cement industry also use coal as the main fuel. In July 2022, the volume of coal used for the smelting industry will reach 18.13 million tons, while for the cement industry it will reach 5.86 million tons, and in 2021 it will reach 4.45 million tons. Therefore, coal is still Indonesia's mainstay energy source until *renewable energy* can reach the expected portion according to the national energy mix target. For this reason, the use of coal must also be taken seriously to reduce its negative impact on the environment, health and air quality in Indonesia (Trianisa et al., 2019).

Coal exports have some influence on the air of the exporting country, depending on a number of factors including the technology used in mining and transportation, and the environmental policies implemented. The following are some of the main impacts of coal exports on the air of exporting countries:

1. Local Air Pollution

   The process of mining, processing and transporting coal can cause local air pollution around mines and transportation routes. Coal dust, gas emissions from heavy equipment and transportation vehicles, and coal manipulation at ports are the main sources of local air pollution.

2. Greenhouse Gas Emissions

   The use of coal as an energy source produces greenhouse gas emissions such as carbon dioxide (CO2). Exporting countries that rely on coal exports for their primary economic income can contribute to increased global emissions that contribute to climate change.

3. Public Health Impact

Air pollution from coal can have negative impacts on the health of local communities, including respiratory problems, heart disease, and other health problems. This is especially true in areas directly exposed to coal emissions from mining and transportation.

4. Natural resource management

   Exploitation of coal for export can cause significant environmental degradation, including damage to forests, land and water. Unsustainable mining practices can result in long-term ecological losses that affect the balance of local ecosystems.

5. Economics and Sustainable Development

   Although coal exports provide significant economic income for exporting countries, reliance on coal can also create economic dependency that is vulnerable to fluctuations in commodity prices and global demand. This can affect the long-term economic sustainability of these countries.

To reduce these negative impacts, it is important to implement cleaner technologies in coal mining and use, as well as adopt policies that promote economic diversification and the transition to cleaner, more sustainable energy sources.

Apart from that, energy also plays an important role in economic development in both developed and developing countries (Al-Mulali, 2011). Ashgar (2008) states that energy is the main source of economic growth because many production and consumption activities involve energy as a basic input. From a physical perspective, energy use drives economic productivity and industrial growth and is central to modern economic operations (Carfora et al., 2019). In this research, the energy consumption used refers to energy consumption that has a polluting impact on the environment, especially air pollution in Indonesia, namely the use of fossil fuels such as petroleum, natural gas and coal as energy sources. Most studies state that the use of fossil energy can encourage economic growth, but resources that use fossil energy ultimately contribute to the resulting carbon emissions (Danish et al., 2019). Problems related to the energy crisis and environmental pollution due to the use of fossil energy have an impact on increasing attention to fossil energy sources due to concerns about unstable fossil fuel prices, dependence on increasingly limited fossil energy sources, and environmental problems (Apergis & Payne, 2010).

Table 3 . Fossil Energy Consumption Mix (TWh)

Year	Crude oil	Natural gas	Coal	Total
2012	892.108	429,712	505,706	1827,526
2013	862,608	445,055	440,756	1748.420
2014	859,077	440,418	469,070	1768,565
2015	819.179	457,556	532,274	1809.009
2016	790,219	446,308	544,316	1780.842
2017	847,520	432,153	566.109	1845,782
2018	874,400	445,286	655,729	1975.415
2019	852,238	439,988	801.231	2093,457
2020	750,039	375,176	765,380	1890,595
2021	780,862	370,807	763,230	1914,898
2022	851,199	370,150	1216.511	2437.859

Source: Statistical Review of World Energy (2023)

The increasing use of energy indicates that industry in the country is experiencing an increase. However, on the other hand, it will also have an impact on environmental degradation due to economic growth because energy use has an impact on the environment, both in terms of the effects of excessive use of natural resources and the pollutants produced (Rahman , 2017). The use or consumption of energy is a means to drive the industrialization of the economy and is a means of accumulating development capital, either complementary or substitute, to produce outputs in the economy. Sectorally, the use of energy resources is divided into several sectors, namely the transportation sector, industry, commercial services, household sector and other sectors (Tang 2017).

Table 4 . Energy Consumption Mix by Sector (percent)

Year	Industry	Transportation	Household	Commercial	Other
2012	39.95	40.26	11.3	4.37	4.12
2013	31.92	45.57	13.31	5.06	4.15
2014	32.25	44.94	13.95	5.1	3.76
2015	32.11	45.48	14.56	4.99	2.86
2016	30.09	46.22	15.48	5.42	2.69
2017	29.77	47.14	15.57	5.32	2.2
2018	33.04	46.08	14.44	4.87	1.57
2019	36.59	43.74	13.81	4.68	1.18
2020	34.37	43.23	16.32	4.85	1.22

2021	31.28	45.69	16.74	5.02	1.27
2022	43.21	38.49	12.97	4.34	0.99

Source: Handbook of Energy & Economic Statistics of Indonesia, 2023

Not only in the industrial sector, energy use from the transportation sector also has an effect on increasing CO 2 emissions , this can be seen from the function of vehicles as the lifeblood of economic growth where economic growth in developing countries can increase due to the existence of transportation services (Mikayilov et al., 2017) . Transportation is the main sector causing air pollution in big cities in Indonesia. The high growth in CO 2 emissions from the transportation sector is caused by the high growth of motorized vehicles in line with increasing population and economic growth. The Department of Transportation noted that motor vehicle growth reached around 12% per year. So it is not surprising that the transportation sector contributes a large amount of CO 2 emissions, namely more than 20% of total CO 2 emissions (Gupio, K, R., & Kodoatie, J., M. 2012). Sectorally, the use of energy resources is divided into several sectors, namely the transportation sector, industry, agriculture, commercial services, household sector and other sectors (Tang 2017). Indonesia currently still depends on the consumption of fossil energy such as petroleum, natural gas and coal . There will be a big impact from the world's dependence, including Indonesia's, on fossil fuels on the environment, such as GHG emissions, air pollution and global warming. Shocks in national energy needs may occur due to the non-renewable nature of fossil energy. These energy resources will run out within a certain period of time, even though the demand for energy is always increasing (Triatmojo, 2013). In particular, CO 2 emissions are produced from burning fossil fuels, so the increasing demand for fossil fuels as an energy source for electricity generation, industry and transportation causes CO2 emission levels to increase. The high level of CO 2 emissions will result in more polluted air (Hossain, 2012).

