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Economic Growth and Carbon Emissions: Environmental Kuznets Curve (EKC) Hypothesis in Indonesia from 1990 to 2020

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Abstract

All countries in the world, both developed and developing countries, are facing pollution problems in order to be able to balance accelerating economic growth with environmental degradation problems due to their economic activities. The acceleration of economic development in Indonesia to achieve high industrial growth is directly proportional to the cause of the high increase in carbon dioxide emissions. The purpose of this study is to see the environmental impact of the regulations set, as well as to provide recommendations for the formulation of environmentally friendly economic development policies in the future. This study applies time series data regression with ECM as the method used. Indonesia was chosen as the object of the theory Environmental Kuznets Curve (EKC) from 1990 to 2020. The results in the study show that the squared industry variable in the short term is not significant, but in the long term it is significant and has an effect of -0.0002, which means that the EKC hypothesis is not proven in the short and long term, only a decrease in environmental degradation occurs. (CO2 emissions) because industry increases in the long term or industry has a significant negative effect on carbon dioxide emissions in the long term.

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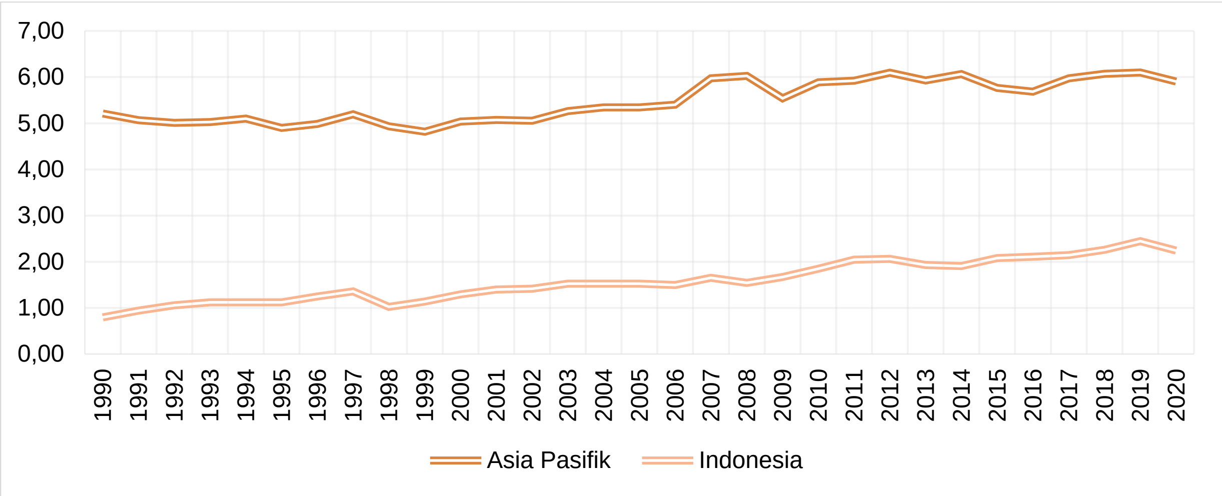
INTRODUCTION

The Asia-Pacific region has witnessed rapid economic growth over the past 50 years. However, the increasing pressure on environmental degradation remains an unresolved development issue (Asian Development Bank, 2018). This global challenge is faced by all countries, both developed and developing, in their efforts to strike a balance between accelerating economic growth and addressing environmental degradation resulting from economic activities. Economic growth aims to alleviate poverty, unemployment, and income disparities, with one approach being through industrial activities and receiving investment from various parties, both local and international. However, on the other hand, these economic activities have adverse impacts on the environment.



Source: Our World in Data

Figure 1 illustrates Carbon dioxide emissions per capita in the Asia-Pacific region and Indonesia from 1990 to 2020.

Indonesia possesses natural wealth, including extensive forests. Indonesian forests can absorb carbon resulting from economic activities aimed at national development. However, current environmental conditions in Indonesia are declining due to increasing carbon emissions each year. CO2 emissions per capita in Indonesia have significantly risen from 0.79 tons in 1990 to 2.2 tons in 2020. This places Indonesia 14th in the Asia-Pacific region and 5th in Southeast Asia, which includes Malaysia, Brunei Darussalam, Thailand, and Singapore, followed by Indonesia. The acceleration of economic development in Indonesia, aimed at achieving high industrial growth to improve societal well-being, may lead to higher carbon dioxide emissions.The Directorate General of Climate Change Control stated that Indonesia has a National Action Plan for Greenhouse Gas Emission Reduction (RAN-GRK) aimed at reducing greenhouse gas emissions by up to 26% by the year 2020.

