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The Link between Economic Growth, Electricity Consumption, and CO_2 Emissions: Evidence from Indonesia

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Abstract

This study investigates the relationship between economic growth, electricity consumption, and CO2 emissions in Indonesia. The data utilized time series for 1971-2020 obtained from the WDI database 2021. The method utilized the ADRL and VEC models. The findings indicate that in the long run, economic growth and electricity consumption positively affect CO2 emissions. The short-run effect that occurs from economic growth is significant and negative, while the lag of CO2 emission is positive on CO2 emissions. There is a two-way causality between economic growth and electricity consumption in the short run. There is a unidirectional causality flowing from CO2 emissions to economic growth. A significant ECT coefficient has confirmed that the long-run relationship between variables in the model used is valid. The policies offered are applying emission taxes, encouraging energy conservation to control emissions, and encouraging efficient and sustainable electricity supply.

Keywords:
electricity consumption; cointegration; CO2 emission; economic growth

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INTRODUCTION

The supply of electricity is one of the factors driving economic growth in every country. The need for electricity has become a significant element in the life of every household. This sector provides a vital role in influencing all activities of economic actors, especially in economic activities. On the other hand, power plants in Indonesia are still very dependent on coal fuel. According to records, coal is the primary energy source for electricity generation in Indonesia; 58 percent of the fuel for power generation in Indonesia is coal. Coal is an inaccessible natural resource with high selling value in international trade. The challenges and problems that arise due to a large amount of coal disaster can produce carbon dioxide (CO2) emissions which worsen environmental quality. This condition is essential when renewable energy is not widely used as an alternative energy source for electricity generation. Another challenge is that the efficient exploitation and development of a country's energy resources are crucial for economic progress and the welfare of society in a sustainable manner.

Inadequate development in Indonesia and inefficient energy sector management have created a demand for supply, especially in unreached rural areas. Electricity supply is one of the country's most popular energy sources. On the other hand, the shortage of electricity supply due to high demand has suppressed the fulfillment of electricity consumption in this country. This electricity supply deficit has left many households and companies operating in the country with electricity generated from the consumption of coal and petroleum fuels. The effect of meeting electricity needs can directly impact climate change and an increasingly massive climate, releasing large amounts of CO2 emissions. Globally, among several pollutants that contribute to climate change, CO2 emissions account for more than 75 percent of greenhouse gas emissions, with about 80 percent being generated by the energy sector (Akpan & Akpan, 2012).

Environmental problems become very important when there is massive climate change. As proposed by many previous studies, it is not uncommon for every country to try to increase economic development by using fossil energy technology. This effort encourages economic growth in the country, but each country still reports the impact on the quality of the environment in that country. In addition, energy is the backbone of the production process because it converts raw materials into goods, and production leads to international trade.

The theory of modernization of development is the basis of previous studies that the impact of development can increase greater energy consumption; this can directly increase CO2 emissions. This theory also explains that human activities are closely related to development. This condition is also a basic Kuznets theory that is analogous to the environmental hypothesis of the Kuznets curve (EKC) that explains the relationship between welfare and the environment. The transformation of development through several stages, such as the first stage, economic development, is known as the pre-industrial economy, the second stage is called the industrial economy, and the third stage is known as the post-industrial economy (service economy). It is assumed that this movement

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will increase the use and management of natural resources, which will decrease the environment's quality. After that, industrialization can expand its role in increasingly stable domestic product orders. The existence of foreign investment has also driven the economic transformation from the agricultural sector to the industrial sector. Increasing the role of the industrial sector in improving a country's economy will have a direct impact on increasing pollution in that country (Panayotou, 2003).

The direction of causality between economic growth, electricity consumption, and CO2 emissions can provide an analogy that can state that the higher the demand for electricity supply is assumed to affect domestic economic growth. This causality can also be done by expanding by implementing policy policies. In addition, the need for electricity can lead to more significant CO2 emissions (Cowan et al., 2014). On the other hand, tremendous economic growth can lead to higher demand for electricity supply. Investigating the direction of causality between these variables is crucial because the implications of energy demand policy can be different for each direction. The existence of a two-way causality between electricity consumption and economic growth can be analogized as feedback. This condition implies that electricity consumption and economic growth together can support a conservative energy policy, which can have a negative impact on economic growth (Cowan et al., 2014). The unidirectional relationship between electricity consumption and economic growth can be analogized as growth. This relationship means that the country can be provided with energy so that electricity consumption can have a direct or indirect effect on economic growth. The growth hypothesis implies that any conservative energy policy will have a negative impact on economic growth (Cowan et al., 2014; Shahbaz et al., 2016).