Sustainable Development Goals (SDGs) are sustainable development throughout the world until 2030 which have formed a series of goals set by the UN in 2015. The SDGs goals include 17 targets covering social, economic and environmental aspects which aim to promote sustainable development and reduce disparities between countries and between generations. Its implementation in Indonesia involves many parties, including the government, non-governmental organizations, the private sector and the general public. Kusumaningrum and Rianto (2020) highlight the implementation of SDGs in Indonesia and show that the Indonesian government has taken action to encourage the implementation of SDGs. The Indonesian government has published the National Action Plan for the Implementation of the Sustainable

Development Goals which contains national strategies and policies to achieve the SDGs goals. Apart from that, many non-governmental organizations and non-governmental organizations in Indonesia are also involved in efforts to implement SDGs, including in the environmental and health sectors. In Indonesia, implementing SDGs has become a government priority in order to achieve sustainable development. Various steps have been taken to achieve SDGs goals, such as programs to improve the quality of education and health, increase access and quality of clean water and sanitation, increase access to electricity and develop renewable energy, reduce poverty, and protect the environment and biodiversity. However, there are still many challenges that must be faced in achieving the SDGs goals in Indonesia, such as a high percentage of inequality, poverty levels that are still high in regions, and environmental challenges such as deforestation and water and air pollution. Therefore, sustainable and integrated efforts need to be made to effectively achieve the SDGs goals in Indonesia

Following is a number of example implementation of SDGs in reduce pollution air :

1. Supervision And Enforcement Law :
   Increase supervision And enforcement law to sources pollution air , like vehicle motor , generator electricity , and factories , for reduce CO2 emissions and pollutant other .
2. Application SDGs Theme Healthy and Prosperous Life :
   Apply 3rd SDGs theme with focus on handling pollution air in Jakarta. Approach chemistry green can become friendly solution environment with apply principles chemistry green , like prevention waste , use material safe chemicals , and efficiency energy .
3. Monitoring Various Source Air Pollutants :
   Do monitoring various source polluter air in Indonesia, incl activity mountain fire , fire forest , and burning material burn fossil , for monitor And reduce emission pollutant .
4. ALBI prototype for Reduce Vehicle Motorized :
   Develop ALBI prototype that can replace tree And reduce CO2 emissions from vehicle motorized , as well support achievements objective development sustainability (TPB) or 3rd SDGs (life Healthy And prosperous), 7th (energy clean And affordable), 9th (industry , innovation , and infrastructure), 11th (city And sustainable settlements) , 13th (handling change climate), and 15th goal (ecosystem land).

The urgency of this research lies in a deep understanding of how GDP, coal exports and fossil energy consumption affect $CO_{2\ emissions}$ which will then influence air pollution in Indonesia. GDP is closely related to $CO_{2\ emissions}$ because based on the EKC hypothesis

increasing economic growth will be followed by air pollution originating from $CO_{2\ emissions}$. Increasingly massive coal mining activities and high consumption of fossil energy can cause deforestation which can cause carbon absorption by nature to decrease and increase $CO_{2\ emissions}$ which in turn will also result in air pollution. So this research is important to analyze further the influence of GDP, coal exports and energy consumption on $CO_{2\ emissions}$ in Indonesia, so that it can provide information for policy makers to formulate and implement policies for sustainable growth , as well as minimizing detrimental impacts on air quality. in Indonesia.

RESEARCH METHODS

The approach in this research is a quantitative approach with an associative type of research. Quantitative methods are used because the data used is in the form of numbers and data processing is carried out using statistical analysis. Quantitative research is carried out by collecting data in the form of numbers, which are then processed and analyzed to obtain scientific information. Meanwhile, this associative quantitative approach is used to determine the relationship between two or more variables (According to Yuliarmi & Marhaeni, 2019). This research analyzes variables using multiple linear regression techniques. In this research, GDP (X1), Coal Exports (X2), and Fossil Energy Consumption (X3) are used as measuring tools to determine the factors that influence CO_2 (Y) emissions in Indonesia.

RESULTS AND DISCUSSION

This research was conducted to analyze the influence of GDP, coal exports and fossil energy consumption on air pollution in Indonesia in terms of $CO_{2\ emissions}$. In this chapter, the research results are presented according to the research methods used. The estimation results will be discussed starting from the stationarity test, long-term OLS test, cointegration test, and ECM (*Error Correction Model*) test and classical assumption test. After everything has been tested, the next step is to explain the interpretation of hypothesis tests such as the F test and t test.

Descriptive Analysis

The following are the results of descriptive analysis processed with the Eviews10 application. This descriptive analysis will highlight several things such as Minimum, Maximum, Average (Mean), and Standard Deviation.

Table 5. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
$_2$ Emissions (Y)	36	123878	728883	370873.8	165298.7
GDP (X1)	36	440.37	4787.99	2007.76	1441.03
GDP Squared (X12)	36	193927.8	22924937	6050021	6874398
Coal Exports (X2)	36	14733	381384	159416.4	138104.4
Energy Consumption Fossil (X3)	36	451.94	2347.85	1323.09	527.31

$_2$ emission level has an average (mean) value of 370873.8 thousand tons. The CO $_2$ emission level has a standard deviation value of 165298.7. The lowest (minimum) CO $_2$ emission level was 123878 thousand tons which occurred in 1987 and the highest (maximum) CO $_2$ emission level in Indonesia was 728883 thousand tons which occurred in 2022. These results show that the CO 2 emission level the highest is in 2022.

