Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes

Year 2025, Volume 13, Issue 4, 1130610

Original Research Article

The Dynamic Linkage between Private Credit, Renewable Energy, Economic Growth, and Carbon Emissions in Indonesia

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Cite as: Prasetyo, A. B., Destiartono, M. E., Firmansyah, F., The Dynamic Linkage between Private Credit, Renewable Energy, Economic Growth, and Carbon Emissions in Indonesia, J.sustain. dev. energy water environ. syst., 13(4), 1130610, 2025, DOI: https://doi.org/10.13044/j.sdewes.d13.0610

ABSTRACT

This study aims to assess the interlinkage between economic growth, clean energy, and carbon dioxide emissions in Indonesia over the period 1980–2020 under the Environmental Kuznets Curve hypothesis, taking a unique perspective by focusing on the impact of private credit, along with controlling for the role of trade openness and total energy consumption. This study applies an Autoregressive Distributed Lag Bounds Testing model for the estimation method, followed by the Granger Causality test. The results demonstrate that total credit to private non-financial sectors significantly contributes to environmental depletion by rising carbon dioxide emissions. The Environmental Kuznets Curve hypothesis is not verified, indicating that economic growth cannot be used as a sole instrument for emissions reduction. Whilst total energy consumption is found to drive emissions, primary energy consumption from renewable resources is negatively associated with carbon dioxide. The Granger causality test signifies the feedback relationship between growth, credit, and carbon dioxide, as well as a unidirectional causality running from total energy consumption toward carbon dioxide. Following the findings, it is recommended that fostering clean energy transition and promoting green credit are among the pivotal policies to reduce carbon dioxide emissions.

KEYWORDS

Private credit, Carbon emissions, Economic growth, Renewable energy, Indonesia.

INTRODUCTION

Reducing carbon dioxide (CO_2) emissions is globally argued to be a necessary condition to tackle climate change and achieve the principle of sustainable development [1]. Over the last three decades, CO_2 emissions have been identified as one of the crucial issues in emerging economies. The amount of emissions in Indonesia tends to follow a positive trend, indicating a substantial annual influx of greenhouse gases released into the atmosphere each year [2]. This implies a significant impediment to achieving the Paris Agreement's objective of constraining the average temperature increase to 1.5 degrees Celsius [3]. Therefore, it is pivotal that policies aimed at the mitigation of CO_2 undergo improvement.

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Balancing economic growth and ecological sustainability is a complex and multifaceted undertaking for emerging countries such as Indonesia. Economic prosperity is globally argued as an underlying driver of air pollution degradation, including CO_2 emissions [4]. An increase in per capita income leads to a scale-up in fossil fuel consumption, particularly for electricity generation and transportation, which, in turn, releases higher emissions [5]. The Stochastic Impacts by Regression on Population, Affluence, and Technology (STRIPAT) model posits a positive linkage between affluence, as a proxy for consumption levels, and anthropogenic CO_2 emissions [6]. Prior investigations focusing on BRICS [7], Pakistan [8], and MENA countries [9] validated the linear nexus of CO_2–income with various scores of elasticities.

Whilst economic growth corresponds to ecological depletion, the Environmental Kuznets Curve (EKC) framework posits that the detrimental impact of affluence on emissions exhibits a non-linear nexus. [10]. The effect of income on environmental depletion is not monotonically increasing; rather, it offers a technological effect after a certain income threshold [11]. The EKC framework implies that economic development can be applied as an instrument for pollution reduction. A past study utilizing panel 208 countries confirmed the presence of the inverted U-shaped linkage for an income-CO_2 relationship, with an estimated Income Turning Point (ITP) of US$19,203 per capita [12]. Similarly, an empirical study in African countries recorded the EKC hypothesis with the ITP of US$5,702 per capita [13]. Nonetheless, another study in developing countries noted that the EKC hypothesis is not evident [14]. The existence of the EKC hypothesis is generally affected by numerous factors, including trade [15], energy consumption [16], and institutions [17].