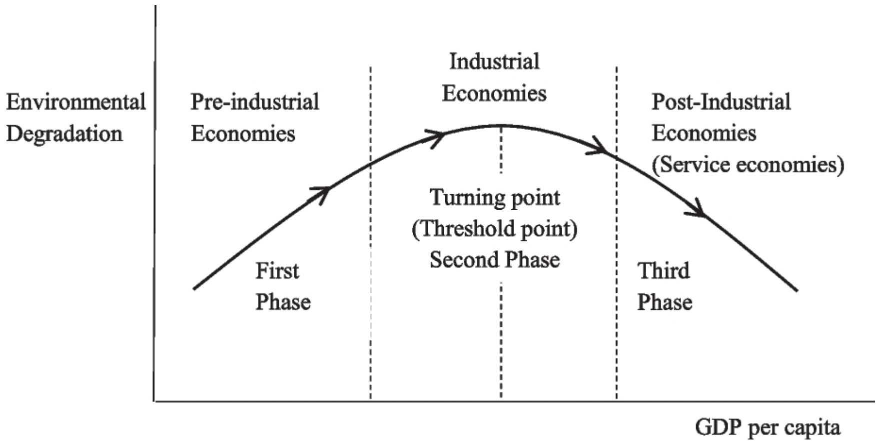
The essence of declining environmental quality has become a primary concern for countries in the Asia-Pacific region, particularly Indonesia. Shahbaz et al. (2011) explain that sustainable economic development can be achieved through activities that promote environmental preservation. In the field of economics, previous researchers have studied the relationship between economic growth and environmental quality decline using the Environmental Kuznets Curve (EKC). The EKC theory hypothesizes that environmental quality deteriorates initially with economic growth, but reaches a turning point where environmental degradation begins to decline, resembling an inverted U-shaped curve. The advancement of technology can aid in reducing pollution levels associated with human development; technological innovation and the use of renewable energy are believed to decrease carbon emissions over time (Saqib et al., 2022).

Previous studies on the relationship between economic growth and environmental quality decline have extensively examined the Environmental Kuznets Curve (EKC) hypothesis, yielding diverse findings. Studies like Noor & Saputra (2020) dan did not find evidence supporting an inverted U-shape in the EKC. In contrast, Santi & Sasana (2021) demonstrated the EKC hypothesis in eight ASEAN member countries. High-income countries with a GDP per capita of USD 51,440 have the potential to exhibit an inverted U-curve, but for lower to middle-income countries, the EKC hypothesis has not materialized Nikensari et al. (2019). Sarkodie & Strezov (2019) demonstrated the EKC hypothesis invalidated the inverted U-shaped relationship with an average income threshold of USD 8,910, where low to middle-income countries were found below this income threshold while high-income countries were above it. These findings suggest that the Environmental Kuznets Curve theory is primarily observable in developing countries, with mixed results in other income categories. Additionally, different energy resource uses can lead to varying research outcomes eight ASEAN member countries. High-income countries with a GDP per capita of USD 51,440 have the potential to exhibit an inverted U-curve, but for lower to middle-income countries, the EKC hypothesis has not materialized Yustisia & Sugiyanto (2014).

The process of economic development involves transforming the economic structure of a country. Initially, this transformation often leads to increased pollution as the economy shifts towards industrial activities. In subsequent stages, carbon emissions tend to decrease as economic activities transition to lighter industries. Eventually, the adoption of new clean technologies replacing old, polluting technologies can lead to a better environment. Effective decision-making requires comprehensive studies on CO2 emissions to formulate appropriate policies, especially for sectors that support economic growth in Indonesia. If Indonesia's development acceleration relies on activities that increase carbon dioxide emissions, high energy consumption may not solely stem from high economic growth activities but also from energy inefficiencies. The rising CO2 emissions pose challenges to sustainability and exacerbate vulnerabilities among poor communities heavily reliant on nature for livelihoods and food security. This study focuses on environmental degradation using CO2 emissions as a benchmark in Indonesia from 1990 to 2020. It incorporates value-added industrial sectors, fossil energy, oil energy, renewable energy, and the ratio of exports to imports as measures of economic openness. The globalization index is added as a crucial variable to analyze the relationship between emissions, growth, and energy. The objective of this research is to assess the environmental impacts of existing regulations and to recommend policies for future environmentally-friendly economic development formulations.

The structure of each article consists of five main parts. The first part is the introduction, which sets out the background of the research topic, explains its significance, and outlines the study's objectives. The second part, the literature review, discusses previous research and relevant theories and concepts. The third part presents the methodology, including details on data sources and models used in the study. The fourth part elaborates on the results and empirical discussions derived from the research findings. Lastly, the fifth part draws conclusions and provides recommendations based on the study's findings.