Indonesia's GDP level has an average of 2007.76 US$. Indonesia's GDP level has a standard deviation value of 1441.03. The highest GDP level was 4787.99 US$ in 2022 and the lowest was 440.37 US$ in 1987. These results show that Indonesia's GDP level is the highest in 2022. The level of coal exports has an average (mean) value of 159416.4 thousand tons. The level of coal exports has a standard deviation value of 138104.4. The lowest (minimum) level of coal exports was 14733 thousand tons which occurred in 1987 and the highest (maximum) level of coal exports in Indonesia was 381384 thousand tons which occurred in 2013. These results show that the level of coal exports The highest was in 2013. The level of fossil energy consumption had an average value of 1323.09 TwH. The level of fossil energy consumption has a standard deviation value of 527.31. The lowest level of fossil energy consumption was 451.94 TwH which occurred in 1987 and the highest level of fossil energy consumption in Indonesia was 2437.86 TwH which occurred in 2022. These results indicate that the highest level of fossil energy consumption was in in 2022.

Stationarity Test

The unit root test for the variables to be tested can be carried out using the ADF (*Augmented Dickey-Fuller*) test using a significance level of 5%. To find out whether the data is stationary or not, you can look at the probability value of the t-statistic. If the t-statistical probability value is smaller than the significance level α (0.05) then H0 is rejected, meaning that the data used is stationary or does not contain a unit root. And conversely, if the probability value is greater than the significance α (0.05), then the data is not stationary.

Table 6. Level Level *Augmented Dickey-Fuller (ADF)* Unit Root Test Results

Variable	Prob.	Interpretation
2 Emissions (Y)	0.996	Not Stationary
GDP (X1)	0.994	Not Stationary
GDP Squared (X12)	0.999	Not Stationary
Coal Exports (X2)	0.938	Not Stationary
Fossil Energy Consumption (X3)	0.879	Not Stationary

Data that is not yet stationary at the level will later be tested on the degree of integration to achieve stationary, either at the *first difference* or *second difference level* . As for the results of the stationary test as in Table 6 , it can be concluded that at the level level, there are no variables that are fulfilled at a probability of 5% or below the significance of α (0.05) which indicates that H 0 is accepted or the data is not stationary at the level level. So all variables must be tested again using the *1st difference level* or degree of integration test and all variables must be tested simultaneously with a significance result of 5% or 0.05.

The degree of integration test is the same as the *root test* , namely to find out whether the data is stationary or not. In the degree of integration test, it will be tested at *the first difference* or *second difference level* to see the stationarity of the data. The test criteria are if the t-statistical probability is smaller than the significance of α (0.05), then the data is stationary or rejects H0 and accepts H1 . The following is a table of the degree of integration test.

Table 7. *Augmented Dickey-Fuller* (ADF) Integration Degree Test Results Level *1st Difference*

Variable	Prob.	Interpretation
2 Emissions (Y)	0.0000	Stationary Data

GDP (X1)	0.0015	Stationary Data
GDP Squared (X12)	0.0084	Stationary Data
Coal Exports (X2)	0.0004	Stationary Data
Fossil Energy Consumption (X3)	0.0000	Stationary Data

Table 7 shows that at the *1st Difference level* all variables have probability values smaller than significance α (0.05) which means that the variable being tested is stationary or significant at the *1st difference level* so that the research can proceed to the next stage.

Cointegration Test

This research uses a cointegration test with the *Engle-Granger method* which detects cointegration through a stationary test on the residual value (*error*) of the regression results. In order to detect cointegration, an *Augmented Dickey Fuller* (ADF) test is carried out on the residuals from the regression results between variables, then the ADF test will be carried out on the residual results using a real level of 5%. This test is based on the t-statistical probability value. If the t-statistical probability value is smaller than the significance level α (0.05), then H0 is rejected, so it can be said that there is cointegration or a long-term relationship between variables.

Table 8. *Augmented Dickey-Fuller* (ADF) Cointegration Test Results

Levels

Variable	t-Stat	Prob.	Decision
ECT	-3.548436	0.0123	Stationary

After carrying out the *root test* or unit root test with the *Augmented Dickey Fuller* (ADF) test, it is known that at the level of the residual *level* the regression between variables has a probability value of 0.0123 < α = 0.05, so H0 $_{is}$ rejected. This means that there is cointegration or there is a short-term and long-term relationship between these variables.

Long Term Model with *Ordinary Least Square* (OLS)

Based on the regression results in table 8 , the long-term equation model using *Ordinary Least Square* (OLS) can be represented in the following equation:

$Y_t = 37082.78 - 18.848 \text{ X } 1t + 0.010X_{1t}^2 - 0.014$

Results Term Model Regression Long with Models

model using *Ordinary Least Squares* (OLS) can be represented in the following equation:

$Y_t = 37082.78 - 18.848 \text{ X } 1t + 0.010X_{1t}^2 - 0.014$

In the long-term model, it can be seen that the GDP value (X1) has an insignificant effect at a probability of 0.3186 > 0.05, while the GDP Squared value has a positive and significant effect on Indonesia's $CO_{2\ \text{emissions}}$ by comparing the probability of 0.0004 < 5%. The coal export variable (X2) has an insignificant effect at the probability value of 0.8846 > 5% on $CO_{2\ \text{emissions}}$. And the fossil energy consumption variable (X3) has a positive and significant influence on $CO_{2\ \text{emissions}}$ with a probability value of 0.000 < 5%.

Short Term Model with *Error Correction Model* (ECM)

Two tests that have been carried out previously, namely the stationarity test and the cointegration test, show that the data is stationary at the *first difference level* and the data is cointegrated. Next is to carry out regression using the *Error Correction Model* (ECM) method. The short-term model in *the Error Correction Model* in this research is as follows:

$DY_t = \beta 0 + \beta_1 DX_{1t} + \beta_2 DX_{1t}^2 + \beta_3 DX_{2t} + \beta_4 DX_{3t} + ECT_{t-1} + \mu_t$ …….…..…. (4.2)

Results ECM regression , shows that only variables in the short term linear GDP (X1) and quadratic GDP (X12) have no significant effect at α (0.05) or 5% significance. Meanwhile, the coal export variable (X2) has no significant effect with a probability of 0.0675 > 5%, and the fossil energy consumption variable (X3) has a positive and significant effect with a probability of 0.0000 < 5%. on the level of $CO_{2\ \text{emissions}}$ in Indonesia.