Going further, there is significant growing attention to the impact of the monetary sector on the environment, such as credit and financial development [18]. Whilst credit is supposed to have a pivotal role in driving businesses, bank lending is also linked to ecological degradation [19]. Credit might serve as an underlying driver of environmental degradation by increasing emissions. In developing economies, financial credit is widely used for investment in carbon-intensive industries: fossil fuel generators, oil and gas extraction, and manufacturing operations [20]. Thus, an expansion of bank lending capacity may lead to a significant increase in CO_2 emissions. Nonetheless, evidence in South Africa indicated that domestic credit is negatively connected to emissions from manufacturing firms and construction [21]. The detrimental effect of net domestic credit on emissions is not clearly discernible [22].

Building on the aforementioned background, this study intends to examine the interlinkage between private credit, economic growth, energy consumption, and environmental depletion in Indonesia by adopting the EKC hypothesis. This study offers empirical novelties regarding the impact of private credit on the environment. In the author's current understanding, this research stands as a pioneering investigation of the interlinkage between credit and CO_2 emissions in Indonesia. Whilst numerous studies investigated CO_2's determinants, none of them focused on the impact of private credit. Understanding the nexus between private credit and CO_2 is pivotal to mitigating the damaging effect of financial markets and business expansion.

Regarding the estimation technique, the current study mainly relies on the Autoregressive Distributed Lag Bounds Testing (ARDLBT) [23]. The ARDLBT model is employed to provide the dynamic relationships and assess the cointegration relationship. It is also proper to estimate short- and long-run elasticities. Additionally, the Granger Causality (GC) test is included to examine the causal direction between variables.

LITERATURE REVIEW

To discern the underlying factors contributing to environmental degradation (including CO_2 emissions) from an economic standpoint, the STRIPAT and EKC models represent two widely adopted theoretical constructs. Whilst the STRIPAT model suggests a linear linkage between affluence and environmental depletion, the EKC model proposes a non-linear association [24]. The EKC hypothesis posits a relationship between economic development and emissions that aligns with distinct stages: the pre-industrial, industrial, and post-industrial phases [25]. It states that the damaging effect of economic growth on the environment exhibits in the early stage of development as a consequence of the scale effect [26]. After a certain threshold, a higher level of income generates ecological improvement on the grounds of investment in technology [27]. This stage represents the technological effect. **Figure 1** depicts a schematic representation of the interlinkage between per capita GDP and pollution (proxied by CO_2) within the framework of the EKC model. In practical terms, the EKC hypothesis applicability extends to various other indicators of environmental degradation, including deforestation [28], nitrous dioxide [29], methane [30], water pollution [31], biodiversity loss [32], and ecological footprint [33].

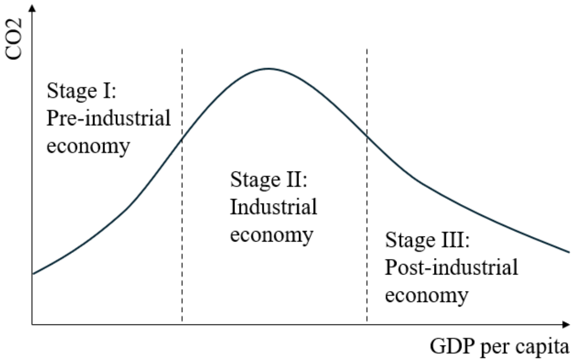


Figure 1. An illustration of the EKC hypothesis [27]

Numerous earlier studies have investigated the impact of economic growth on emissions under the EKC hypothesis, generally adding other factors into the empirical model to provide a more comprehensive understanding of the drivers of environmental change. For instance, an empirical study in Pakistan confirmed the EKC hypothesis and the importance of renewable energy consumption [34]. Similarly, the inverted U-curve association between income and CO_2 and the advantageous role of green energy are validated in the context of developing countries [35]. Using yearly data for the period 1980–2020, a study in Indonesia provided corroborating evidence for the inverse U-curve association between income and emissions [36]. Nonetheless, the EKC hypothesis for CO_2 was not validated in the case of Southeast Asia [37].