However, if the causality goes from economic growth to energy consumption which can be analogized as a conservation hypothesis, the economy is less dependent on energy, and energy policy policies can be implemented with little or no adverse effects on economic growth (Bashir et al., 2019; Cowan et al., 2014; Wolde-Rufael, 2014). The absence of a causal relationship between economic growth and electricity consumption can be analogized as a neutrality hypothesis. This condition raises the question that there is no long-run relationship between the two variables and that any consumption policy, either expansive or conservative, has no effect on economic growth (Cowan et al., 2014; Wolde-Rufael, 2014).

Seeing the current condition, the economic growth rate in Indonesia during 1985-2017 grew positively, with an average growth of 5.07 percent. In the same period, the trend of primary energy consumption was 5.26 percent, and CO2 emissions grew by 5.90 percent: which increased the economy and CO2 emissions in Indonesia (Bashir et al., 2021). Likewise, in 1998 and 2008, there was a phenomenon of the global financial crisis. Countries in the world mostly felt this crisis. Not only Indonesia, but economic activity experienced a sluggishness, resulting in negative economic growth. Moreover, the political situation in Indonesia is not conducive.

The role of electricity consumption in economic growth has been carried out intensively but the evidence so far is contradictory and inconclusive (Ozturk & Acaravci, 2010; Shahbaz et al., 2014). he essence of hope is whether electricity consumption encourages, inhibits, or is neutral to economic growth. The literature has identified four possible hypotheses regarding a causal relationship between electricity consumption and economic growth (Menyah & Wolde-Rufael, 2010). The first growth hypothesis postulates that a one-way Granger causality goes from electricity consumption to economic growth. This postulate means that policies that reduce electricity consumption can lead to economic growth. The second is the conservation hypothesis, which implies a one-way causality from economic growth to electricity consumption, where economic growth encourages higher electricity consumption. Based on this hypothesis, policy consideration is given because a strategy to reduce electricity consumption may not have a negative impact on economic growth. After all, it allows a reduction in electricity consumption without economic growth (Gielen et al., 2019). While the primary fuel for electricity generation in this country is dominated by fossil fuels, in the literature, it is recorded that 58 percent is coal fuel; the rest is fuel oil and steam energy. In addition, the large number of land uses with the use of chemicals and industrial activities that use large amounts of fossil fuels also cause environmental degradation (Akil et al., 2020; Rajaguru & Khan, 2021).

This study refers to several studies, such as the study conducted by Hirsh & Koomey (2015), explaining changing trends in the relationship between growth in economic activity and electricity use, and finds that these new trends require utility system stakeholders to rethink old assumptions and prepare to face the new reality of lower electricity consumption growth rates. The study conducted by Atchike et al. (2020) investigated the relationship between electricity consumption, foreign direct investment, and economic growth and found evidence of a unidirectional causality of electricity consumption for economic development and foreign direct investment and a long-run relationship with an adjustable rate of 60.72 percent. The study by Bah & Azam (2017) explored the causal relationship between electricity consumption, economic growth, financial development, and CO2 emissions, and found that there is no causality between electricity consumption and economic growth. This condition indicates that the neutrality hypothesis holds for South Africa throughout the study period.

In addition, there is unidirectional causality from CO2 emissions to electricity consumption and unidirectional causality from financial development to CO2 emissions. In addition, a study conducted by Rahman (2020) found a long-run relationship between these variables; electricity consumption and economic growth positively and significantly affect CO2 emissions in these countries. On the other hand, globalization has a significant negative impact on CO2 emissions that has implications for improving environmental quality. A study by Thaker et al. (2019) found that electricity consumption positively affects economic growth. In addition, there is a unidirectional Granger causality from electricity consumption to real GDP but not vice versa. A different study by Akil et al. (2020) found that perception is critical for increasing EEA utilization rates and improving user habits to save electricity. The information presented is helpful as a reference for energy policy planning for the housing sector in Indonesia.

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This study is still very rarely carried out in Indonesia. A different perspective from this study shows that using electrical energy and economic growth have various effects on increasing CO2 emissions. Challenges Indonesia is currently faced with increasing energy consumption and GDP, which is a significant challenge in the context of environmental quality. As a result, the current study can assist policymakers in pursuing more pragmatic planning and maximizing decision-making regarding increasing CO2 emissions in general and in Indonesia. This study also offers some significant contributions to the existing literature and provides more detailed information that can be used for various purposes, such as designing more sensible energy conservation policies or electricity saving programs in Indonesia. It investigates the impact of electricity consumption and economic growth on CO2 emissions in Indonesia. In addition, this study uses an auto-regressive distributed lag approach and vector error correction model to see the short and long-run relationship between variables. In addition, we can see the relationship between variables in the study for the benefit of future policy.