The ECT(-1) (*Error Correction Term*) coefficient in the ECM equation is the *lag error value* for $CO_{2\ \text{emissions}}$ in the previous quarter. The ECT coefficient value is -0.522031 and has a significant probability of 0.0037 with a significance of α (0.05) 5%. This means that ECT(-1) has a negative and significant effect on $CO_{2\ \text{emissions}}$, which means the ECM model used in this research is valid. From table 4.6 it can be analyzed that the F-statistic probability number is 0.0000 < 0.05, so it can be concluded that the variables GDP, GDP squared, coal exports and

fossil energy consumption simultaneously have a significant influence on $CO_{2\ emissions}$ in the short term .

Classic assumption test

1) Normality test

The aim of the normality test is to see whether the data in the form of the dependent and independent variables under study has a normal distribution or not. One method for examining whether data is normally distributed or not is using *the Jarque-Bera* (JB) test. A regression data model is said to be good if the data used is normally distributed. If the data does not have a normal distribution for large data then the Central Limit Theorem can be *used the Jarque Bera* probability value to the normality histogram. If the probability value is > 0.05, it means the data is normally distributed. Briefly, the normality test hypothesis is: H0: Data is normally distributed H_1 : Data is not normally distributed. The following are the results of the normality test using *Jarque Bera* (JB).

results of the *Jarque Bera* (JB) normality test have a probability value of 0.903380 > 0.05, and a decision was made to accept H0 $_{and}$ reject H1 , which means that in this study the data is normally distributed and further tests can be carried out.

2) Multicollinearity Test

To find out whether the regression model has a relationship between the independent variables used in a study, namely the multicollinearity test. A regression model that is said to be good certainly does not have a relationship between the independent variables. If there is a correlation between the dependent variables then there is a multicollinearity problem. To see whether or not there is a multicollinearity problem in this research, you can use the correlation coefficient value or VIF value. If the VIF is less than 10 then a regression model can be said to be free from multicollinearity problems. And if the VIF value is more than 10, it means that there is a multicollinearity problem in a regression model. Below are the results of the multicollinearity test.

The number shown by *the centered* VIF in variable X1 is 5.198, X12 is 6.713, X2 is 1.071 and X3 is 1.245. All VIF values above show numbers less than 10. This can be concluded if the data used does not have multicollinearity problems between the independent variables in the model or H0 is accepted.

3) Heteroscedasticity Test

The heteroscedasticity test is a test to see whether there are deviations in the assumptions of the regression model used. This deviation is caused by unequal variance of a residual for all observations in the regression model. The test criteria are that the *Obs*R-squared* probability number is greater than the significance level of 5% (0.05), so there is no heteroscedasticity problem or accept H0. The following are the results of the heteroscedasticity test using *Breusch Pagan Godfrey* .

The *Obs*R-squared* number is 1.094990 with a *Chi-Square probability number* of 0.9545 and this number is above 0.05, which means accepting H0 or the conclusion is that there is no heteroscedasticity problem in this research.

4) Autocorrelation Test

Autocorrelation is defined as the correlation between observations measured based on a time series in a regression model, or in other words, one observation is influenced by *the error* from the previous observation. As a result of autocorrelation in the regression model, the regression coefficient obtained becomes inefficient, meaning the error rate becomes very large and the regression coefficient becomes unstable (Gujarati, 2004). A good test model is free from autocorrelation. One way to see whether there is an autocorrelation problem in a model or not is to use the *Breusch Pagan-Godfrey Serial Correlation LM Test method* . Through this method the author can see whether the data experiences symptoms of autocorrelation or not.

From the results of the Autocorrelation Test that has been carried out, *Prob. The Chi-Square* (2) shown is 0.2371, which means this number is more than α (0.05). This indicates that the regression model in this study does not experience symptoms of autocorrelation.

Testing the Effect of GDP, Squared GDP, Coal Exports, and Fossil Energy Consumption on Indonesia 's CO_2 Emissions (F Test)

The F test aims to find out whether all the independent or independent variables included in the model have a joint influence on the dependent or dependent variable (Ghozali, 2013). The following is the F test for each independent variable on Indonesia's CO_2 emissions :

1) The Effect of GDP, GDP Squared, Coal Exports, and Fossil Energy Consumption on Indonesia's CO_2 Emissions in the Short Term

The F-statistic probability value in short-term regression is 0.00000. The F-statistic probability value is 0.00000 < 5% which means this research model is significant. Based on the F test results, the $_{\text{calculated F value}}$ is 23.378 with a total of 35 observations, k = 4, df = nk = 31(4);(31).), α = 0.05, so the $F_{\text{table value}}$ is 2.68. Because F_{count} (23.378) > F_{table} (2.68) and the probability value < 0.05, H0 is rejected and H1 is accepted, which means that GDP, GDP squared, coal exports and fossil energy consumption simultaneously have a significant effect on $CO_{2\ \text{emissions}}$ from 1987 to 2022. It is known that the coefficient of determination R Square is 0.801225 or 80.12 percent. So the magnitude of the influence of the variables GDP, GDP squared, coal exports and fossil energy consumption on Indonesia's $CO_{2\ \text{emissions}}$ is 80.12 percent. Meanwhile, 19.88 percent is influenced by other variables outside the model.

2) The Effect of GDP, GDP Squared, Coal Exports, and Fossil Energy Consumption on Indonesia's $CO_{2\ \text{Emissions}}$ in the Long Term

The F-statistic probability value in long-term regression is 0.00000. The probability value of F-statistics is 0.00000 < 5%, which means that this research model is significant. Based on the results of the F test, the $_{\text{calculated F value}}$ is 691.47 with a total of 36 observations, k = 4, df = nk = 32 (4);(32).), α = 0.05, so the $F_{\text{table value}}$ is 2.67. Because F_{count} (691.47) > F_{table} (2.67) and the probability value is < 0.05, H0 is rejected and H1 is accepted, which means that GDP, GDP squared, coal exports and fossil energy consumption simultaneously influence significant for $CO_{2\ \text{emissions}}$ from 1987 to 2022. It is known that the coefficient of determination R *Square* is 0.988916 or 98.89 percent. So the magnitude of the influence of the variables GDP, GDP squared, coal exports and fossil energy consumption on Indonesia's $CO_{2\ \text{emissions}}$ is 98.89 percent. Meanwhile, 1.11 percent is influenced by other variables outside the model.