Within the EKC hypothesis, clean energy is expected to tackle the ecological depletion in the post-industrial phase. Whilst non-renewable energy usage is positively associated with $CO_{2,}$ renewable energy theoretically contributes to carbon mitigation [38]. Clean energy resources offer a pathway to decouple energy consumption from Greenhouse Gases (GHG) [39]. Thus, increasing energy use from renewable sources corresponds to a decrease in fossil fuel usage, which, in turn, leads to emissions reduction [40]. Relying on panel data from 163 countries for the period 2000–2016, the negative association between clean energy consumption and CO_2 is robust and reliable [41].

Beyond the aforementioned factors, the financial sector is also argued to exert a moderating effect on emissions trajectories, with its operations and investment decisions potentially either exacerbating or mitigating environmental degradation [42]. Empirical evidence from Turkey highlighted a positive association between financial development and CO_2, suggesting that the expansion of financial markets leads to environmental depletion [43]. Nonetheless, based on a panel of 88 developing countries over the period 2000–2014, financial development is noted to mitigate the adverse effects of income, trade, and FDI on emissions [44]. Furthermore, an empirical investigation encompassing European countries over the period 1985-2014 recorded the validity of the neutrality hypothesis between financial development and emissions [45]. An empirical study in Malaysia for the period 1971–2012 found a unidirectional causality running from financial development toward CO_2 [46].

METHOD

The main motivation of the current study is to assess the impact of private credit, economic growth, and renewable energy on the environmental quality, particularly CO_2, in the context of Indonesia. Therefore, several econometric approaches are employed to provide comprehensive findings, including regression, causality, and the unit root test. The empirical model is based on the augmented version of the EKC model.

Data

This study relies on Indonesia's annual series spanning 1980 – 2022; therefore, the length of observation is 43 years. The number of observations is sufficient for econometrics methods such as ARDLBT and the GC test. To establish multivariate analysis, CO_2 serves as a response variable. The predictor variables under consideration include economic growth, private credit, per capita energy consumption, and renewable energy.

The response variable of CO_2 emissions is expressed in metric tons. Economic growth is proxied by per capita GDP (constant 2015 $US). In addition, per capita GDP squared (YPC^2) is computed to establish a non-linear model. Private credit is measured by total credit to the private non-financial sector, adjusted for breaks (% of GDP). Per capita energy consumption is measured in terawatt-hours (TWh). Renewable energy is proxied by the percentage of primary energy consumption from renewables. The datasets are gathered from Federal Reserve Economic Data (FRED), Our World in Data (OWD), and the World Bank Database (World Development Indicators-WDI).

Model Specification

The baseline model for the ECK hypothesis can be defined as Eq. (1) [47].

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln YPC_t + \alpha_2 \ln YPC_t^2 + \mu_t \tag{1}$$

wherein CO_2 signifies carbon dioxide emissions. YPC and YPC^2 depict per capita income and per capita income squared. The term Ln is the operator of the natural logarithm. μ shows the error term. The subscript t represents that the data relies on a time series. Following previous studies, Eq. (1) is modified by integrating the impact of private credit and energy consumption. Therefore, Eq. (2) shows the empirical model.

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln YPC + \alpha_2 \ln YPC_t^2 + \alpha_3 \ln CRD_t + \alpha_4 \ln REU_t + \alpha_5 \ln ENC_t + \mu_t \tag{2}$$

wherein CRD stands for private credit. REU signifies renewable energy consumption. ENC is energy consumption. CRD can have a positive or negative effect on CO_2. REU is supposed to have a negative sign; conversely, ENC is expected to have a positive sign. The EKC hypothesis will be verified only if $\alpha_1 > 0$ while $\alpha_2 < 0$. The monetary value of an Income Turning Point (ITP) can be estimated through Eq. (3) [27];

$$T_{EKC}^{*} = \exp\left(-\frac{\alpha_1}{2\alpha_2}\right) \tag{3}$$

Estimation Technique

Integrating a stationary test is crucial in time-series modeling, including the application of ARDLBT. It should be noted that ARDLBT is not a proper regression method for second-order stationary variables, I(2). Hence, this study applies the augmented version of the Dickey-Fuller test (ADF) to assess whether the unit root is present in the series analyzed [48]. A model for the ADF test is specified as Eq. (4).

$$\Delta y_t = \nu + \beta t + \pi y_{t-1} + \sum_{i=1}^{m} \tau_i \Delta \mathrm{y}_{\mathrm{t}-1} + e_t \tag{4}$$

wherein Δ stands for first-difference notation. e is assumed to be the white noise error term; y_t denotes the time series being tested; ν is the constant term. m shows the maximum lag length. The subscript t signifies a time trend. As part of the robustness check, this study includes the Phillips-Perron (PP) unit root test to provide reliable and valid findings regarding the order of integration.

