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Research Article

Examining the Relationship Between Energy Consumption, Economic Growth, and Environmental Degradation in Indonesia: Do Capital and Trade Openness Matter?

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ABSTRACT. This paper examines the relationship between energy consumption, economic growth, and environmental degradation in Indonesia in 1965-2018 with the inclusion of gross capital formation and trade openness as relevant factors. The autoregressive distributed lag model to cointegration, fully modified ordinary least squares, dynamic ordinary least squares, and canonical cointegrating regression approach applied to estimate this relationship. The result of cointegration confirms the existence of a cointegration relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation. The empirical result, in the long run, indicates that energy consumption, economic growth, and trade openness have a positive relationship with environmental degradation. However, the gross fixed capital formation was found to be negatively associated with environmental degradation. It implies that gross fixed capital formation plays a pivotal role in reducing environmental degradation in Indonesia. The error correction model coefficient indicates that the deviation of CO₂ emissions from its long run equilibrium will be adjusted by 0.53% through the short run channel per annum. The findings of this paper propose implementing an energy policy that focuses on energy from environmentally friendly sources. It is also recommended to reverse the effect of openness to the international markets to improve and facilitate access to advanced and environmentally friendly technologies to mitigate environmental degradation and improve environmental quality.

Keywords: Energy consumption, Economic growth, Environmental degradation, environmental quality, environmentally friendly technologies

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1. Introduction

Environmental degradation has been one of the most pivotal challenges facing decision-makers and researchers recently and needs to be addressed. The increasing of carbon dioxide emissions have a significant impact on the greenhouse and are even perceived as the main contributor to the greenhouse effects, thus exacerbating the environmental problems through global warming and climate change (Ozturk and Acaravci, 2010). The escalating CO₂ emissions aggravate environmental degradation and increase overall pollution. The environmental costs of economic growth have become a topic of research in different fields and a basic theme of policy arguments at both local and global levels (Koc and Bulus, 2020).

The significant primacy of public policy in OECD countries is to focus on the interrelationship between energy consumption, economic growth, and environmental degradation (Ozcan *et al.*, 2020).

The rise of economic growth has led to increasing demand for energy as a major economic factor, followed by growing carbon emissions and global warming, which called for policymakers to take action (Pala, 2020). Many studies attribute the increase in CO₂ emissions to energy consumption due to the rapid economic growth (Ahmad *et al.*, 2017; Andreoni and Galmarini, 2016)

Hamit-Hagggar (2012) stated that studying the relationship between energy consumption, economic growth and emissions is ultimately important to the policymakers to gain a superior understanding of the dynamic relationship between emissions, energy consumption, and economic growth, and to develop efficient energy policies to mitigate human activities that eventually minimize the emissions of greenhouse gases and maintain economic growth. Reducing CO₂ emissions without damaging real production would potentially be done by evolving effective energy policies (Dogan and Turkecul, 2016).

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There is numerous literature regarding the relationship between energy consumption, economic growth, and environmental degradation; however, the relationship must be examined by taking into consideration certain economic sectors by introducing extra variables to reduce the omitted variables bias problem (Dogan and Turkekul, 2016). To study the relationship between economic growth consumption of energy and environmental degradation, the existing literature utilized various variables and analysis methods. Some studies examined the relationship between energy consumption, economic growth, and CO₂ emissions (see Adebayo and Akinsola, 2021; Hamit-Haggar, 2012), trade openness (see Acheampong, 2018; Adebayo, 2021; Dogan & Turkekul, 2016; Farhani *et al.*, 2014; Jayanthakumaran *et al.*, 2012; Kasman & Duman, 2015), gross capital formation (Adebayo *et al.*, 2021; Soytaş *et al.*, 2007; Zhang *et al.*, 2021). and capital stock (Jafari *et al.*, 2012; Jamel & Abdelkader, 2016).

Trade expansion that accompanies economic growth might have an obvious immediate effect on the environment in addition to higher pollution or damaged natural resources. If the strictness of environmental policy is different across countries, trade liberalization may contribute to the specialization of intensive pollution activities in some countries: the so-called pollution haven hypothesis. However, in turn, raised trade can contribute to increasing capacity to handle the environment more effectively. More substantially, openness to international markets enhances the ease of accessing advanced technology which contributes to more efficiency in local production by reducing the use of environmentally damaging inputs (OECD, 2021). The environmental problems can be exacerbated by the movement of pollution-intensive goods industries in times of increasing free trade (Ansari *et al.*, 2020).