METHODS

This study focuses on the relationship between economic growth, electricity consumption, and CO2 emissions and investigates this relationship in the long or short-run. The variables used in the study include economic growth (real GDP per capita), electricity consumption (kWh per capita), and CO2 emissions (metric tons per capita). This study used time-series data, the observation period 1971-2020. The data source is obtained from the official World Bank. The descriptions of the operational variables in this study are shown in Table 1.

Table 1. Data, Description, and Sources

Variable	Description	Unit	Source
CO2	CO_2 emissions	Kiloton per capita	World Bank
GDP	Real GDP per capita	US$, constant 2010	World Bank
ELEC	Electricity consumption	kwh per capita	World Bank, CEIC

The unit root tests are available in applied economics to determine the nature of the variable stationarity. Unit root testing of each time series data is using the Augmented Dickey-Fuller test (ADF-test) criteria. This test detects whether time series data contain the unit root or not. If the data contains a unit root, then an appropriate estimation method is the autoregression vector, but the data cannot be separated from the unit root. The next step is determining how long the optimal lag is proper in the causality model. Determination of the optimal lag length is vital in modeling causality. If the optimal input lag is too short, it is feared that it cannot explain the overall model dynamics. However, too long an optimal lag will result in an inefficient estimate due to reduced degrees of freedom (minimal sample models). Therefore, looking at the optimal lag before doing the causality estimation model is necessary.

The Johansen cointegration test is used to see the long-run equilibrium relationship of several variables. One of the methods of cointegration test is the Johansen method. The procedure begins with identifying data, testing data, testing data, testing the degree of integration, and testing cointegration with the Johansen method. The Johansen cointegration test uses two statistical tests: the trace statistic and the maximum-eigenvalue. The method used in the Johansen cointegration test compares the calculated value in the critical value test statistic. If the calculated value of the statistical trace test statistic and the maximum eigenvalue are more significant than the critical value, there is cointegration (Johansen, 1988).

The next approach is to test the ARDL model developed by Pesaran et al. (2001) to investigate the cointegration for the long-run relationship between economic growth, electricity consumption, and CO_2 emissions in Indonesia. The various cointegration approaches have been applied to test the existence of cointegration between variables in various studies. The approach based on the equations developed by Engle & Granger (1987) and Johansen (1996) requires that all equations be integrated. The ARDL model testing approach is more appropriate than other cointegration approaches. This approach is more suitable after the variable is found to be stationary at *I*(1) or *I*(0). The ARDL boundary testing approach will provide efficient and consistent empirical evidence for small sample data (Narayan & Smyth, 2005). This approach investigates the short-run and long-run parameters instantly. The infinite error correction model (ECM) version of the ARDL model in this study is presented as follows

$$\mathrm{lnCO2_t} = \alpha_1 + \alpha_2 lnCO2_t + \alpha_3 lnELEC_t + \alpha_4 lnGDP_t + \textstyle\sum_{i=1}^{m} \beta_i \, \Delta\mathrm{lnCO2}_{t-i} + \sum_{j=0}^{n} \gamma_j \, \Delta\mathrm{lnELEC}_{t-j} + \sum_{k=0}^{o} \eta_k \, \Delta\mathrm{lnGDP}_{t-k} + ECM_{t-1} + \varepsilon_{1t} \quad (1)$$

Where: t is the time period (t = *1, ..., t*) and shows the lag of each variable; lnCO2 is indicates pollution emissions; lnELEC is electricity consumption; and lnGDP is GDP real per capita; and ε_{1t}, ε_{2t} and ε_{3t} assuming the error rate in the model (error-term).

The second model to reveal the direction of the causality between economic growth, electricity consumption, and CO_2 emissions, it is investigated by applying the VECM Granger causality approach after confirming the cointegration between variables. According to Granger (1969) the vector error correction model (VECM) is more appropriate to check the causality between the series if the variables are integrated in *I*(1). The VECM is a finite form of the autoregressive indefinite vector and restrictions are imposed if there is a long-run relationship between the circuits. The error correction model (ECM) system uses all series endogenously. This system allows the predicted variable to explain itself both by its own lag and the indolence of the force variable as well as in error-correcting terms and in terms of residual. The VECM equation is presented as follows:

$$(1-L)\begin{bmatrix} \ln GDP \\ \ln ELEC \\ \ln CO2 \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} + \sum_{i=1}^{p} (1-L) \begin{bmatrix} \alpha_{11i}\alpha_{12i}\alpha_{13i} \\ \beta_{21i}\beta_{22i}\beta_{23i} \\ \gamma_{31i}\gamma_{32i}\gamma_{33i} \end{bmatrix} x \begin{bmatrix} \ln GDP_{t-i} \\ \ln ELEC_{t-j} \\ \ln CO2_{t-k} \end{bmatrix} + \begin{bmatrix} \delta \\ \rho \\ \varphi \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \rho_{1t} \\ \rho_{2t} \\ \rho_{3t} \end{bmatrix} \quad (2)$$