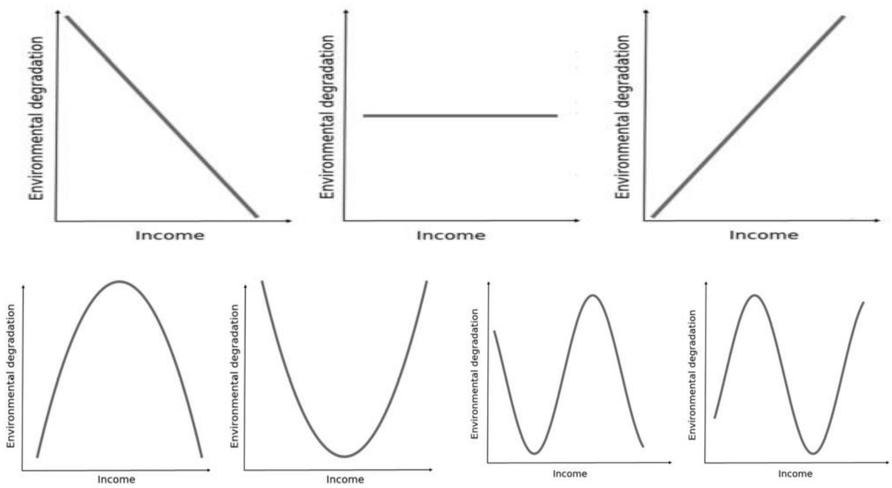
The inception of the Kuznets curve, as articulated by Kuznets (1955) reveals the relationship between per capita income and income inequality, forming an inverted U shape. In the initial stages of economic growth, income inequality decreases simultaneously with rising per capita income after reaching a turning point. During this phase, early economic growth is marked by income disparities, which decrease as economic productivity increases. This hypothesis gained prominence with the work of Grossman & Krueger (1991) who found a negative relationship between environmental quality and per capita income. Their discovery of an inverted U-shaped relationship between air pollution and per capita income reaffirmed the validity of the Environmental Kuznets Curve (EKC) hypothesis, as proposed by (Panayotou, 1993). This investigation manifests increasing air pollution alongside income levels, yet air pollution concentrations decrease at higher income levels. According to Panayotou (1993), policy distortions such as carbon subsidies, industrial regulations, economic structure, energy incentives, low prices of natural resources, and market failures influence the curvature of the curve.



Source: Sarkodie & Strezov (2019)

Figure 2. The Relationship between Environmental Degradation and Income Level

The Environmental Kuznets Curve (EKC) hypothesis reveals the correlation between changes in a country's economic structure and economic growth over a specific period. The phases within the EKC depict the transition from pre-industrial agricultural-based economies to industrial economies, and subsequently to post-industrial service-based economies. Environmental degradation typically increases during the shift from agricultural to industrial economies due to increased production, economic activity, and energy consumption. However, environmental damage can decrease with innovations, research, development, and the adoption of clean and modern technologies driven by awareness of the environmental impacts of emissions, aimed at reducing pollution levels (Sarkodie & Strezov, 2019).



Source: Sarkodie & Strezov (2019)

Figure 3. Interpretation of the Relationship between Environmental Degradation and Income Level

Specifically, the relationship between environmental degradation and income level is not as straightforward as depicted in Figure 2, where degradation initially increases and then decreases at a certain point due to increased awareness of environmental damage caused by human exploitation. In reality, different countries have varying natural resources, living needs, and methods of utilization, resulting in diverse EKC graphs. In graph (a), there is no relationship between x and y; (b) shows a positive monotonic relationship between x and y; conversely, (c) illustrates a negative relationship between the x-axis and the y-axis; (d) depicts an inverted U-shaped relationship between x and y; (e) demonstrates a U-shaped relationship between x and y; (f) shows an N-shaped relationship between the x-axis and the y-axis; and (g) indicates an inverted N-shaped relationship between x and y.

The Environmental Kuznets Curve (EKC) hypothesis has been extensively studied in

Indonesia. Findings vary, with some studies proving the EKC hypothesis, while others state it is not proven, and speculation remains on its verification in Indonesia. Rulinawaty (2022) utilizing ARDL analysis, found evidence supporting the EKC in Indonesia with variables such as economic growth, energy consumption, and urbanization. Other studies using ARDL that have successfully proven EKC include Kusumawardani & Dewi (2020), Sugiawan & Managi (2016) and (Prastiyo et al., 2020). Tak hanya itu Prasetyanto & Sari (2021) demonstrated EKC in Indonesia using the ECM method. Muhammad Fajar & Hariyanto (2021) utilized OLS and found evidence for EKC in Indonesia using GDP and population data, though the comprehensiveness of the data used may not fully represent actual conditions. Bashir et al. (2021) employing VECM, investigated the impact of urbanization, economic growth, energy consumption, and CO2 emissions in Indonesia, confirming the EKC hypothesis. Government policies are needed to increase awareness and improve environmental quality and energy use efficiency. In contrast, Saboori et al. (2012) investigated the relationship between economic growth, CO2 emissions in Indonesia from 1971-2007, including energy consumption and trade openness data, but found no support for the EKC hypothesis in Indonesia despite using ARDL. Setiawan & Anwar (2022) introduced a new perspective using VECM and indicators such as GDP, population, electricity consumption, international trade ratio, and CO2 emissions, revealing an empirical finding of an open U-shaped curve rather than an inverted one, due to Indonesia's incomplete post-industrial phase leading to increased CO2 emissions. The increasing awareness of global warming has prompted studies like Adebayo et al. (2021) which examined the impact of CO2 emissions and energy use on economic performance, trade openness, urbanization, and agriculture in Indonesia from 1965-2019. Their findings indicated mixed (significant and insignificant) interactions between economic growth and regressors. Long-term relationships were identified through ARDL calculations, showing that agriculture and energy use drive economic performance in Indonesia. Studies by Idris & Sari (2022) and Nuansa & Widodo (2018) concluded that EKC has not been proven in Indonesia, necessitating further research. Therefore, this study addresses inconsistencies in previous studies due to inappropriate methodological choices, insufficient study periods, and limited data complexity affecting environmental degradation research outcomes.