Testing the Effect of GDP, Squared GDP, Coal Exports, and Fossil Energy Consumption on Indonesia's $CO_{2\ \text{Emissions}}$ (t Test)

This test is used to determine the effect of each independent variable, namely GDP, GDP squared, coal exports, and energy consumption on the dependent variable, namely $CO_{2\ \text{emissions}}$.

Short Term t Test

1) Testing the effect of GDP (X1) on $CO_{2\ \text{Emissions}}$ (Y) in the short term

The probability value for the influence of GDP (X1) on $CO_{2\ emissions}$ (Y) is 0.08387 > 0.05 and the $_{calculated\ t\ value\ is}$ 0.205, with a total of 35 observations, k = 4, df = 31, α = 0.05, it is obtained The $t_{table\ value}$ is 1.695. Because $t_{count\ is}$ 0.205 < t_{table} 1.695 and the probability value is 0.8387 > α (0.05), then H_0 is accepted. This means that GDP (X1) does not have a significant effect on Indonesia's $CO_{2\ emissions}$.

2) Testing the effect of GDP squared (X12) on $CO_{2\ emissions}$ (Y) in the short term

The probability value for the effect of GDP squared (X12) on $CO_{2\ emissions}$ (Y) is 0.4352 < 0.05 and the t value is 0.791, with a total of 35 observations, k = 4, df = 31, α = 0.05, it is obtained The $t_{table\ value}$ is 1.695. Because $t_{count\ is}$ 0.205 < t_{table} 1.695 and the probability value is 0.4352 > α (0.05), then H_0 is accepted. This means that GDP squared (X12) does not have a significant effect on Indonesia's $CO_{2\ emissions}$.

3) Testing the effect of coal exports (X2) on $CO_{2\ emissions}$ (Y) in the short term

The probability value for the effect of coal exports (X2) on $CO_{2\ emissions}$ (Y) is 0.0675 > 0.05 and the $_{calculated\ t\ value}$ is -1.899, with a total of 35 observations, k = 4, df = 31, α = 0.05 then The t_{table} value obtained was 1.695. Because $t_{count\ is}$ -1.899 < t_{table} 1.695 and the probability value is 0.0675 > α (0.05), then H_0 is accepted. This means that coal exports (X2) do not have a significant effect on Indonesia's $CO_{2\ emissions}$.

4) Testing the effect of fossil energy consumption on $CO_{2\ emissions}$ in the short term

The probability value for the influence of fossil energy consumption (X3) on $CO_{2\ emissions}$ (Y) is 0.0000 < 0.05 and the $_{calculated\ t\ value}$ is 6.940, with a total of 35 observations, k = 4, df = 31, α = 0.05 then the $t_{table\ value}$ is 1.695. Because $t_{count\ is}$ 6.94 > t_{table} 1.695 and the probability value is 0.000 < α (0.05), then H_0 is rejected. This means that fossil energy consumption (X3) has a positive and significant effect on Indonesia's $CO_{2\ emissions}$.

5) Effect of ECT variables on $CO_{2\ emissions}$ in the short term

The probability value for the effect of ECT on $CO_{2\ emissions}$ (Y) is 0.0037 < 0.05 and the $_{calculated\ t\ value}$ is -3.155 < t_{table} 1.695, so it can be concluded that H_0 is rejected and H_1 is accepted, meaning that ECT has a negative and significant effect on CO emissions. $_2$ .. This shows that if there is a shock *that* causes a disturbance in the long-term balance, then the disturbance will be short-term, and the long-term balance will be achieved again. The ECT(-1) coefficient value of -0.522031 below the value of 0.05 means that the recovery of long-term balance is slow.

Long Term t Test

1) Testing the effect of GDP (X1) on long-term CO $_{2\ emissions\ (Y).}$

   The probability value for the influence of linear GDP (X1) on CO $_{2\ emissions}$ (Y) is 0.3186 > 0.05 and the $_{calculated\ t\ value}$ is -1.013, with a total of 36 observations, k = 4, df = 32, α = 0.05 then the t $_{table\ value}$ is 1.6939. Because t $_{count\ is}$ -1.013 < t $_{table}$ 1.6939 and the probability value is 0.3186 > α (0.05), then H $_0$ is accepted. This means that GDP (X1) has no significant effect on Indonesia's CO $_{2\ emissions}$.

2) Testing the effect of GDP squared (X12) on CO $_{2\ emissions}$ (Y) in the short term

   The probability value for the effect of GDP squared (X12) on CO $_{2\ emissions}$ (Y) is 0.0004 < 0.05 and the $_{calculated\ t\ value}$ is 3.999, with a total of 36 observations, k = 4, df = 32, α = 0.05 then The t $_{table}$ value obtained was 1.6939. Because t $_{count}$ is 3.999 > t $_{table}$ 1.6939 and the probability value is 0.0004 < α (0.05), then H $_0$ is rejected and H $_1$ is accepted. This means that GDP squared (X12) has a positive and significant effect on Indonesia's CO $_{2\ emissions}$.

3) Testing the effect of coal exports (X2) on CO $_{2\ emissions}$ (Y) in the short term

   The probability value for the effect of coal exports (X2) on CO $_{2\ emissions}$ (Y) is 0.8846 > 0.05 and the $_{calculated\ t\ value}$ is -0.1463, with a total of 36 observations, k = 4, df = 32, α = 0.05, the t $_{table\ value}$ is 1.6939. Because t $_{count}$ is 0.1463 < t $_{table}$ 1.6939 and the probability value is 0.8846 > α (0.05), then H $_1$ is rejected and H $_0$ is accepted. This means that coal exports (X2) do not have a significant effect on Indonesia's CO $_{2\ emissions}$.