Mesagan *et al.* (2019) stated that capital investment is a substantial channel to enhance environmental quality through reducing CO₂ emissions. The projects of environment-friendly capital formation can back up the government in decarbonization projects through managing environmental sustainability with the capital formation of modern technology (Majeed *et al.*, 2021). Gross capital formation would improve environmental quality by providing environmentally friendly technologies for production (Bukhari *et al.*, 2014).

Farhani *et al.* (2014) used the autoregressive distributed lag (ARDL) model to study the relationship between energy consumption, GDP, trade openness, and CO₂ emissions in the period of 1971-2008 in Tunisia, the findings reveal that energy consumption and GDP have a positive link with CO₂ emissions; however, trade openness showed an insignificant connection with CO₂ emissions. Adebayo *et al.* (2021) applying the autoregressive distributed lag (ARDL) model, FMOLS, DOLS, and CCR approach and found that energy consumption, GDP growth, and gross capital formation have a positive impact on CO₂ emissions in Thailand between 1971 and 2016. Kalmaz and Kirikkaleli (2019) found energy consumption and economic growth were positively linked with CO₂ emissions in Turkey from 1960 to 2015, while trade openness has an insignificant effect on CO₂ emissions when analyzed using autoregressive distributed lag (ARDL) model, fully modified ordinary least squares (FMOLS), and dynamic least squares (DOLS).

Bukhari *et al.* (2014) found that gross capital formation improved environmental quality by reducing CO₂ emissions in Pakistan from 1974 to 2010 using the autoregressive distributed lag (ARDL) model. Dogan & Turkekul (2016) reported that GDP and trade openness had a negative relationship with CO₂ emissions in the USA by applying the autoregressive distributed lag (ARDL) model in the period 1960–2010, while energy consumption positively affected CO₂ emissions. Gasimli *et al.* (2019) found energy consumption and trade openness are positively associated with environmental degradation in Sri Lanka, while per capita income showed a negative sign with environmental degradation.

There is limited literature on the relationship between energy consumption, economic growth, and environmental degradation/CO₂ emissions with the inclusion of gross capital formation and trade openness simultaneously (Chen *et al.*, 2021; Ling *et al.*, 2015; Ekundayo Peter Mesagan & Nwachukwu, 2018; Rauf *et al.*, 2018).

For the case of Indonesia, Purnama *et al.* (2020) tested the effect of urbanization, energy consumption, economic growth, trade openness on environmental degradation by using the autoregressive distributed lag (ARDL) model in the period 1970-2018. The result indicated that energy consumption and economic growth showed a positive significant relationship with environmental degradation. However, trade openness is found to be negatively affected environmental degradation. Shahbaz *et al.* (2013) investigated the connection between energy consumption, economic growth, financial development, trade openness, and CO₂ emissions in Indonesia covering the period 1975Q1–2011Q4. The results of the autoregressive distributed lag (ARDL) model, in the long run, indicate that energy consumption and economic growth are positively correlated with CO₂ emissions, while trade openness improves environmental quality by decreasing CO₂ emissions. Adebayo (2021) applied the autoregressive distributed lag (ARDL) model to examine the link between energy consumption, trade openness, economic growth, and CO₂ emissions in Indonesia during 1980-2016. The findings demonstrate a positive link between energy consumption, economic growth, and CO₂ emissions. In contrast, trade openness revealed negative effect on CO₂ emissions.

Capital investment and capital formation enhance environmental quality and support the government in decarbonization projects (Bukhari *et al.*, 2014; Majeed *et al.*, 2021; Mesagan *et al.*, 2019). Shahbaz *et al.* (2013) and Purnama *et al.* (2020) used financial development and urbanization, respectively to analyze the relationship between energy consumption, economic growth, trade openness, and environmental degradation (measured by CO₂ emissions) in Indonesia. To the best of our knowledge, the main contribution of this paper is by introducing gross capital formation in examining the relationship between energy consumption, economic growth, and environmental degradation (measured by CO₂ emissions) in Indonesia in the presence of trade openness in one model which has not been studied before to fill this gap in the existing literature. Furthermore, this paper added another contribution by applying several analyzing approaches with the autoregressive distributed lag (ARDL) model, such as fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and canonical cointegrating regression (CCR) approaches to examine this relationship.

The rest of this paper is structured as follows: Section 2 discusses the literature review, Section 3 presents data and methodology, Section 4 is devoted to empirical results, and Section 5 focuses on the conclusion and policy implications.