RESEARCH METHODOLOGY

Data from The World Bank, KOF Swiss Economic Institute and Our World in Data In this study, data from the period 1990 to 2020 was used. The study utilized time series data from Indonesia. The model included several variables such as carbon dioxide emissions per capita, industrial value added, fossil energy consumption per capita, oil energy consumption per capita, renewable energy consumption per capita, trade openness where total exports plus imports were calculated as a percentage of GDP, and globalization index representing the level of globalization in Indonesia from 1990 to 2020.

ChatGPT In this study, the variables were constructed using a model based on the research by Kostakis et al. (2023). Additionally, to achieve optimal results regarding the role of energy in economic growth and CO2 emissions in Indonesia, fossil energy consumption was included in the model. Time series data was used in this research as it focused solely on Indonesia as the object, spanning the period from 1990 to 2020. Carbon dioxide (CO2) emissions per capita served as the dependent variable. Generally, the time series data model is presented as follows:

$$CO2_t = \beta_0 + \beta_1 INDUSTRI_t + \beta_2 INDUSTRI_t^2 + \beta_3 EF_t + \beta_4 EO_t + \beta_5 ER_t + \beta_7 TO_t + \beta_8 GI_t + \varepsilon_t$$

Where, $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$, and β_7 as an estimate of carbon dioxide emissions in response to a 1% change in Industry (INDUSTRY), the square of Industry (INDUSTRY²), fossil energy consumption (EF), oil energy consumption (EO), renewable energy consumption (ER), trade openness (TO), and globalization index (GI). β_0 represents the constant, ε denotes the error term, and t refers to the year.

This study uses the Error Correction Model (ECM) proposed by Domowitz and Elbadawi. This method was chosen because it addresses the issue of spurious regression by incorporating appropriate differencing variables into the model without altering Long Term findings, as level variables are also included in the ECM (Domowitz & Elbadawi, 1987). When the ECM model is valid, it indicates a long-term relationship between variables, correct model specification, and significant causal relationship (Astuti, 2016). The ECM method can be estimated according to the equation below:

$$\Delta CO2_t = \gamma_0 + \gamma_1 \Delta INDUSTRI_t + \gamma_2 \Delta INDUSTRI_t^2 + \gamma_3 \Delta EF_t + \gamma_4 \Delta EO_t + \gamma_5 \Delta ER_t + \gamma_6 \Delta TO_t + \gamma_7 \Delta GI_t + \gamma_8 INDUSTRI_{t-1} + \gamma_9 INDUSTRI_{t-1}^2 + \gamma_{10} EF_{t-1} + \gamma_{11} EO_{t-1} + \gamma_{12} ER_{t-1} + \gamma_{13} TO_{t-1} + \gamma_{14} GI_{t-1} + \gamma_{15} ECT + \omega_t$$

The variables considered include CO2 emissions, measured in metric tons per capita, which serves as the dependent variable. The independent variables consist of Industri, representing the annual growth rate of industrial value added in percentage terms; Industri2, the squared term of Industri in percentage; EF, fossil energy consumption per capita in kWh; EO, oil energy consumption per capita in kWh; ER, renewable energy consumption per capita in kWh; TO, the ratio of trade openness (exports plus imports) to GDP in percentage; and GI, the Globalization Index in percentage.

The use of γ_1 refers to $\lambda\beta_0$. Following this, the parameters $\gamma_1,\ \gamma_2, \gamma_3, \gamma_4,\ \gamma_5, \gamma_6,\ \text{and}\ \gamma_7$ are denoted as $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \text{and}\ \alpha_7$ respectively, representing coefficients of short-term influence. To establish long-term relationships, the formula is employed to find $\gamma_8 = -\lambda(1-\beta_1), \gamma_9 = -\lambda(1-\beta_2), \gamma_{10} = -\lambda(1-\beta_3), \gamma_{11} = -\lambda(1-\beta_4), \gamma_{12} = -\lambda(1-\beta_5), \gamma_{13} = -\lambda(1-\beta_6), \text{and}\ \gamma_{14} = -\lambda(1-\beta_7)$. ChatGPT ECT, singkatan dari Error Correction Term, adalah istilah yang menunjukkan koreksi kesalahan, yang direpresentasikan oleh γ_{15}. $ECT = INDUSTRI_{t-1} + INDUSTRI_{t-1}^2 + EF_{t-1} + EO_{t-1} + ER_{t-1} + TO_{t-1} + GI_{t-1} - CO2_{t-1}$. The definition of the variables used is as follows: emissions refer to carbon dioxide emissions from fossil fuel combustion and cement production. The concept and statistical methodology for these variables encompass carbon dioxide generated from solid, liquid, and gas fuel consumption. Anthropogenic CO2 emissions typically arise from fossil fuel combustion and cement production. When burned, different fossil fuels produce varying amounts of CO2 for the same energy output. Oil energy emits over 50% more CO2 compared to coal and natural gas. The production of one ton of cement releases approximately 0.5 tons of carbon dioxide.