The long-run relationship between these variables is further confirmed by the statistical significance of the lagging error correction term (ECT_{t-1}). The ECT_{t-1} estimate

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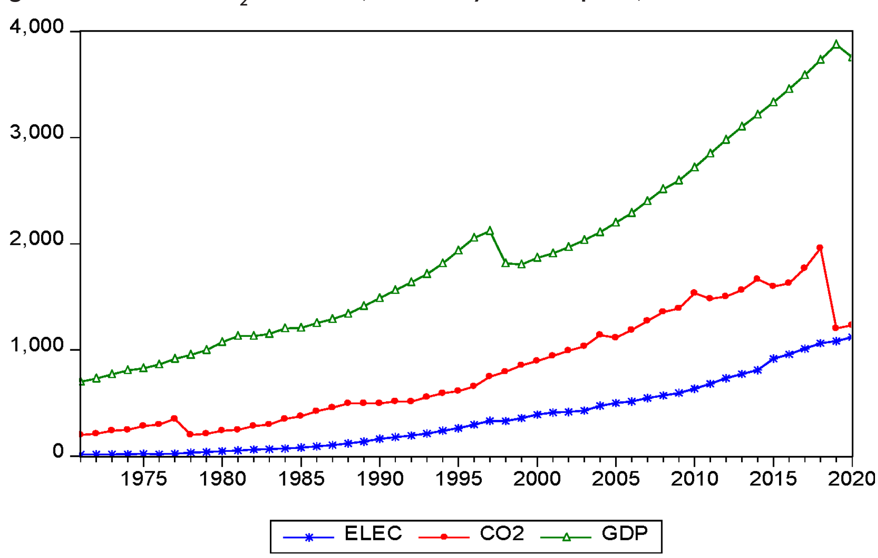
also shows the velocity of convergence from the short run to the long run equilibrium path. The vector error correction method is appropriate to test the causality between co-integrated variables and the causality in at least one direction. The VECM also distinguishes causality between the short and long run. The VECM is also used to detect causality in the long-run and short-run respectively. The term lagging error t-test is ECT_{t-1} with negative sign was used to test the long-run causal relationship and the X^2 combined statistical significance of the first difference estimate of lagging independent variables was used to investigate short-run causality. Granger's economic growth causes carbon emissions if $\alpha_{12,i} \neq 0\forall_i$ are found to be statistically significant.

RESULTS AND DISCUSSION

The development of CO2 emissions in Indonesia is currently showing a positive trend, CO2 emissions produced by Indonesia in 2020 have reached 1120 million tons, with an average of 364 million tons, and the growth rate is 3.78 percent during the 1971-2020 period. Most of the CO2 emissions produced by Indonesia come from illegal logging or peat forest fires which always occur during the dry season (Santika et al., 2017). In addition, CO2 emissions are also generated from burning fossil fuels for energy in the industrial and transportation sectors. Economic development in Indonesia directly impacts the growth of other economic sectors.

The development of electricity consumption in Indonesia during the 1971-2020 period showed a positive trend throughout the year (Figure 1). The growth in average electricity consumption during the study period reached 9.30 percent. It cannot be denied that Indonesia is the world's fifth-largest coal producer and the world's tenth-largest producer of coal reserves. In addition, 58 percent of the primary energy source for electricity generation in Indonesia still uses coal. The increase in electricity consumption in Indonesia has worsened industrial development, and the population's production activities can directly increase electricity consumption.

Figure 1. Trends in CO_2 Emissions, Electricity Consumption, and Economic Growth



Economic growth seen from per capita income (purchasing power parity) from 1971-2020 showed a positive trend. Figure 1 shows that it is 3.49 percent. The main factor driving Indonesia's economic growth is still dominated by domestic demand, especially in household consumption, investment, and government consumption. Despite this, Indonesia's economic growth has slowed in the last five years. This condition is related to the relatively limited export performance in line with the weakening trend in world trade because of pressure from external turmoil.

Table 2. Descriptive Statistics Results

Descriptive	$lnCO_2$	lnELEC	lnGDP
Mean	6.469	5.246	7.448
Median	6.451	5.634	7.504
Maximum	7.579	7.021	8.262
Minimum	5.296	2.664	6.552
Std. Dev.	0.719	1.356	0.489
Skewness	-0.155	-0.517	-0.088
Kurtosis	1.660	1.999	1.978
Jarque-Bera	3.940	4.314	2.237
Probability	0.139	0.115	0.326
Observations	50	50	50
Correlation			
$lnCO_2$	-	-0.657	-0.724
lnELEC	-0.657	-	0.632
lnGDP	-0.724	0.632	-

Table 2 also reports the correlation matrix between the independent variables, indicating that the relationship matrix between the independent variables in this study has medium and low categories. Thus, this study model does not have multicollinearity statistical assumptions, which means that the study model can display the following stages.