2. Literature review

The relationship between energy consumption, economic growth, and environmental degradation has received the attention of researchers and decision-makers to understand how this relationship is complicated and to mitigate the impact of CO₂ emissions on environmental quality. There is no specific standard to determine which variables should be included when studying the dynamic between energy consumption, economic growth, environmental, and degradation/CO₂ emissions. Some studies test energy consumption-economic growth-environmental degradation/CO₂ emissions nexus (Koengkan *et al.*, 2019; Pao & Tsai, 2010; Phrakhuopatnontakitti *et al.*, 2020; Tzeremes, 2018). Others including trade openness (Acheampong, 2018; Adebayo, 2021; Dogan & Turkekul, 2016; Farhani *et al.*, 2014). Other studies including gross capital formation (Adebayo *et al.*, 2021; Zhang *et al.*, 2021). However, studies on the relationship between energy consumption, economic growth, and environmental degradation/CO₂ emissions with the inclusion of gross capital formation and trade openness simultaneously are lacking in the existing literature and needs to receive more attention in empirical analysis in the future (for example, Chen *et al.*, 2021; Ling *et al.*, 2015; Ekundayo Peter Mesagan & Nwachukwu, 2018; Rauf *et al.*, 2018; Soytaş *et al.*, 2007). One corresponding study by Rauf *et al.* (2018) found that energy consumption, economic growth, and gross capital formation positively influence CO₂ emissions, while trade openness and CO₂ emissions are negatively connected by applying fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) data from 47 of Belt and Road Initiative (BRI) countries.

Mesagan and Nwachukwu (2018) applied the autoregressive distributed lag (ARDL) model to study the determinants of environmental quality in the period of 1981-2016 for the case of Nigeria. The gross fixed capital formation is used as a proxy for capital investment, environmental degradation index is used to capture the environmental quality. The empirical findings indicate that economic growth and energy consumption have a positive impact on the environmental degradation index, CO₂ emissions, and particulate emissions. Trade intensity was found to have a positive effect on the environmental degradation index and CO₂ emissions, while particulate emissions were affected negatively by trade intensity. Capital investment is insignificantly connected with environmental degradation index and CO₂ emissions but particulate emissions are negatively influenced by capital investment. Jamel & Abdelkader (2016) used trade openness and capital stock as control variables to study the effect of energy consumption and economic growth on environmental degradation in eight Asian economies between 1991 and 2013. The findings of fully modified ordinary least squares (FMOLS) reveal a positive association between energy consumption, economic growth, trade openness, capital stock, and environmental degradation (measured by CO₂ emissions). Koc and Bulus (2020) used the autoregressive distributed lag (ARDL)

model to examine the relationship between gross domestic product (GDP) per capita, energy consumption per capita, renewable energy consumption per capita, trade openness, and CO₂ emissions in South Korea in 1971-2017. The empirical results show that GDP and energy consumption positively influence CO₂ emissions, while trade openness negatively influences CO₂ emissions. Also, Cetin *et al.* (2018) found that economic growth, energy consumption, and trade openness have a positive impact on CO₂ emissions in 1960–2013 in Turkey by applying the autoregressive distributed lag (ARDL) model.

Ansari *et al.* (2020) inspect the relationship between energy consumption, economic growth, trade openness, and CO₂ emissions in the USA, Canada, Iran, Japan, Saudi Arabia, Italy, UK, Australia, Spain, and France as the top CO₂ emitters between 1971 and 2013 by applying the autoregressive distributed lag (ARDL) model. The empirical results reveal that energy consumption increases CO₂ emissions in the USA, Canada, Japan, Saudi Arabia, Italy, Spain, and France. Economic growth statistically negatively affected CO₂ emissions in Canada and Italy, while a positive association was found between Economic growth and CO₂ emissions in the USA and France. The effect of trade openness on CO₂ emissions was found to be negative in the USA and Italy, whereas the link between trade openness and CO₂ emissions was statistically positive in Canada and Saudi Arabia.

3. Data and method

3.1. Data

The data used in this paper are energy consumption measured as primary energy consumption per capita, economic growth as captured by gross domestic product at constant 2010 US\$, gross fixed capital formation at constant 2010 US\$, trade openness described by the sum of exports and imports of goods and services as percent of GDP, and environmental degradation proxies by million tonnes of carbon dioxide emissions. The data of carbon dioxide emissions and energy consumption are obtained from the British Petroleum Statistical Review of World Energy (BP, 2021). The data of economic growth, gross fixed capital formation, and trade openness are extracted from World Bank Indicators (World Bank, 2021).