Growth is defined as the annual growth rate of value added in industries based on constant local currency. Industries are calculated through the value added in the mining, manufacturing, construction, electricity, gas, and water sectors. Value added represents the net output of a sector after summing all outputs without deducting for depreciation of built assets or depletion and degradation of natural resources. Most countries worldwide rely on fossil energy, and oil plays a significant role in global energy, albeit with negative impacts when burned, resulting in carbon dioxide emissions that drive global climate change. To reduce CO2 emissions and pollution levels, there is an urgent need to transition to low-carbon energy sources, with renewable energy being key to decarbonizing the energy system in the coming years. The trade balance ratio of exports and imports illustrates a country's economic openness, while the globalization index measures political, social, and economic globalization to assess the impacts of globalization.

RESULTS AND DISCUSSION

The indirect estimation results serve as decision-making tools, deemed adequate when they demonstrate predictive power and pass several tests such as the stationarity test using the ADF (Augmented Dickey Fuller) approach as shown in Table 1, classical assumption tests in Table 2, and Goodness of Fit indicated in Table 3. Table 1 on stationarity tests indicates that variables such as Carbon dioxide (CO2), INDUSTRY, Fossil Energy (EF), and Globalization Index (GI) are stationary at the level level, while variables INDUSTRY2, Oil Energy (EO), Renewable Energy (ER), and Trade Openness (TO) are stationary at D or First Different.

Table 2, the classical assumption tests, concluded that there are no issues with normality, autocorrelation, and heteroskedasticity. Therefore, the classical assumption tests are considered passed. Normality testing using the Jarque Bera approach yielded a p-value of 0.3453 (> 0.05), indicating that residuals are normally distributed. Autocorrelation testing using the Breusch-Godfrey test resulted in a probability value of 0.7972 (> 0.05), suggesting no autocorrelation issue where past values of the variables do not influence future values. Heteroskedasticity testing produced a probability of 0.8659 (> 0.05), demonstrating no heteroskedasticity issue, meaning the variation in residuals across observations is consistent. Model adequacy testing using the Ramsey Reset Test showed a p-value of 0.9778 (> 0.05), indicating the model specification is appropriate.

Table 3, Goodness of Fit, includes model fitness tests such as the F-test for model existence and prediction accuracy. The F-test assesses whether the model exists under the condition that the probability is below α (0.0002 < 0.05), implying that CO2 is collectively influenced by the independent variables in the model. Meanwhile, the R-squared value of 0.8952 explains that 89.52% of the variation in CO2 can be explained by the statistical model consisting of INDUSTRY, INDUSTRY2, EF, EO, ER, Trade Openness, and Globalization Index variables, while the remaining 10.48% is explained by variables outside the model.

Table 1.
Stationer Test

Variable	Model	Coeffisien	AIC	t-stat	Prob.
Carbon Dioxide (CO2)	*Level*				
	None	0.0248	-1.2794	1.7496	0.9780
	Intercept	-0.0560	-1.3021	-1.0816	0.7098
	*Trend and intercept*****	-0.8754	-1.6058	-3.9016**	0.0250
INDUSTRI	*Level*				
	None	-0.3469	5.9281	-2.6516***	0.0098
	*Intercept*****	-0.8372	5.8529	-3.6477**	0.0108
	Trend and intercept	-1.0366	6.0725	-2.7748	0.2177
$INDUSTRI^2$	*Level*				
	None	-0.2014	10.3058	-1.3734	0.1537
	Intercept	-0.8255	10.2457	-2.9034	0.1760
	Trend and intercept	-0.8255	10.2457	-2.9034	0.1760
	First Difference				
	*None*****	-1.6456	10.3505	-11.4025***	0.0000
	Intercept	-1.6509	10.4044	-11.3002***	0.0000
	Trend and intercept	-3.4270	10.0321	-3.1803	0.1128
Energy Fossil (EF)	*Level*				
	None	0.0198	14.2669	2.1773	0.9913
	*Intercept*****	-0.1809	14.0404	-3.2964**	0.0265
	Trend and intercept	-0.4400	14.0800	-2.3610	0.3909
Energy Oil (EO)	*Level*				
	None	0.0055	12.9222	0.5814	0.8363
	Intercept	-0.1525	12.7841	-2.4122	0.1470
	Trend and intercept	-0.0577	12.8227	-0.4598	0.9800
	First Difference				
	None	-0.7545	12.9089	-3.6068***	0.0008
	Intercept	-0.7850	12.9697	-3.5373**	0.0140
	*Trend and intercept*****	-1.4014	12.8146	-4.6165***	0.0051
Energy Renewable (ER)	*Level*				
	None	0.1090	-3.0666	3.3521	0.9995
	Intercept	0.3342	-3.1605	3.7403	1.0000
	Trend and intercept	0.3479	-3.0920	2.2210	1.0000