Table 3. The Unit Root test

Variable	Unit root test				
	Critical value (%)	level		first difference	
		t-stat	ADF-test	t-stat	ADF-test
ln CO2	1%	-3.571		-3.574	
	5%	-2.934	-1.396	-2.924	-7.685***
	10%	-2.529		-2.599	
ln ELEC	1%	-3.643		-3.446	
	5%	-2.922	-3.018	-2.978	-5.096***
	10%	-2.599		-2.592	
ln GDP	1%	-3.573		-3.546	
	5%	-2.829	-1.127	-2.927	-4.971***
	10%	-2.593		-2.592	

Note: ***1%, **5%, *10% at significant level

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Table 2 shows a statistical description of the study data for each variable. According to the results of the descriptive statistics, it can be interpreted that the central tendency of the variable is relatively good. The standard deviation results show a relatively small value. This result means that the standard deviation or dispersion is still relatively average. The Jarque-Bera results also show that the study's data were normally distributed with an observation period of 50 years.

Based on the study results on the variables presented in Table 3, it shows that in the stage testing, all variables contain unit roots, which means they are not stationary, meaning that at this stage, this study variable cannot be made in the next stage. Based on the alpha value of 5 percent in the test in the first stage, all variables do not contain a unit root. It is found that the time series data used is stationary. Thus, the variables that can be used in the study are in the first stage.

Table 4. Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	172.557	-	7.54e-08	-7.886	-7.763*	-7.841
1	185.727	23.890	6.22e-08	-8.080	-7.588	-7.899
2	198.638	21.618*	5.23e-08*	-8.262*	-7.402	-7.945*
3	206.832	12.576	5.52e-08	-8.224	-6.996	-7.771
4	209.861	4.226	7.53e-08	-7.947	-6.349	-7.357
5	220.024	12.763	7.53e-08	-8.001	-6.035	-7.276
6	224.003	4.441	1.03e-07	-7.767	-5.432	-6.906

* Indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

The results of the optimal lag length test on the time series data presented in Table 4 reports the optimal lag criterion in the data is lag two, this can be seen from the LR, FPE, AIC, SC, and HQ criteria which show that statistically, it supports lag two, variable This is tested with a distributed lag model. The cointegration relationship can only be formed by integrated variables to the same degree.

Table 5. Johansen cointegration test

Hypothesis	Trace test	Prob.**	Max-Eigen test	Prob.**
r = 0*	36.798	0.006	24.466	0.016
r ≤ 1	12.331	0.141	6.543	0.544
r ≤ 2*	5.788	0.016	5.788	0.016

Trace and Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
*Denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Table 5 shows the results of the cointegration test. This test is to obtain long-run relationships between variables in modeling. This test is done as a starting point to avoid false regression. If the linear combination between variables is stationary or r = I (0). This result means that even though the variables used are not stationary, in the long run, these variables tend toward balance. Therefore, the linear combination of these variables is called cointegration regression, and the resulting parameters are called long-run coefficients. The test results presented in Table 5 report that the variables of economic growth, electricity consumption, and CO2 emissions in Indonesia are co-integrated from the two tests through Trace and Max-Eigen. The trace statistical test indicates that three equations have cointegration at a significance level of 5 percent. While the Max-Eigen statistical test also shows three co-integrated equations at the 5 percent significance level. From 1990-2018, Indonesia's fourth economic growth variable, electricity consumption and CO2 emissions have a positive long-run balance.

Table 6. Error correction representation of the selected ARDL model

Dependent Variable: $lnCO_2$				
Long-run result				
Regressors	Coefficient	S.E.	t-stat	Prob.*
Intercept	0.380	1.677	0.227	0.821
lnGDP	0.291	0.107	2.719	0.009***
lnELEC	0.611	0.299	2.043	0.046**
R^2 = 0.926; Adj.R^2 = 0.923; F-stat = 29.005***; DW-stat = 2.295				
Short-run result				
Regressors	Coefficient	S.E.	t-stat	Prob.*
Intercept	0.080	0.014	5.714	0.000***
ΔlnGDP	-0.497	0.112	-4.437	0.000***
ΔlnELEC	-0.162	0.253	0.640	0.525
$\Delta lnCO_{2\,t-1}$	0.135	0.064	2.109	0.041**
ECM_{t-1}	-0.522	0.127	-4.110	0.000***
R^2 = 0.745; Adj.R^2 = 0.721; F-stat = 31.421***; DW-stat = 1.994				
Diagnostic test	*X^2 - test*			
Serial correlation	0.485 [0.619]			
Heteroscedasticity	0.892 [0.477]			
Normality	3.765 [0.796]			

Notes: ***1%, **5% and *10% at significant levels respectively.