4) Testing the effect of fossil energy consumption (X3) on CO $_{2\ emissions}$ (Y) in the short term

   The probability value for the influence of fossil energy (X3) on CO $_{2\ emissions}$ (Y) is 0.0000 < 0.05 and the $_{calculated\ t\ value\ is}$ 13.86 with a total of 35 observations, k = 4, df = 31, α = 0.05 then the t $_{table\ value}$ is 1.694. Because t $_{count\ is}$ 13.86 > t $_{table}$ 1.6939 and the probability value is 0.000 < α (0.05), then H $_0$ is rejected. This means that fossil energy consumption has a positive and significant effect on Indonesia's CO $_{2\ emissions}$.

Discussion of Research Results

1) $_2$ Emissions

   The results of this research state that in the short term linear GDP and quadratic GDP do not have a significant effect. And in the long term, linear GDP has no significant effect, while quadratic GDP has a positive and significant effect. This means that the EKC hypothesis which states that the relationship between GDP and CO $_{2\ emissions}$ is in the shape of an inverted U is not proven, because the validation of the EKC hypothesis can be proven by regression results when GDP has a significant positive influence and GDP squared has a significant negative influence on CO $_2$, so it can form a U curve relationship backwards.

The failure to prove the EKC hypothesis in the case of research on Indonesia as a developing country could indicate that the increase in GDP per capita is not or cannot be followed by an increase in public environmental awareness. In the context of carbon dioxide emissions, energy and transportation sector policies can reflect environmental awareness. This is because carbon dioxide emissions are almost entirely contributed by the use of fossil fuels *for* these two sectors. In the context of energy policy, Indonesia tends to continue to increase the portion of coal in the energy mix.

The insignificance of GDP and GDP squared affects $CO_{2\ emissions}$ in the short term because in the short term the environment can still accommodate and act as an assimilator in processing waste naturally. However, in the long term, the regression results for the GDP variable have no significant effect, while GDP squared has a significant effect and has a positive value, namely 0.0109. This means that initially when economic growth occurs, economic development does not affect the level of carbon dioxide (CO_2) emissions because $CO_{2\ emissions}$ can still be accommodated and neutralized by the environment until they reach a certain minimum point, which is the turning point of the relationship between GDP and $CO_{2\ emissions}$. Because in the end an increase in GDP will increase $CO_{2\ emissions}$ and will result in air pollution.

The results of this research are in line with the opinion expressed by Rahman (2017), who explains that economic growth is one of the drivers of environmental degradation, namely air pollution due to increasing carbon dioxide (CO_2) emissions in the atmosphere. Economic growth will increase industrial and transportation activities which are the main sources of CO_2 emissions which will ultimately have an impact on increasingly declining air quality. The results of this research are in line with the results of research by Putriani et al. (2018) which shows that in the short term GDP and GDP squared do not have a significant effect, and GDP squared in the long term has a positive and significant effect on CO emissions. The results of this research are also in line with research conducted by Hossain (2012) which shows that in the long term economic growth has a positive and significant effect on carbon dioxide (CO_2) emissions.

2) Effect of Coal Exports on $CO_{2\ Emissions}$

The research results show that coal exports do not have a significant effect in the long term or short term on $CO_{2\ emissions}$. The coefficient value for the effect of coal exports (X2)

on $CO_{2\ emissions}$ in the long term is -0.0144 and in the short term is -0.1790, the negative value of the coal export variable indicates the increasing volume of coal exported abroad then CO_2 emissions in Indonesia will decrease. This could be because the activity of burning coal as a fossil fuel can increase the level of $CO_{2\ emissions}$ produced through this burning, but this can be reduced if the coal is exported abroad so that the amount of coal that will be used as a fossil fuel energy source will increase. reduce. If the amount of coal used as an energy source is reduced by increasing the supply of coal to be exported, it can slow down or even reduce the level of $CO_{2\ emissions}$ in Indonesia. Especially if the Indonesian government focuses policies so that energy sources in Indonesia switch to more environmentally friendly fuels.

However, this decrease was not significantly caused by coal export activities, because the decrease in $CO_{2\ emissions}$ can also be caused by many other factors such as reducing fossil energy consumption, which is supported by research results from Zakaria Zoundi (2017) which states that renewable energy consumption is able to reduce GHG emissions. and fossil energy consumption has a positive and significant effect on CO2 emissions. The increase in $CO_{2\ emissions}$ can also be influenced by other factors such as the number of industries and economic growth, which is supported by the research results of Karimi et al. (2022) which states that GDP and the number of industries have a significant and positive long-term relationship with CO2 emissions in Indonesia . The results of this research are also in line with research by Yesi Widawati and Muhammad Anas (2024) that coal exports in the short and long term have no effect on CO2 emissions.

3) Effect of Fossil Energy Consumption on $CO_{2\ Emissions}$

The results of this research state that fossil energy consumption has a positive and significant effect in both the long and short term on $CO_{2\ emissions}$ in Indonesia. The results of this research are supported by research by Isnaeni (2019) where energy consumption, especially fossil energy, has a positive and significant effect on $CO_{2\ emissions}$. So as energy consumption increases, $CO_{2\ emissions}$ will increase because the main source of $CO_{2\ emissions}$ comes from burning fossil fuels. This illustrates that in Indonesia there is still not a massive use of environmentally friendly energy. One of the causes is the high cost of environmentally friendly energy such as solar panels, so the use of fossil fuels such as petroleum and coal is still the government's choice for producing electricity.

The high use of fossil energy in Indonesia can cause various problems to arise, especially in the environmental health sector, which will increase pollution and emissions,

especially if there is no technology to reduce emissions, it will be dangerous for human health. This is supported by research by Zoundi (2017) which also provides evidence showing that renewable energy is able to reduce GHG emissions, especially CO_2 emissions . In both the short and long term, fossil energy consumption has a positive and significant effect on CO_2 emissions .