	First Difference				
	None	-0.3598	-2.8992	-1.4387	0.1370
	Intercept	-0.5218	-2.8879	-1.8659	0.3427
	*Trend and intercept*****	-1.2033	-2.9809	-6.2028***	0.0001
Trade Openness (TO)	*Level*				
	None	-0.0252	7.5281	-0.7453	0.3848
	Intercept	-0.3880	7.5294	-2.3912	0.1525
	Trend and intercept	-1.2175	7.2919	-3.3324*	0.0850
	First Difference				
	None	-1.8570	7.4973	-5.7687***	0.0000
	*Intercept*****	-2.1894	5.5580	-5.3691***	0.0003
	Trend and intercept	-2.1190	5.6468	-3.4335*	0.0725
Globalization Index (GI)	*Level*				
	None	0.0097	3.6243	2.1131	0.9899
	*Intercept*****	-0.1263	3.3251	-3.2510**	0.0267
	Trend and intercept	-0.2096	3.4624	-1.9606	0.5975

Note: *** Significant at α 1%; ** significant at α 5%; and * significant at α 10%;
**** The model is selected based on the criteria of the smallest AIC, δ<0, and Significant.
Source: Processed Data from Eviews 12

Table 2.
Classic Assumption Test

Classic Assumption Test	Statistic	Prob.
Normality Test (Jarque-Bera)	2.1265	0.3453
Autocorrelation Test (Breusch-Godfrey)	0.2310	0.7972
Heteroskedasticity Test (White)	0.5538	0.8659
Model Spesfication (Ramsey Reset)	0.0008	0.9778

Source: Processed Data from Eviews 12

Table 3.
Goodness of Fit

Goodness of Fit	Statistic	Prob.
Uji F	7.9734	0.0002
R-squared	0.8952	

Source: Processed Data from Eviews 12

Table 4.
***Error Corection Model* Test Results**

Variable	Coeffisien	t-Stat	Prob.
C	0.5062	1.1091	0.2861
D(INDUSTRI)	-0.0002	-0.0280	0.9781

D(INDUSTRI2)	-0.0006	-1.0266	0.3220
D(EF)	0.0003	3.8362***	0.0018
D(EO)	-0.0001	-0.2816	0.7823
D(ER)	0.0557	0.1916	0.8508
D(TO)	-0.0029	-0.7162	0.4856
D(GI)	-0.0097	-0.4924	0.6301
INDUSTRI(-1)	-0.6709	-3.0702***	0.0083
$INDUSTRI^2(-1)$	-0.6702	-3.1052***	0.0078
EF(-1)	-0.6700	-3.1011***	0.0078
EO(-1)	-0.6700	-3.1017***	0.0078
ER(-1)	-0.4054	-1.3254	0.2062
TO(-1)	-0.6792	-3.1053***	0.0078
GI(-1)	-0.6670	-3.0681***	0.0083
ECT	0.6701	3.1011***	0.0078

Note: *** Significant at α 1%; ** Significant at α 5%; and * Significant at α 10%
Source: Processed Data from Eviews 12

Table 5.
Coefficients Short-Term and Long-Term

Variable	Coeffisien	
	Short Term	Long Term
INDUSTRI	-	-0.0012
$INDUSTRI^2$	-	-0.0002
EF	0.0003	0.0002
EO	-	0.0001
ER	-	-
TO	-	-0.0136
GI	-	0.0046

Note: (-) Not significant based on t-test results
Source: Processed Data from Eviews 12

Findings the coefficient of ECT has a positive and significant value, indicating a long-term relationship with a probability of less than α (0.0078 < 0.05) at 0.6701. Further calculations revealed that only fossil energy was significant in the short term. In the long term, only renewable energy was found to be not significant. The squared Industrial variable was not significant in the short term but showed significance in the long term with an effect of -0.0002, suggesting that the Environmental Kuznets Curve (EKC) hypothesis is not supported in Indonesia. Instead, the findings indicate a decrease in environmental degradation (CO2 emissions) due to industrial growth in the long term, or that industry significantly negatively impacts carbon dioxide emissions in the long run.

The relationship between Industry and Carbon Dioxide

The industrial activities are closely linked to CO2 emissions originating from the use of fossil fuels such as oil, coal, and natural gas for energy production in industrial processes. Carbon dioxide emissions from industries contribute significantly to climate change and global warming. In the short-term model, INDUSTRY has a probability above α (0.9781 > 0.05), indicating that INDUSTRY does not have a significant influence on CO2 (Table 4). In the short term, industrial activities in Indonesia have not been optimized, thus CO2 emissions reduction remains suboptimal. Based on Indonesia's GDP according to the Central Statistics Agency (Badan Pusat Statistik) until 2022, the manufacturing industry still plays a crucial role with a GDP value of Rp 3.591 trillion, followed by the wholesale and retail trade sector at Rp 2.516 trillion, agriculture at Rp 2.428 trillion, and mining at Rp 2.393 trillion. Increased industrialization tends to increase CO2 emissions, resembling the early stage of the Environmental Kuznets Curve (EKC). Currently, Indonesia is categorized as a developing country focusing on economic development through increased production and income.