Table 6 reports the estimation results of the ARDL model showing that the estimated parameters are exogenous in the long run. The intercept value is 0.380, it is developed that statistically CO_2 emissions automatically increase by 0.380 percent with the assumption that other factors are constant. The parameter value for economic growth of 0.291 that

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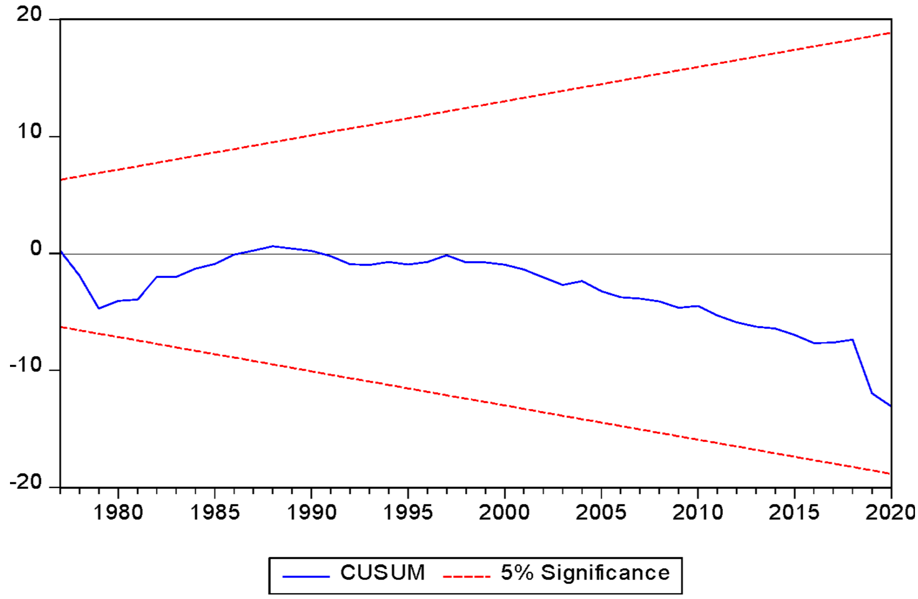
can be increased by 1 percent in economic growth will increase CO_2 emissions by 0.291 percent. Statistically, economic growth has a positive sign and a significant effect on CO_2 emissions with other assumptions being constant. These findings support the results of a study conducted by Bashir et al. (2021); Baydoun & Aga (2021); Lin et al. (2018); Majewska & Gierałtowska (2022); and Rahman (2020). On the other hand, contrary to the results of a study conducted by Aye & Edoja (2017); Chontanawat (2020); and Osadume & University (2021).

Likewise for electricity consumption that has a parameter value of 0.611 that means that electricity consumption increases by 1 percent will increase CO_2 emissions by 0.611 percent assuming other factors are constant. These findings empirically can be interpreted that an increase in economic activity and electricity demand in the long run directly increases CO_2 emission (Khan et al., 2020; Osobajo et al., 2020). These policy changes in the long run have not been effective in reducing CO_2 emissions, this has an impact on the balance and carrying capacity of nature which in turn causes environmental changes and increased pollution (Manisalidis et al., 2020). Not only that, but other impacts are natural disasters such as floods and other natural disturbance (Davidsson, 2020). The use of energy, especially in the electricity sector, is still relatively large in Indonesia, which can encourage an increase in the concentration of CO_2 emissions. In the ecological theory, all energy sources have an impact on the environment, especially fossil fuels such as coal, oil, and natural gas are far more dangerous than renewable energy sources by most actions, including air and water pollution, damage to public health, full of wildlife and habitats, global water use, land use, and emissions. These findings are in line with and support the study results Arouri et al. (2012), Fauzi (2017), Shahbaz et al. (2013), and Wang et al. (2011) which also found evidence that energy consumption for electricity has a significant and positive influence on the environment.

Table 6 also reports the estimation results in the short run. The intercept value is 0.080, which indicates that CO2 emissions can increase independently by 0.080 percent, assuming other factors do not change. The value of the GDP variable parameter in the short run is -0.497. This result indicates that an increase in the economic growth of 1 percent can reduce CO2 emissions is -0.497 percent assuming other factors are constant, which means that economic growth negatively affects CO2 emissions. This indicates that the government can still control environmental risks due to increased economic activity through standard policies in the short run. Likewise, the negative parameter value of electricity consumption is -0.162 but has no significant effect on reducing CO2 emissions.