Following the stationary test, ARDLBT is preferred for analyzing the nexus between CO_2 and a set of independent variables (YPC, YPC^2, CRD, REU, and ENC) since it offers notable advantages for time series modeling. First, it can be applied to stationary or non-stationary (integrated of order one) variables. Second, it produces short- and long-run parameters of the nexus between variables, as well as a cointegration model [49]. Third, it is a proper method to unravel hidden cointegration in the case of a small sample size [50]. Last of all, it can handle series correlation and endogeneity issues by incorporating sufficient lags [23]. Following Eq. (2), the ARDLBT (k) model is specified in Eq. (5).

$$\begin{aligned} \Delta \ln CO_{2t} = {} & \eta_0 + \eta_1 \sum_{i=1}^{k} \Delta \ln CO_{2t-i} + \eta_1 \sum_{i=0}^{k} \Delta \ln YPC_{t-i} + \eta_2 \sum_{i=0}^{k} \Delta \ln YPC_{t-i}^2 \\ & + \eta_3 \sum_{K=0}^{k} \Delta \ln CRD_{t-i} + \eta_4 \sum_{K=0}^{k} \Delta \ln REU_{t-i} + \eta_5 \sum_{K=0}^{k} \Delta \ln ENC_{t-i} \\ & + \alpha_1 \ln CO_{2t-1} + \alpha_2 \ln YPC_{t-i} + \alpha_3 \ln YPC_{t-i}^2 + \alpha_4 \ln CRD_{t-i} \\ & + \alpha_5 \ln REU_{t-i} + \alpha_6 \ln ENC_{t-i} + \varepsilon_t \end{aligned} \tag{5}$$

wherein k signifies the optimal lag length, determined by working with the Akaike Information Criterion (AIC) test. $\eta_1 \ldots . \eta_5$ are short-run coefficients. $\alpha_1 \ldots \alpha_6$ are long-run coefficients. Δ shows the first difference term.

The bounds test procedure is applied to assess whether a cointegration association among CO_2, YPC, YPC^2, REU, CRD, and ENC is evident. Therefore, the H_0 of no-level relationships (α_1=α_2=α_3=α_4=α_5=0), is evaluated in comparison with the H_1 ($\alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0$). The rule of thumb is that H_0 must be rejected only if the computed F-statistics exceed the upper bounds. Otherwise, there is no cointegration.

Within the framework of ARDLBT, an Error Correction Model (ECM) can be specified as Eq. (6).

$$\begin{aligned} \Delta \ln CO_{4t} = {} & \eta_0 + \eta_1 \sum_{i=1}^{k} \Delta \ln CO_{2t-i} + \eta_1 \sum_{i=0}^{k} \Delta \ln YPC_{t-i} + \eta_2 \sum_{i=0}^{k} \Delta \ln YPC_{t-i}^2 \\ & + \eta_3 \sum_{i=0}^{k} \Delta \ln CRD_{t-i} + \eta_4 \sum_{i=0}^{k} \Delta \ln REU_{t-i} + \eta_5 \sum_{i=0}^{k} \Delta \ln ENC_{t-i} \\ & + \varphi ECT_{t-1} + \varepsilon_t \end{aligned} \tag{6}$$

where φ shows the speed of adjustment. There is a long-run equilibrium if φ varies between 0 and -1 and is statistically significant. To ensure reliable findings, the diagnostic and stability tests are included shortly after the application of ARDLBT.