The probability value of INDUSTRY in the long-term model is 0.0083 < 0.05. With a t-statistic of -0.0012 indicating a significant negative impact, aligning with research from Pratama (2022) and Christy & Sakti (2022). The indication that higher industrial activity reduces carbon dioxide emissions by 0.0012 metric tons per capita suggests that increasing industrialization will raise awareness of the importance of carbon emission management in industrial activities. In the future, regulations and policies promoting carbon dioxide reduction will be implemented to encourage environmentally friendly practices within companies. The lack of significance in the short term but significance in the long term indicates that industries in Indonesia are currently not fully aware of the CO2 emissions resulting from their activities. However, there is a growing awareness of environmental concerns expected in the future.

The Relationship between Industri2 and Carbon Dioxide

The addition of the variable Industri2 aimed to test the presence of the Environmental Kuznets Curve (EKC) in Indonesia during the period 1990-2020. In the short term, the model indicates that Industri2 is not significant with $\alpha > 0.05$ (0.3220 > 0.05), suggesting that Industri2 does not affect CO2 emissions in the short term because companies have not efficiently managed industrial activities to reduce carbon dioxide emissions and have not utilized energy sources other than fossil fuels efficiently due to potential profit implications.

However, in the long term, the Industri2 variable significantly affects CO2 emissions with a probability of (0.0078 > 0.05) and has an impact of -0.0002, indicating that an increase in Industri2 decreases carbon dioxide emissions by 0.0002 metric tons per capita. The more efficient the energy used in the industry, the lower the resulting CO2 emissions. Industri2 only has a negative impact in the long term because awareness of carbon dioxide emissions and environmental degradation is currently inadequate. In the initial phase of industrialization, many countries pursued economic growth acceleration without considering the future impacts of their activities. Therefore, the long-term findings reflect growing environmental awareness in industrial activities, as evidenced by the Industri2 coefficient of -0.0002.

The Industri squared variable is not significant in the short term, but it becomes significant in the long term at -0.0002. This suggests that the hypothesis of the EKC remains unproven in Indonesia. The findings regarding the EKC in Indonesia not being supported are attributed to a reduction in environmental degradation (CO2 emissions) as industries expand in the long term or have a significantly negative impact on carbon dioxide emissions in the long term. These findings are consistent with research conducted by Saboori et al. (2012) dan Setiawan & Anwar (2022).

Relationship between Fossil Energy and Carbon Dioxide

Carbon dioxide (CO2) emissions from fossil fuel combustion are a major cause of global climate change. When CO2 is released into the atmosphere, it traps heat from the sun and prevents it from escaping back into space, thereby increasing the Earth's average temperature. This leads to the greenhouse effect and climate change, which can impact the environment, human health, and the economy. In the short term, the value of EF (Fossil Energy) has a significant influence on CO2, with a probability of (0.0018 < 0.05) and a coefficient of 0.0003, indicating that each increase in fossil fuel combustion per capita kWh will also increase CO2 emissions by 0.0003 metric tons per capita. Countries in the Asia-Pacific region, particularly Indonesia, still heavily rely on fossil fuels, especially coal-fired power plants, which pose challenges to achieving net-zero emissions in Indonesia. Transitioning energy use in the short term is difficult because fossil energy remains a critical component of energy security, while renewable energy is still considered unreliable.

In the long term model, there is a significant positive effect of 0.0002, indicating that each increase in fossil fuel combustion per capita kWh will increase carbon dioxide emissions by 0.0002 metric tons per capita. A decrease of 0.0001 metric tons per capita in the long term indicates a shift towards using fossil energy to develop clean and renewable energy sources. These findings are based on research conducted by Yustisia & Sugiyanto (2014) indicating that energy use has a positive and significant long-term impact on carbon dioxide emissions, leading to deteriorating environmental quality and reducing the availability of land to absorb CO_2 emissions.

Relationship between Oil Energy and Carbon Dioxide

Many human activities rely on oil as a fuel source, such as power generation, motor vehicles, and industrial processes. All of these activities involve oil combustion, which results in CO_2 emissions. In the short term, oil energy does not affect CO_2 levels because its probability is greater than α ($0.7823 > 0.05$); there is no impact due to the primary issue of carbon emissions originating from fossil fuels and oil itself. Despite current global trends promoting the shift towards electric energy use, this transition has not been achievable in the short term due to the high demand for petroleum in Indonesia, driven by increasing societal mobility via land transportation. The annual increase in motor vehicles, including passenger transport, freight transport, and motorcycles, has led to a rise in demand for oil fuel.