Meanwhile, the lag of the CO2 emission parameter is 0.135, which means that a 1 percent increase in CO2 emissions from the previous year can increase CO2 emissions is 0.135 percent. This result indicates that last year's CO2 emissions were positive and had a significant effect on CO2 emissions. As anticipated, the error correction model (ECM) is negative (0.522), which indicates that corrections made in the previous period can be corrected in the next period.

Figure 2. CUSUM Stability Test



In theory, economic growth means an increase in real output created from production and consumption activities, in the short run an increase in economic activity can still be controlled by standard policies and an increase in electricity demand in the short run does not have a significant effect on increasing CO_2 emissions in Indonesia. These findings are in line with and support the study results by Bargaoui et al. (2014); Liu et al. (2016); and Wang et al. (2017) found evidence that economic growth has a significant effect on increasing CO_2 emission in various developing countries.

Figure 2 shows the Cumulative Sum of Recursive Residual (CUSUM) stability test, which shows that the model used is stable because the CUSUM line is still between the 5 percent significant line. Thus, the emission of CO2 emissions changes economic growth and increases electricity consumption in Indonesia.

The results of the Granger causality test in the short term are presented in Table 7; there is evidence of a unidirectional relationship that runs from CO_2 emissions to economic growth, this relationship occurs when uncontrolled CO_2 emissions control freely stimulates economic growth. The findings are unavoidable considering that policies in promoting economic growth have not been in line with controlling the impact of pollution. This finding confirms the results of a study conducted by Azam et al. (2016), Issaoui et al. (2015), Osobajo et al. (2020), and Saidi & Hammami (2015). A unidirectional relationship from economic growth to CO_2 emissions was found in the study conducted by Adom et al. (2012), Kim et al. (2010), Radmehr et al. (2021), and Shikwambana et al. (2021). These findings contradict the study conducted by Kasperowicz (2015), and Odugbesan & Rjoub (2020) found that there is no causality between economic growth and CO_2 emissions.

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Table 7. VECM Granger Causality test

Dependent Variable	Causality test			*Log-run* ECT_{t-1}
	Short-run			
	$\Sigma\Delta lnCO2_{t-1}$	$\Sigma\Delta lnGDP_{t-1}$	$\Sigma\Delta lnELEC_{t-1}$	
$\Delta lnCO2_t$	-	0.576 (0.749)	3.102*** (0.001)	-0.117*** [-3.179]
$\Delta lnGDP_t$	-3.039** (0.042)	-	0.917 (0.632)	-0.122** [-2.181]
$\Delta lnELEC_t$	0.635 (0.728)	6.238** (0.004)	-	-0.045*** [-4.672]

Note: *10%, **5% and ***1% at significant levels respectively; ( ) probability; [ ] t-stat

Government policies encourage increased economic activity directly impacting household electricity needs, especially in urban areas. There is also evidence of the direct unidirectional relationship between economic growth to electricity consumption. These findings support the results of a study conducted by Bayar & Özel (2014), Cowan et al. (2014), Rahman (2020), Shengfeng et al. (2012), Thaker et al. (2019), and Thapa-Parajuli et al. (2021). The results of the study which also got the opposite result were carried out by Altunbas & Kapusuzoglu (2011), Atchike et al. (2020), Bildirici (2012), Shengfeng et al. (2012), and Thaker et al. (2019) found a unidirectional relationship from electricity consumption to economic growth. The results contradict this study conducted by Bah & Azam (2017), and Ibrahiem (2018) found no causal relationship between economic growth and electricity consumption.

The policy of meeting the increasing electricity demand is the main factor causing the increase in coal consumption in Indonesia, which directly increases CO2 emissions. Therefore, it is necessary for the role of all parties to encourage energy savings to maintain energy security and reduce the increase in CO2 emissions in this context. Likewise, there is a unidirectional relationship between electricity consumption and CO2 emissions at a significance level of 5 percent. This finding supports the results of a study conducted by Al-Mulali & Che Sab (2018), Bildirici (2012), Chontanawat (2020), and Rahman (2020). Conflicting findings from the results of a study by Bah & Azam (2017), and Rahim et al. (2018).