3.2. Method

In this paper, the autoregressive distributed lag (ARDL) model, fully modified ordinary least Squares (FMOLS), dynamic least squares (DOLS), and canonical cointegrating regression (CCR) were applied to estimate the long run relationship between energy consumption, economic growth, gross fixed capital formation, trade openness and environmental degradation covering the period 1965-2018 in Indonesia. Besides, the ARDL error correction model (ECM) is used to estimate the short run relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation. Moreover, this paper used the Augmented Dickey-Fuller (ADF)(1979) and Phillips and Perron (PP) (1988) unit root tests to check the stationarity of the variables. The ARDL model bounds test to cointegration developed by Pesaran *et al.* (2001) was used to determine the cointegration relationship. The diagnostic and residual stability tests have been applied

to test the goodness and stability of the estimated model. The diagnostic tests are serial correlation, normality, heteroscedasticity, and Ramsey RESET. The stability tests employed are the cumulative sum (CUSUM) of recursive residuals and the cumulative sum of squares (CUSUMSQ) of recursive residuals. The ARDL has been selected because it is more applicable in the small sample; also it takes into account the error correction model. ARDL approach provides consistent and robust results because it allows describing the existence of an equilibrium-relationship in both long-run and short-run dynamics without losing long-run information (Pesaran *et al.*, 2001). The unit root test is applied to ensure whether the mean and variance of the variables change over time. On the other hand, to ensure whether the time series data are stationary or nonstationary. The time-series data in some cases involve random features that influence the statistical inferences and lead to the estimate of a spurious model. To check the unit root for the variables under consideration the null hypothesis of non-stationary time series data tested against the alternative hypothesis of the data are stationary. Notwithstanding the autoregressive distributed lag (ARDL) model to cointegration can be used irrespective of the variables under consideration are integrated at the order $I(0)$ or $I(1)$. Nevertheless, the unit root tests utilized to confirm that all the series are not integrated at the order $I(2)$ because in integration at order $I(2)$, the computed F-statistic becomes unusable or invalidate to confirm the existence of cointegration relationship among the variables (Pesaran *et al.*, 2001). The cumulative sum (CUSUM) of recursive residual and cumulative sum square (CUSUMSQ) of recursive residuals techniques developed by (Brown *et al.*, 1975) to identify the moving from the constancy of regression coefficients.

To examine the relationship between environmental degradation and the main explanatory variables, this paper considered environmental degradation as a function of energy consumption, economic growth, gross fixed capital formation, and trade openness. Therefore, the economic model describing this relationship can be presented in the following functional form:

$$CO_{2t} = f(EC_t, GDP_t, K_t, TO_t) \quad (1)$$

The econometric model describing the relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation as presented in equation (1) was given in the following log-linear form:

$$LCO_{2t} = \beta_0 + \beta_1 LEC_t + \beta_2 LGDP_t + \beta_3 LK_t + \beta_4 LTO_t + \mu_t \quad (2)$$

Where LCO_2 represents the natural log of carbon emissions, LEC indicates the natural log of energy consumption, $LGDP$ is the natural log of gross domestic product (GDP), LK denotes the natural log of gross fixed capital formation, LTO signifies the natural log of trade openness, β_0 is a constant, μ represents the error term, and $\beta_1, \beta_2, \beta_3,$ and β_4 are the coefficients of energy consumption, gross domestic product (GDP), gross fixed capital formation, and trade openness respectively.

As a first step to estimate the long run and short relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and

environmental degradation, equation (2) can be reformulated in the general framework of the autoregressive distributed lag (ARDL) model as follows:

$$\begin{aligned} \Delta LCO_{2t} = & \alpha_0 + \alpha_1 LCO_{2t-1} + \alpha_2 LEC_{t-1} + \alpha_3 LGDP_{t-1} \\ & + \alpha_4 LK_{t-1} + \alpha_5 LTO_{t-1} + \sum_{i=1}^q \beta_1 \Delta LCO_{2t-i} \\ & + \sum_{p=0}^q \beta_2 \Delta LEC_{t-p} + \sum_{m=0}^q \beta_3 \Delta LGDP_{t-m} \\ & + \sum_{h=0}^q \beta_4 \Delta LK_{t-h} + \sum_{v=0}^q \beta_5 \Delta LOP_{t-v} \\ & + \mu_{2t} \end{aligned} \quad (3)$$

Δ represents the first difference, α_0 is constant, q denotes the optimal lag length selected based on the Akaike Information Criterion (AIC). $\alpha_1, \alpha_2, \alpha_3, \alpha_4,$ and α_5 denote the long run coefficients. $\beta_1, \beta_2, \beta_3, \beta_4,$ and β_5 indicate the short run coefficients. μ_{2t} is the error term.

The cointegration relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation was tested based on the null hypothesis of no cointegration relationship ($H_0: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$) in contrast to the alternative null hypothesis of the existence of cointegration relationship ($H_1: \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0$). The existence of the cointegration relationship depends on comparing the calculated F-statistic with the lower $I(0)$ and upper $I(1)$ critical values of bounds test at 1%, 5%, and 10% significant level as proposed by Pesaran *et al.* (2001). If the estimated F-statistic falls below the lower critical value of the bounds test at 1%, 5%, and 10% significant level, the null hypothesis will be accepted, and therefore, there is no long run cointegration relationship between the variables. In contrast, if the estimated F-statistic falls above the critical value of bounds test at 1%, 5%, and 10% significant level, the null hypothesis will be rejected, confirming the existence of a long run cointegration relationship between the variables under consideration.