Carbon dioxide emissions are influenced by oil energy in the long term. Research by Kostakis et al. (2023) demonstrates significant effects on CO_2 emissions, with the EO coefficient in the long term amounting to 0.0001, indicating that each per capita consumption of kWh increases emissions by 0.0001 metric tons per capita. Similar to fossil energy, oil energy has a close relationship with carbon emissions, as the use of this energy increases CO_2 content in the atmosphere, contributing to the greenhouse effect.

Relationship between Renewable Energy and Carbon Dioxide

Renewable energy plays a crucial role in reducing CO_2 emissions because its use does not directly emit CO_2, thereby helping to mitigate greenhouse gases such as carbon dioxide that contribute to global climate change. However, findings from the study concluded that renewable energy has no significant impact on CO_2 emissions in both the short and long term. According to BPS (Statistics Indonesia), the share of renewable energy in Indonesia was only 12.16% in 2021 and 11.27% in 2020, and even less than 10% in 2019. These findings indicate that Indonesia lags significantly in the substantial use of renewable energy. Furthermore, utilizing renewable energy helps maintain environmental balance and ensures sustainable energy availability.

In contrast, according to Saqib et al. (2022) in their study of E-7 countries, there is a significant expectation for reducing carbon pressure through renewable energy and technological innovation, highlighting how renewable energy and technological advancements can enhance environmental quality. This underscores the importance of increasing environmental awareness.

Relationship between Trade Openness and Carbon Dioxide

Trade openness can enhance prosperity and economic growth, ultimately increasing production and consumption, which may also lead to higher CO_2 emissions. The value of Trade Openness (TO) shows no significant impact on CO_2 emissions in the short term, consistent with the analysis conducted by Adebayo et al. (2021), indicating that Indonesia's economic openness to the outside world does not increase carbon dioxide emissions. In contrast, in the long run, TO has a significant negative impact on CO_2 emissions by -0.0136, suggesting that each increase in trade can reduce carbon dioxide emissions by 0.0136 metric tons per capita. Trade openness does not always lead to increased CO_2 emissions; in this finding, trade openness can help reduce emissions by enabling technology transfer and foreign investment that promotes the development of more effective and efficient technologies. The trade ratio between exports and imports does not significantly affect CO_2 emissions because Indonesia's trade ratio is less than 100 percent and is relatively low. This is due to the composition of commodities exported by Indonesia being dominated by the primary sector, while the manufacturing sector remains relatively low.

Indonesia's leading export products according to The Center for Export Training and Human Resource Development (PPEJP) include shrimp, coffee, palm oil, cocoa, rubber, textiles and textile products, footwear, electronics, motor vehicle components, and furniture. This relates to the low CO_2 emissions generated in export and import activities. include shrimp, coffee, palm oil, cocoa, rubber, textiles and textile products, footwear, electronics, motor vehicle components, and furniture. This relates to the low CO_2 emissions generated in export and import activities.

Relationship Between Globalization Index and Carbon Dioxide

Globalization Index can enhance economic growth and prosperity, which in turn may increase production, consumption, and ultimately lead to higher CO_2 emissions. Moreover, with increased international trade, transportation, and shipping of goods also rise, contributing to higher CO_2 emissions. In the short term, GI does not have a significant impact on CO_2 as it exceeds α (0.6301 > 0.05).

However, in the long term, it has a significant positive effect on CO_2, indicated by a probability of (0.0083 < 0.05) with a coefficient of 0.0046. Thus, it can be inferred that an increase in the Globalization Index will raise carbon dioxide emissions by 0.0046 metric tons per capita. These findings are consistent with research results from (Kostakis et al., 2023).

CONCLUSION AND RECOMMENDATION

Conclusion

This study examines the variables influencing carbon dioxide emissions in Indonesia from 1990 to 2020 using the Environmental Kuznets Curve (EKC) hypothesis. The results indicate that in the short term, Industry, Industry2, EO, ER, TO, and GI do not affect CO_2 emissions. However, in the long term, Industry, Industry2, EF, EO, TO, and GI have an impact on carbon dioxide emissions, while ER does not affect emissions in either the short or long term. Industry squared is not significant in the short term but becomes significant in the long term, showing an effect of -0.0002. This suggests that the EKC hypothesis is evident in Indonesia, indicating that an increase in Industry2 will reduce carbon dioxide emissions by 0.0002 metric tons per capita; the more efficient the energy used in industry, the lower the resulting CO_2 emissions. This aligns with Kuznets' theory that environmental degradation will reach its peak and then decline as environmental awareness grows.

Recommendation

Understanding the limitations of using fossil energy and oil derived from the Earth, it is hoped that energy use can be more effectively and efficiently utilized. Reducing environmentally unfriendly energy consumption has direct impacts on the environment. This research is expected to indirectly promote the development of sustainable and environmentally friendly energy resources. Additionally, continuous research on carbon dioxide emissions is crucial and appealing for students of Development Economics in particular.

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