In developing countries, fossil fuels are used to accelerate economic growth and meet increasing energy needs. Like other developing countries, Indonesia also faces various economic challenges and continues to struggle to improve people's living standards. To produce more goods, Indonesia uses more fossil fuels which produce waste, one of which is in the form of CO_2 emissions . The use of fossil fuels produces high CO_2 emissions, due to the lack of use of environmentally friendly technology. This is in line with the conditions that occurred in Indonesia, in 1990-2018 fossil energy consumption in Indonesia experienced fluctuations with an upward trend. This has resulted in an increase in CO_2 emissions in Indonesia . This research is in line with the research results of Ersalina Tang (2017) which shows that energy consumption variables positively influence greenhouse gas concentrations, especially CO_2 emissions. The research results of Hanif et al. (2019) also supports this research, which shows that in developing countries in Asia, fossil fuel consumption has a positive and significant effect on CO_2 emissions.

CONCLUSION

The results of the analysis carried out regarding the influence of GDP, coal exports and fossil energy consumption in the short and long term on Indonesian air pollution in terms of CO_2 emissions , provide several conclusions as follows:

1) In the short and long term, the variables GDP, coal exports and fossil energy consumption simultaneously have a significant effect on the level of CO_2 emissions in Indonesia.
2) Linear GDP based on partial short-term and long-term regressions does not have a significant effect on the level of CO_2 emissions in Indonesia. Meanwhile, GDP squared in the short term partially has no significant effect and in the long term it partially has a positive and significant effect on the level of CO_2 emissions in Indonesia. This proves that the EKC hypothesis which states the relationship between CO_2 emissions and GDP is

expressed in an inverted U curve does not apply in Indonesia because the validation of the EKC hypothesis can be proven by regression results when GDP has a significant positive influence and GDP squared has a significant negative influence on CO_2.

3) Coal exports in the short term and long term partially do not have a significant effect on $CO_{2\ emissions}$.
4) Fossil energy consumption in the short term and long term partially has a positive and significant effect on $CO_{2\ emissions}$.

REFERENCE

Ajija, SR, Sari, DW, Setianto, RH, & Primanti, MR (2011). The smart way to master Eviews. *Jakarta: Salemba Empat* .

Alam, MM, Murad, MW, Noman, AHM, & Ozturk, I. (2016). Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia . *Ecological Indicators* , 70, p. 466-479.

Albertus, F., & Zalukhu, Y. (2019). The impact and influence of coal mining on society and the environment in East Kalimantan. *LEGALITY: Scientific Journal of Legal Studies* , *4* (1), p. 42-56.

Al-mulali, Usama. 2011. Oil consumption, CO2 emissions and economic growth in MENA Countries. *Journal of Energy* . Vol. 36, pp. 6165-6171.

Amri, F. (2018). Developing character in economic learning. In *Proceedings of the National Multidisciplinary Seminar* . Vol. 1, p. 110-124.

Andarini, A., Idris, I., & Ariusni, A. (2016). The Influence of Industrial, Mining and Transportation Sector Activities on Environmental Quality in View of CO2 Emissions in Indonesia. *Ecosains: Scientific Journal of Economics and Development* , *5* (2), p. 125-136.

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and economic growth: evidence from a panel of OECD countries. *Energy Policy* , 38(1), pp. 656-660.

Ariefanto, MD (2012). *Essentials and Applications of Using Eviews* . Jakarta: Erlangga.

Arifin, K., Ruslan, B., & Ramadhan, E. (2023). The Effect of Economic Growth on CO2 Emissions in Indonesia. *Journal of Economic Education: Scientific Journal of Education, Economics and Social Sciences, 17* (1), p. 119-127.

Ashgar, Zahid. (2008). Energy-GDP Relationship: A Causal Analysis for the Five Countries of South Asia. *Applied Econometrics and International Development* . Vol. 8 No. 1. pp. 167-180.

Azizah, IA, & Soelistyo, A. (2022). Analysis of Factors Affecting the Value of Indonesian Coal Exports 2014-2020. *Journal of Economic Sciences* , *6* (4), p. 584-596.

Bakhri, MS (2018). Energy Consumption, Economic Growth, Globalization and CO2 emissions: ASEAN-5 Case Study. *Economics Bulletin.*

Bui, D.T. (2020). Transmission Channels Between Financial Development and CO2 Emissions: A Global Perspective. *Heliyon,* 6(11).

Carfora, Alfonso., Pansini, Rosaria., Scandurra, Giuseppe. 2019. The causal relationship between energy consumption, energy prices and economic growth in Asian developing countries: A replication. *Journal of Energy Strategy Review* s. Vol 23, pp. 81 – 85

Danish, Baloch, M.A., Mahmood, N., & Zhang, J.W. (2019). Effect of natural resources, renewable energy and economic development on CO2 emissions in BRICS countries . *The Science of the Total Environment* , 678, pp. 632–638.

Duki, M.Z., Sudarmadi, S., Suzuki, S., & Kawada, T. (2003). Effect of Air Pollution on Respiratory Health in Indonesia and its Economic Cost. *Archives of Environmental Health: An International Journal* , pp. 135-143.

Enders, W. (2003). *Applied Econometric Time Series.* Hoboken, NJ : Wiley

Gaghana, & Jordan, R. (2019). Legal Responsibilities of Foreign Investment Companies Regarding Name Borrowing Agreements (Nominees) in Environmental Management. *Lex Et Societatis* . Vol. 7 No. 3.

Ge, C., Yu, Z., Sheng, H., Shen, X., Sun, X., Zhang, Y., & Yuan, Q. (2022). Redesigning regulatory components of quorum-sensing system for diverse metabolic control. *Nature communications* , 13(1), pp. 2182.

Ghozali, Imam. 2006. *Multivariate Analysis Applications with the SPSS Program (4th Edition)* . Semarang: Diponegoro University Publishing Agency.

Ghozali, Imam. 2016. *Multivariate Analysis Applications with the IBM SPSS 23 Program (Edition 8).* Printing VIII. Semarang: Diponegoro University Publishing Agency.