The cointegration estimation results show that the error correction adjustment coefficient in this equation shows evidence of a speed of convergence towards a long-term balance between economic growth, electricity consumption, and CO2 emissions in Indonesia at a significant level of 5 percent. The error correction term (ECT) coefficient of lnCO2 is negative and statistically significant at 5 percent with a speed of convergence towards equilibrium of 11.7 percent. Therefore, it is assumed that in the short run, lnCO2 will be adjusted by 11.7 percent of last year's deviation from equilibrium. Furthermore, lnGDP is negative and statistically significant at 5 percent with a speed of convergence towards balance adjustment of 12.2 percent. Therefore, it is assumed that in the short run, lnGDP will be adjusted by 12.2 percent of last year's deviation from equilibrium. Likewise, the error correction term coefficient for lnELEC is negative and significant at the 5 percent level with the speed of convergence towards balance adjustment of 4.5 percent. Therefore, it is assumed that in the short run, lnELEC will be adjusted by 4.5 percent of last year's deviation from equilibrium. This finding is in line with the results of studies conducted by Bah & Azam (2017); Khan et al. (2020;) Rahim et al. (2018); Salahuddin et al. (2015); Soytas et al. (2007); and Thaker et al. (2019).

The variance decomposition test aims to measure the contribution and composition of the effect of each variable on the endogenous variables over the following ten periods. Table 8 reports that the standard deviation shocks caused by economic growth and electricity consumption in period 10 contributed 6.27 percent and 23.88 percent, respectively, to CO2 emissions. The composition of the prohibition on electricity consumption is relatively dominant in Indonesia's economic growth of CO2 emissions. However, this finding predicts that the contribution of electricity consumption and economic growth to environmental damage in Indonesia is still relatively low compared to the contribution of the CO2 emission variable over the next ten years.

Table 8. Forecast error variance decomposition analysis

Variable	Period	S.E.	ln CO2	ln GDP	ln ELEC
ln CO2	1	0.113	100.000	0.000	0.000
	5	0.161	87.917	5.580	6.503
	10	0.183	69.855	6.268	23.877
ln GDP	1	0.033	0.0215	99.979	0.000
	5	0.080	5.298	94.693	0.009
	10	0.093	11.115	87.118	1.767
ln ELEC	1	0.071	13.424	3.723	82.853
	5	0.170	11.707	11.584	76.709
	10	0.221	9.504	14.484	76.011

Cholesky Ordering: ln CO2, ln GDP, ln ELEC

The decomposition variance of the existing energy consumption variable, the standard deviation of shocks originating from the CO2 emission variable, and electricity consumption on economic growth contributed 11.12 percent and 1.77 percent in the following ten periods. This result shows that CO2 emissions have a more dominant influence on economic growth than electricity consumption, but during the early to the late period, electricity consumption shows an increasing trend towards economic growth as the effect of CO2 emissions. This finding assumes that CO2 emissions occur because of more efficient energy consumption. Meanwhile, electricity consumption shows a positive influence on economic growth. This condition is related to the relative slowdown in Indonesia's economic growth from the previous year due to the global economic contraction.

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The results of the decomposition of the electricity consumption variable variance, the influence of standard deviation shocks originating from the CO2 emission variable, and economic growth contributed 9.50 percent and 14.48 percent, respectively, to electricity consumption in the following ten periods. This result shows that economic growth has a more dominant effect on electricity consumption for ten periods. Then the electricity consumption variable contributes to the electricity consumption by 76.01 percent. This condition shows that electricity consumption in Indonesia has led to an increase in electricity consumption itself, even though these developing countries need to control energy consumption for electricity optimally and efficiently because energy consumption that exceeds the limit can have a negative impact on environmental, economic, and social sustainability.

CONCLUSION

Based on the research findings, the conclusions of this study are as follows. First, evidence from the ARDL model shows that economic growth and electricity consumption significantly affect CO2 emissions in the long run. In contrast, in the short run, economic growth is negative, emission lags CO2 is positive and has a significant effect on CO2 emissions, while electricity consumption does not affect CO2 emissions in Indonesia. Second, evidence from the VECM Granger causality shows that in the short run, there is unidirectional causality from economic growth to electricity consumption. Besides that, there is unidirectional causality from electricity consumption to CO2 emissions and a unidirectional causality flowing from CO2 emissions to economic growth. In contrast, evidence from the ECT coefficient value on the Granger causality VECM, in the long run, shows a speed of convergence towards a balance adjustment from the short to the long run in the equations of economic growth, electricity consumption, and CO2 emissions.

Unexpectedly, electricity consumption increases CO2 emissions, and economic growth increases electricity consumption, and CO2 emissions drive economic growth because pollution control is less than optimal in the short term. The implications of the study model can be the basis and source of information in environmental policy improvement policies, this country needs to implement development policies that prioritize pollution control, emission taxes, and energy conservation on electricity consumption, such as the use of renewable energy consumption can be an alternative to CO2 emission control. The policy offered in this study is to encourage the implementation of emission taxes and energy conservation, especially in the provision of efficient and sustainable electricity, to increase the productivity of energy-efficient project implementation to achieve GDP growth.

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