To assess causal relations between the model variables, this study applies the GC test **[51]**. The GC test is employed within the framework of the Vector Autoregressive (VAR) system to ascertain the causal linkage. Since the GC test is sensitive to the lag included, AIC is considered for selecting the optimal lag length. By proxing the model variables using X and Y notations, models for the GC test can be written as Eqs. (7) and (8), respectively.

$$Y_t = v_1 + \sum_{i=1}^{n} \pi_i Y_{t-i} + \sum_{i=1}^{n} \omega_i X_{t-i} + \varepsilon_{1t} \tag{7}$$

$$Y_t = v_2 + \sum_{i=1}^{n} \upsilon_i Y_{t-i} + \sum_{i=1}^{n} \varpi_i X_{t-i} + \varepsilon_{1t} \tag{8}$$

wherein v_1 and v_2 signify the constant term. ε_1 and ε_2 are the error terms. π, ω, υ, and ϖ are parameters to be estimated. n represents the optimal lag length. The null hypothesis, H_0: $\omega_1 = \omega_2 \ldots \omega_3 = 0$, is evaluated against the alternative hypothesis, H_1: $\omega_1 \neq \omega_2 \ldots \omega_3 \neq 0$. The GC test relies on the Wald statistics in examining the significance of lagged variables **[51]**.

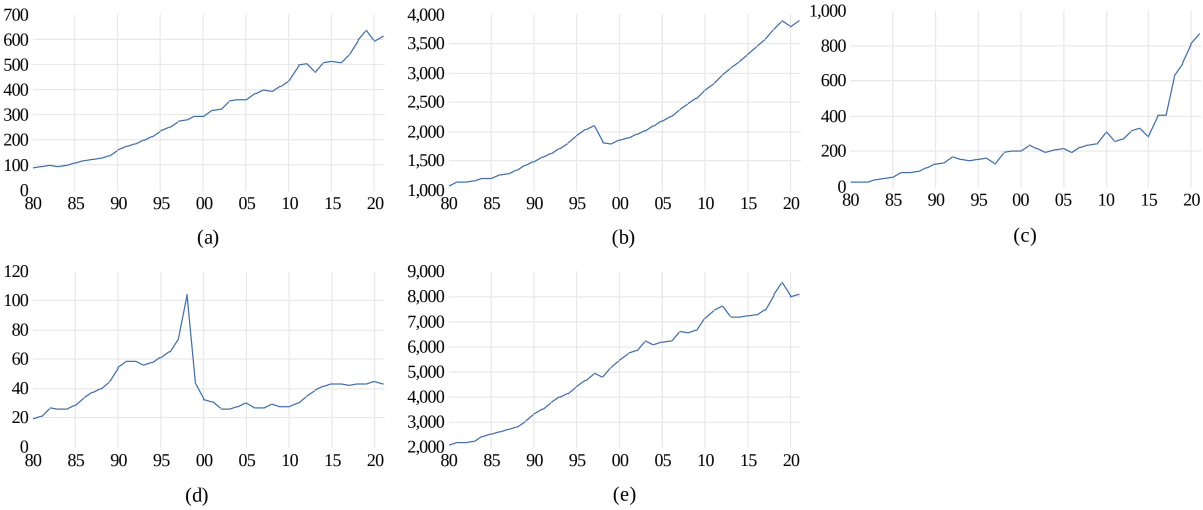
RESULTS

Table 1 displays descriptive statistics of variables, consisting of CO_2, YPC, CDR, ENC, and REU. To estimate elasticity and mitigate the issue of heteroscedasticity, all the variables utilized are modified in natural logarithm terms. Based on the Skewness scores, YPC and CRD are right-tail distributions while CO_2, ENC, and REU are left-tail distributions. Referring to the Kurtosis values, CO_2, YPC, and ENC follow a platykurtic curve, whereas CRD and REU tend to exhibit a mesokurtic curve. The Jarque-Bera scores denote that the p-values for each variable are higher than 0.5. Therefore, the natural logarithms of CO_2, YPC, CRD, ENC, and REU are verified to follow a normal distribution.