Greenstone, M., and Fan, Q. C. (2019). Indonesia's deteriorating air quality and its impact on life expectancy. *Chicago: Energy Policy Institute At The University of Chicago* .

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics* , 110(2), pp. 353-377.

Gujarati, D.N. (1995). *Basic Econometrics, 3rd Edition* . Mexico: McGraw-Hill International Edition. Economics Series.

Gujarati, D.N. (2004). *Basic Econometrics. 4th Edition* . Mexico: McGraw-Hill Companies.

Gujarati, DN and Porter, DC (2010) *Econometría.* . Mexico: McGraw-Hill.

Gupito, KR (2013). The Relationship between GRDP Per Capita from the Industrial, Transportation, Agricultural and Forestry Sectors on Environmental Quality Measured from CO2 Emissions in Central Java. *Diponegoro Journal of Economics* . Vol. 2, No. 1, p. 1-7 .

Habibi, Ahmad. (2022). Environmental Pollution Due to Coal Mining in Serongga Village, Kotabaru Regency. *OSF Preprints: Learning Publication Series* . Vol. 1 No.1.

Hanif, Imran et al. (2019). Fossil fuels, foreign direct investment, and economic growth have triggered CO2 emissions in emerging Asian economies: Some empirical evidence. *EnergyJournal* . Vol. 171, 15. No. 11. Page: 493-501.

Hanley, N. and Barbier, E.B. (2009) *Pricing Nature: Cost-Benefit Analysis and Environmental Policy.* Cheltenham: Edward Elgar. ISBN 9781845427894

Harris, J.M., and Roach, B. (2021). *Environmental and Natural Resource Economics: A Contemporary Approach* (fifth ed.). New York: Routledge.

Herlambang, T., Sugiarto, B., and Said, K (2001). *Macroeconomics: Theory, Analysis and Policy* . Jakarta: Gramedia Pustaka Utama.

Melissa Denchak. (2022). *Fossil Fuels: The Dirty Facts* . Nrdc.Org.

Mikayilov, J., Shukurov, V., Mukhtarov, S., Yusifov, S. (2017). *Does Urbanization Increase Pollution from Transport.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 65(5), pp. 1709–1718.

Mukono, H. J. (1997). *Air Pollution and its Effect on Respiratory Tract Disorders* . Surabaya: AUP.

Nachrowi and Hardius Usman. (2006). *Popular and Practical Economometric Approaches to Economic and Financial Analysis* . Jakarta: Publishing Institute for the Faculty of Economics, University of Indonesia.

Nadeak, SAH, & Nasrudin, N. (2023). The Influence of GDP per Capita and Energy Consumption on GHG Emissions in Indonesia. *Indonesian Journal of Economics and Development* , 23(2), 2.

Nikensari, SI, Destilawati, S., & Nurjanah, S. (2019). Environmental Kuznets curve study in Asia: before and after the millennium development goals. *Journal of Economics and Development* , *27* (2), p. 11-25.

Noor, MA, & Saputra, PMA (2020). Carbon emissions and gross domestic product: Investigation of the environmental Kuznets curve (EKC) hypothesis in middle-income countries in the ASEAN Region. *Journal of Regions and Environment* , 8(3), p. 230-246.

Nurmawaddah, S. (2019). The influence of non-oil and gas exports on the economic growth of East Kalimantan province. *Accountable* , *16* (1), p. 128-133.

and Policy , 9(4), pp. 313–319.

Suparmoko. (2002). *Public Economics for Regional Finance and Development* (First Edition) . Yogyakarta: BPFE-Yogyakarta.

Suparmoko, M. (2011). *Environmental Economics* . Yogyakarta. BPFE-Yogyakarta.

Tang, Ersalina. (2017). The Influence of Foreign Investment, Gross Domestic Income, Energy Consumption, Electricity Consumption, and Meat Consumption on Environmental Quality in 41 Countries in the World and 17 Countries in Asia for the 1999-2013 Period. *University of Surabaya Student Scientific Journal* , Vol. 6. No. 2., p. 1896-1914.

Tietenberg, Tom and Lyonn Lewis. (2011). *Environmental & Natural Resource Economics.* Boston: Pearson Education.

Todaro, M. P., & Smith, S. C. (2004). *Economic Development. 8th Edition* , New York: Longman Publications.

Todaro, M. P., & Smith, S. C. (2014). *Economic development* . UK: Pearson.

Tong, T., Ortiz, J., Xu, C., & Li, F. (2020). Economic growth, energy consumption, and carbon dioxide emissions in the E7 countries: A bootstrap ARDL bound test. *Energy, Sustainability and Society* , 10(1), pp. 1-17.

Trianisa, K., Purnomo, EP, & Kasiwi, AN (2020). The Influence of the Coal Industry on Air Pollution in the Balance of the World Air Quality Index in India. *J. Sci Technol. Environment* , *6* (2), p. 156-168.

Tsandra, NA, Sunaryo, RP, Syafri, S., & Octaviani, D. (2023). The Influence of Energy Consumption and Economic Activities on CO2 Emissions in G20 Countries. *e-Journal of Business Economics and Accounting* , *10* (2), p. 69-79.

United Nations. (2022). *Causes and Effects of Climate Change* . Un.Org.

Wardhana, Vishnu Arya. (2004). *Impact of Environmental Pollution* . Yogyakarta: Cv. Andi Offset

Widarjono, A. (2009). *Introductory Econometrics and Its Applications* (Third Edition). Yogyakarta: Ekonisia FE UII.

Wijaya, SH (2017). Analysis of the Effect of GDP, Coal Consumption, PMA, Urban and Energy Consumption on CO2 in ASEAN Countries 2000-2011. *Calyptra* , *6* (1), p. 1830-1842.

Yasa, IGWM (2010). Green Economy, Clean Production and Creative Economy: Approaches to Preventing Environmental Risks Towards Quality Economic Growth in Bali Province. *Bumi Lestari Journal of Environment* , 10(2), p. 285-294.