The existence of a cointegration relationship is a supporting step to estimate the long run and short run relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation. Consequently, based on equation (3) the error correction model (ECM) has been formulated in equation (4) to estimate the short term relationship as follows:

$$\begin{aligned} \Delta LCO_{2t} = & \gamma_0 + \sum_{i=1}^q \gamma_1 \Delta LCO_{2t-i} + \sum_{p=0}^q \gamma_2 \Delta LEC_{t-p} \\ & + \sum_{m=0}^q \gamma_3 \Delta LGDP_{t-m} + \sum_{h=0}^q \gamma_4 \Delta LK_{t-h} \\ & + \sum_{v=0}^q \gamma_5 \Delta LOP_{t-v} + \phi ECM_{t-1} + \varepsilon_t \end{aligned} \quad (4)$$

Where; γ_0 is the intercept; $\gamma_1, \gamma_2, \gamma_3, \gamma_4,$ and γ_5 are the short run coefficients; ECM denotes the error correction term; ϕ is the coefficient of error correction term which explains the speed of adjustment; ε_t represents the error term.

Table 1
Descriptive statistics and correlations

	LCO2	LEC	LGDP	LK	LTO
Mean	4.846372	2.413910	26.43471	24.98531	3.835007
Median	5.032219	2.594360	26.55757	25.33828	3.898568
Maximum	6.364268	3.425221	27.76804	26.66021	4.566286
Minimum	2.927777	1.025510	24.92413	22.32858	2.399007
Std. Dev.	1.108793	0.796783	0.832364	1.207382	0.323109
Skewness	-0.338833	-0.440823	-0.233174	-0.690032	-1.782569
Kurtosis	1.798749	1.820073	1.937390	2.511129	9.086115
Jarque-Bera	4.280025	4.881434	3.029896	4.823033	111.9398
Probability	0.117653	0.087098	0.219820	0.089679	0.000000
LCO2	1				
LEC	0.998014	1			
LGDP	0.993655	0.987835	1		
LK	0.977651	0.976129	0.984159	1	
LTO	0.593847	0.60764	0.560422	0.642363	1

Table 2
Unit root tests

Variables	PP				ADF			
	Level		First difference		Level		First difference	
	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.
LCO ₂	-1.3467	0.6012	-5.6805***	0.0000	-1.5146	0.5186	-3.9935***	0.0030
LEC	-1.3116	0.6177	-6.2777***	0.0000	-4.2811***	0.0014	-3.8777***	0.0042
LGDP	-1.3644	0.5927	-5.3531***	0.0000	-1.4743	0.5386	-5.3531***	0.0000
LK	-2.5587	0.1079	-5.0839***	0.0001	-3.9883***	0.0031	-5.1274***	0.0001
LTO	-5.5346***	0.0000	-14.2889***	0.0000	-5.5996***	0.0000	-14.2889***	0.0000

*, **, and *** denote significant at the 10%, 5%, and 1% respectively

4. Results analysis

4.1. Descriptive statistics and correlation pair

Before estimating the long run and short run relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation, this paper provides some descriptive statistics and correlations analysis in Table 1. Table 1 shows that environmental degradation, energy consumption, economic growth, and gross fixed capital formation have high variations among the series, while trade openness demonstrates low variation. Jarque-Bera indicates that all the variables are normally distributed except LTO. Skewness reveals that all the variables are negatively skewed. Also, all series exhibit excess kurtosis.

The correlation analysis from Table 1 revealed that energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation are positively correlated with each other. Moreover, trade openness has shown a low correlation with all variables.

4.2. Unit root stationarity tests

To determine the order of integration and avoid the inclusion of the variables under *I*(2) order of integration, all variables are subjected to Augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) unit root tests. The results presented in Table 2 indicate that trade openness

is stationary at a level based on PP, while at the first difference all the variables are stationary at 1% significant level. The results of ADF reveal that energy consumption, gross fixed capital formation, and trade openness are stationary at a level. Moreover, after taking the first difference all the variables are stationary at a 1% significant level. Therefore, the stationarity of all variables at the first difference allows us to run the ARDL bounds test.

4.3. ARDL bounds test to Cointegration

To determine the cointegration between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation, the ARDL bounds test was applied. The results are reported in Table 3.