Table 1. Descriptive statistics

	$LnCO_2$	LnYPC	LnCRD	LnENC	LnREU
Mean	19.441	7.633	3.626	8.491	5.169
Median	19.547	7.606	3.667	8.655	5.291
Maximum	20.407	8.312	4.643	9.224	6.911
Minimum	18.368	6.973	2.972	7.632	3.204
Std. Dev.	0.614	0.404	0.361	0.457	0.910
Skewness	-0.283	0.076	0.524	-0.525	-0.388
Kurtosis	1.828	1.891	2.990	1.976	3.016
Jarque-Bera	3.032	2.243	1.968	3.852	1.079
p-value	0.220	0.326	0.374	0.146	0.583

Furthermore, this study displays trends of model variables in **Figure 2**. CO_2, YPC, ENC, and REU exhibit upward trends over the observed period. Therefore, it can be concluded that CO_2, per capita GDP, per capita energy consumption, and primary energy consumption from renewable sources demonstrate increasing trends over the period 1980-2022. CRD denotes an upward trend from 1980 to 2020, after which its trajectory became more volatile, fluctuating within a band of 20 to 40 percent of GDP.



(a)

(b)

(c)

(d)

(e)

Figure 2. Trends of model variables: CO_2 emissions (a), per capita GDP (b), primary energy consumption from renewable sources (c), total credit to the private non-financial sector (d), and per capita energy consumption (e)

Unit root test results

Testing the order of integration is a crucial step before the application of ARDLBT. Thus, two types of stationarity tests are considered, the ADF and PP approaches. The outcomes of the ADF approach denote that all the model variables, i.e., CO_2, YPC, CRD, REU, and ENC, fail to reject the null hypothesis at the level. They are non-stationary at their level. Nonetheless, CO_2, YPC, CRD, REU, and ENC are stationary after the first difference is computed. Similarly, the results of the PP test demonstrate that CO_2, YPC, CRD, ENC, and REU are first-order stationary, *1*(1). Since none of the variables are second-order stationary, *I*(2), ARDLBT is a proper method for CO_2 emissions modeling. **Table 2** reports the combined findings of unit root tests, obtained from ADF and PP approaches.

Table 2. Unit root test results

Variable	Level		First difference	
	Stat.	p-value	Stat.	p-value
ADF test				
CO_2	-2.522	0.317	8.308	0.000
YPC	-2.467	0.342	-4.928	0.001
CRD	-2.047	0.559	-5.443	0.000
ENC	-2.069	0.546	-4.911	0.002
REU	-2.096	0.533	-7.869	0.000
PP test				
CO_2	-2.386	0.381	-9.250	0.000
YPC	-2.136	0.512	-4.919	0.002
CRD	-2.139	0.510	-5.443	0.000
ENC	-1.513	0.809	-4.027	0.015
REU	-2.102	0.530	-7.708	0.000

Cointegration test results

Having determined the order of integration of the model variables, the next step is to assess the presence of cointegration. However, an essential preliminary step before proceeding with cointegration analysis is the identification of the optimal lag length. For this purpose, this study works with the AIC test in the model specification. **Table 3** suggests that lag order 2 represents the maximum lag length.

Table 3. Maximum lag length test results

Lag	AIC	SC	HQ
0	31.71	31.96	31.80
1	18.38	20.13*	19.02
2	17.80*	21.06	18.99*

Using the selected lag length, the next analysis is to examine the presence of cointegration. The findings of the Bounds test are documented in **Table 4**. The H0 is observed to be rejected given that the estimated F-statistic (18.11) surpasses the upper bounds (4.15). Thus, it can be inferred that the cointegration relationship between CO_2, YPC, YPC^2, CRD, ENC, and REU is strongly confirmed.

Table 4. Cointegration test results

	Value	Sign.	$I[0]$	$I[1]$
F-stat.	18.11	0.10	2.08	3.00
κ	5	0.50	2.39	3.38
		0.01	3.06	4.15

Dynamic long-run relationships

The presence of cointegration reveals that potential spurious regression is not evident. Thus, the dynamic short- and long-run estimates are meaningful to be interpreted. **Table 5** displays the results of long-run parameters. YPC is negatively associated with $CO_{2,}$ whereas YPC^2 is positively linked to CO_2, denoting the absence of the EKC hypothesis. The inverse U-shaped linkage between per capita GDP and CO_2 emissions is not validated. Instead, there is a U-shaped (ball-shaped) association. Economic growth initially leads to CO_2 reduction, but after a certain point, it positively influences emissions. The estimated ITP is US$1,879 per capita. Although the findings contradict the EKC framework, the U-shaped relationship between income and CO_2 is similar to earlier studies **[52]**, **[53]**. It should be highlighted that the lack of evidence for the EKC hypothesis indicates that economic development cannot be utilized as a sole instrument for CO_2 reduction.