Table 3
ARDL Bounds test

Test Statistic	Value	k
F-statistic	4.119455	4
Critical bounds value		
Significance	I(0)	I(1)
10%	2.2	3.09
5%	2.56	3.49
2.5%	2.88	3.87
1%	3.29	4.37

Table 4.
ARDL long run and short run relationship

The long run relationship			
Variable	Coefficient	t-Statistic	Prob.
LEC	0.884465***	10.48840	0.0000
LGDP	0.805039***	7.287674	0.0000
LK	-0.231459***	-4.100271	0.0002
LTO	0.213141***	3.340585	0.0020
C	-13.59843***	-6.513655	0.0000
The short run relationship			
Variable	Coefficient	t-Statistic	Prob.
D(LCO ₂ (-1))	0.152370**	2.276998	0.0292
D(LEC)	0.874851***	14.33562	0.0000
D(LGDP)	0.333591**	2.162012	0.0377
D(LGDP(-1))	-0.405876**	-2.493177	0.0177
D(LGDP(-2))	-0.366666**	-2.493975	0.0177
D(LK)	-0.029969	-0.536358	0.5952
D(LK(-1))	0.242138***	3.904412	0.0004
D(LK(-2))	0.125500**	2.536075	0.0160
D(LK(-3))	0.081806***	2.538836	0.0159
D(LTO)	0.040468	1.454240	0.1550
ECM(-1)	-0.537354***	-5.324617	0.0000
R ²	0.872564	Adjusted R ²	0.8399

*, **, and *** indicate significant at the 10%, 5%, and 1% respectively

The cointegration result presented in Table 3 ensures the rejection of the null hypothesis at a 5% significant level confirming the presence of a cointegration relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation.

4.4. ARDL long run and short run relationship

Once the long run cointegration relationship is confirmed, the next step is to estimate the long run and short run estimation between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation. Table 4 presents the long run and short run relationships obtained from ARDL. In the long run, energy consumption was found to have a positive connection with environmental degradation at 1% significance. This reveals that a 1% increase in energy consumption will raise environmental degradation by 0.884% due to the increase of CO₂ emissions. This result is consistent with previous studies of (Adebayo *et al.*, 2021; Adebayo, 2021; Dogan & Turkekul, 2016; Farhani *et al.*, 2014; Purnama *et al.*, 2020; Rauf *et al.*, 2018; Shahbaz *et al.*, 2013). Economic growth stimulated environmental degradation, where is found to be positively associated with environmental degradation at a 1% level of significance. Accordingly, 1% increase in economic growth will increase environmental degradation by 0.805%, and these findings agreed with (Adebayo *et al.*, 2021; Adebayo, 2021; Farhani *et al.*, 2014; Purnama *et al.*, 2020; Rauf *et al.*, 2018; Shahbaz *et al.*, 2013), however, contradicted with (Dogan & Turkekul, 2016). Trade openness showed a positive linking with environmental degradation at 1% level of significance, implying that 1% increase in trade openness will reflect in high environmental degradation

by 0.213%. This result is inconsistent with (Adebayo, 2021; Dogan & Turkekul, 2016; Purnama *et al.*, 2020; Rauf *et al.*, 2018; Shahbaz *et al.*, 2013). In contrast, gross fixed capital formation has shown a negative linkage with environmental degradation at 1% significant level, indicating that 1% increase in gross fixed capital formation will decrease environmental degradation by 0.231%. This result was in line with (Bukhari *et al.*, 2014) and contrast with (Adebayo *et al.*, 2021; Rauf *et al.*, 2018). The short run result in Table 4 indicates that energy consumption exhibits a positive connection with environmental degradation at 1% significant level. Meanwhile, GDP has shown significant positive and negative signs regarding the environment. However, gross fixed capital formation demonstrates a statistically significant positive association with CO₂ emissions, or inconsistent with the long run findings. The ECM coefficient indicates that the deviation of CO₂ emissions from its long run equilibrium will be adjusted by 0.537354% through the short run channel per annum. The error correction coefficient was negative and statistically significant. The coefficient of determination (R²) illustrates that 0.87% of the variation in CO₂ emission is explained by explanatory variables included in the model.

4.5. FMOLS, DOLS, and CCR long run relationship

Along the same line with ARDL, fully modified ordinary least Squares (FMOLS), dynamic least squares (DOLS), and canonical cointegrating regression (CCR) were utilized to estimate the long run relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation. The results are illustrated in Table 5.

Table 5
FMOLS, DOLS, CCR long run relationship

Variable	FMOLS		DOLS		CCR	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
LEC	0.872850***	10.90199	0.670885***	8.027777	0.897462***	13.37941
LGDP	0.734111***	6.901757	1.042304***	8.898680	0.705869***	7.477335
LK	-0.180986***	-3.925888	-0.289077***	-5.465602	-0.175510***	-3.974206
LTO	0.131129**	2.369448	0.368791***	5.277336	0.111728***	2.630637
C	-12.64849***	-6.195122	-18.56518***	-8.548233	-12.02199***	-6.960153
R ²	0.999143		0.999543		0.999096	
Adjusted R ²	0.999072		0.999328		0.999021	

*, **, and *** indicate significant at the 10%, 5%, and 1% respectively

Table 6
Diagnostic tests

Test	F-statistic	Prob
Heteroskedasticity B-P-G	0.273529	0.9951
Serial Correlation B-G	0.665901	0.5208
Ramsey RESET	0.069191	0.7942
Normality Jarque-Bera	0.930701	0.6279

The results of FMOLS, DOLS, and CCR provided in Table 5 are similar and robust to ARDL results in signs. Energy consumption was found to be positively connected with environmental degradation, economic growth showed a positive linkage with environmental degradation, and trade openness was found to have a positive relationship with environmental degradation. However, gross fixed capital formation demonstrated a negative relationship with environmental degradation, this implying that gross fixed capital formation plays a pivotal role in reducing environmental degradation in Indonesia.

4.6. The diagnostic tests and stability

To accomplish the purpose of this paper, the heteroscedasticity, serial correlation, normality, and Ramsey RESET tests were applied. The findings in Table 6 indicate that the model successfully passed the white heteroscedasticity and there was no serial autocorrelation in the model. Also, the result of Ramsey RESET test suggests that the model is not miss-specified and the normality test proves the model is normally distributed as long as the p-value greater than 5% significant level.

The stability of estimated coefficients emphasizes the robustness of the long run and short run relationship in the model. Therefore, this paper applied the cumulative sum (CUSUM) of recursive residual and cumulative sum square (CUSUMSQ) of recursive residuals to test the stability of estimated coefficients. The results are reported in Figures 1 and 2, respectively.

Figures 1 and 2 show that the cumulative sum (CUSUM) of recursive residual and cumulative sum square (CUSUMSQ) of recursive residuals fall within the critical bounds straight line at a 5% significance level. it is indicative of stable estimated coefficients during the study period.

The empirical findings of this paper concerning energy consumption and economic growth are rational and agree with early studies of (Adebayo, 2021; Purnama *et al.*, 2020; Shahbaz *et al.*, 2013) where they found energy consumption and economic growth are the main

determinants of environmental degradation. Also, gross capital formation and capital investment play a crucial role to improve environmental quality through decarbonization, environmental sustainability management, and providing environmentally friendly technologies (Bukhari *et al.*, 2014; Majeed *et al.*, 2021; Mesagan *et al.*, 2019). International trade openness enables countries to access modern technology and stimulate foreign direct investment inflow which enhances clean industries.

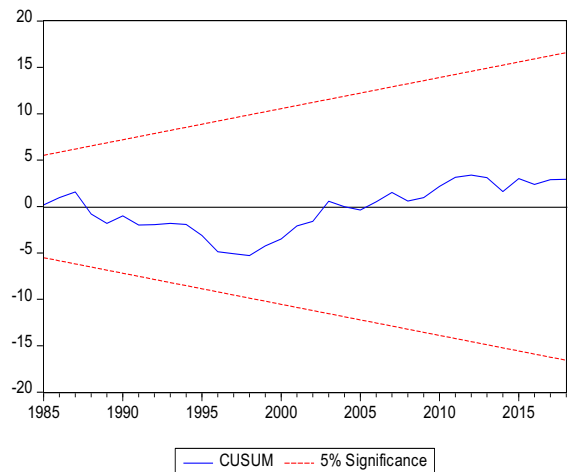


Fig. 1. Plot cumulative sum (CUSUM) of recursive residuals

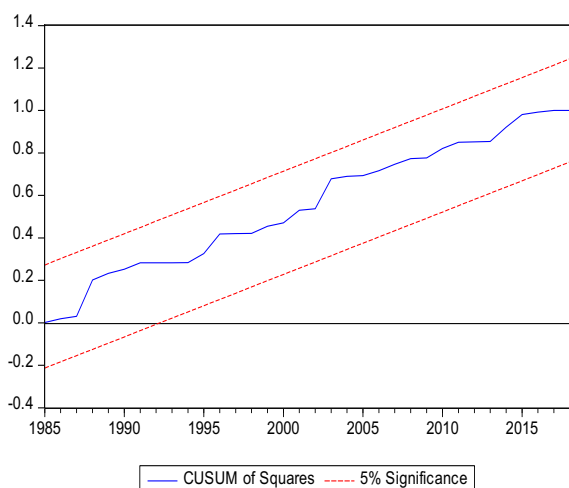


Fig. 2. Plot cumulative sum of squares (CUSUMSQ) of recursive

Fossil fuels as the primary energy supply represent one of the main sources of CO₂ emissions used in Indonesia for energy generation. Indonesia is a resource-rich country, the fourth-largest coal producer in the world, and the largest gas supplier in Southeast Asia. Also, Indonesia is the biofuel's largest producer worldwide and is intensifying efforts to take the advantage of its renewable energy potential (International Energy Agency, 2021).

Considerable foreign direct investment and government incentives have contributed to placing the industry for growth in the future. Around 40 percent of GDP in 2015 came from the industrial sector including petroleum and natural gas (asialinkbusiness, 2021). Industrialization contributes to economic growth by producing the necessary goods, encourage innovation, and optimal use of resources. On the other hand, industrialization expansion increases the energy demand. Energy use contributes to economic growth through industry expansion as an input factor of production, conversely, energy consumption has a damaging impact on environmental quality by rising carbon dioxide emissions which indirectly affects economic growth. Therefore, to reduce the cost of environmental damages, policies that encourage the use of renewable sources of energy must become the most essential focal point.

5. Conclusion and policy implications

5.1. Conclusion

This paper examines the long run relationship between energy consumption, economic growth, and environmental degradation in Indonesia between 1965 and 2018 using the autoregressive distributed lag (ARDL), fully modified ordinary least Squares (FMOLS), dynamic least squares (DOLS), and canonical cointegrating regression (CCR). Gross fixed capital formation and trade openness are included for their relevant influence. The result of cointegration confirms the existence of a cointegration relationship between energy consumption, economic growth, gross fixed capital formation, trade openness, and environmental degradation. The empirical result obtained from ARDL, in the long run, indicate that energy consumption, economic growth, and trade openness are positively linked with environmental degradation at 1% level of significance, implying that 1% increase in energy consumption, economic growth, and trade openness will raise environmental degradation by 0.884%, 0.805%, and 0.213%, respectively due to the increase of CO₂ emissions. Meanwhile, the gross fixed capital formation was found to be negatively associated with environmental degradation at 1% significant level, suggesting that 1% increase in gross fixed capital formation will decrease environmental degradation by 0.231%. Similarly, the results of FMOLS, DOLS, and CCR are the same as ARDL results in signs and magnitude, except for GDP is greater than 1 based on DOLS, where energy consumption, economic growth, and trade openness were found to be positively connected with environmental degradation. However, gross fixed capital formation demonstrates a negative relationship with environmental degradation, this suggesting that gross fixed capital formation plays a pivotal role to reduce environmental degradation in Indonesia. In the short run energy consumption exhibit a positive connection with

environmental degradation at a 1% significant level. Meanwhile, GDP has shown significant positive and negative signs regarding the environment. However, gross fixed capital formation demonstrates a statistically significant positive association with CO₂ emissions which is inconsistent with long run findings. The ECM coefficient indicates that the deviation of CO₂ emissions from its long run equilibrium will be adjusted by 0.53% through the short run channel yearly. The diagnostic and stability tests indicate that the model successfully passed the white heteroscedasticity and there was no serial autocorrelation in the model. The result of the Ramsey RESET test suggested the model was not mis-specified, while the normality test proved the model was normally distributed as long as the p-value was greater than 5% significant level. Moreover, the results of the cumulative sum of recursive residuals (CUSUM) and cumulative sum squared of recursive residuals (CUSUMSQ) show that all estimated coefficients in the long run and short run are stable.

5.2. Policy implications

The findings of this study clearly show that increasing energy consumption will lead to a rise in CO₂ emissions and exacerbated environmental degradation. These outcomes propose implementing an energy policy that focuses on energy from environmentally friendly sources. Besides, energy conservation policy that targeted reducing CO₂ emissions might slow down economic growth which was found to be connected positively with CO₂ emissions in this study. Therefore, to ensure the sustainability of economic growth, the decision-makers are asked to provide alternatives energy sources, such as clean energy from renewable sources.

The positive link between environmental degradation and trade openness explains the negative influences of trade openness on environmental quality might be due to the weakness of environmental conservation policy in terms of moving intensive pollution industries from one country to another (Ansari *et al.*, 2020; OECD, 2021). However, international openness to the international markets would improve and facilitate access to advanced and environmentally friendly technologies to mitigate environmental degradation and improve environmental quality. Similarly, capital formation could play an essential role to improve environmental quality. Also, capital accumulation has become a major incentive and supporter for companies to fetch advanced and environmentally friendly technologies and efficiently contribute to managing natural resources.

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