Table 5. Long-run relationships

	Coeff.	Std. Err.	t-stat.	p-value
LnYPC	-4.900	1.546	-3.17	0.003
$LnYPC^2$	0.325	0.095	3.41	0.002
LnCRD	0.077	0.025	3.14	0.004
LnENC	1.455	0.108	13.47	0.000
LnREU	-0.054	0.024	-2.28	0.029
Constant	11.666	5.381	2.17	0.037

Total credit to the private non-financial sector is found to have a positive and significant effect on CO_2 at a 1% critical value. The estimated parameter of CRD is 0.077. This implies that a 1% increase in total credit to the private non-financial sector results in a 0.077% rise in CO2, indicating an inelastic relationship. This finding suggests that credits accessed by non-financial firms contribute to environmental degradation by increasing emissions.

Credit can directly and indirectly impact emissions. A positive link between credit and CO_2 indicates that the vast majority of financial credits accessed by firms are used for unsustainable business. Credits mainly contribute to air pollution through fossil fuel financing and energy-intensive industries such as mining extraction, transportation, cement, chemicals, and steel. As an emerging economy, it is difficult for Indonesia to decouple emissions from businesses that drive economic growth **[39]**. Another channel is that private credits induce CO_2 by financing unsustainable agriculture practices, particularly those involving land use change.

Since the positive impact of credit on CO_2 is evident, enhancing green financing is crucial for Indonesia. Neglecting the detrimental impact of credit may impair the endeavor to satisfy the principle of sustainable development, including the CO_2 reduction target. Thus, financial products related to green credit should be promoted. Sustainable finance policies are verified to have the capacity to drive the green transformation of heavily polluting firms **[54]**. Green financial credit, combined with disruptive low-carbon innovation, is confirmed to significantly foster carbon reduction **[55]**.

A further novel result is that the percentage of primary energy consumption from renewable sources is found to have a negative influence on CO_2 emissions, as expected. This empirical evidence corroborates findings reported in prior investigations in the case of G-20 countries **[56]** and OECD members **[57]**. The estimated parameter of REU is -0.10604. Thus, a 1% hike in primary energy consumption from renewable sources leads to a 0.11% decrease in CO_2, demonstrating an inelastic relationship.

The negative association between CO_2 and clean energy gives an insight into the pivotal role of the Renewable Energy Transition (RET). Higher clean energy consumption corresponds to lower emissions produced. The bright side is that Indonesia has a massive potential for clean energy development, including solar PV, geothermal, wind power, bioenergy, and hydropower **[58]**. As mentioned in the National Energy Policy (NEP) 2014, Indonesia intends to have 23% of its energy mix supplied by clean sources by 2025 **[59]**.

Regarding control variables, per capita total energy consumption is positively associated with $CO_{2,}$ while, surprisingly, trade openness is negatively linked to CO_2. The damaging impact of energy consumption on the environment is verified, consistent with several earlier studies **[60]**, **[61]**. This evidence emphasizes that the vast majority of energy generators in Indonesia are derived from fossil fuel sources. Next, the negative connection between trade openness and emissions suggests that export and import activities have the ability to support environmental sustainability by lowering emissions. This finding is consistent with previous works reported in Europe **[62]** and Indonesia **[63]**.

Dynamic short-run relationships

The results of the short-run and the ECT parameters are displayed in **Table 6**. The short-run estimates denote that the EKC hypothesis is validated. The linkage between per capita GDP and CO_2 reveals the inverse U-shaped pattern in the short run. Another novel finding is that private credit to non-financial sectors positively affects CO_2. Therefore, it can be inferred that increased access to borrowing contributes to environmental degradation by raising CO_2 levels. This evidence emphasizes the crucial need for green credit products.

Table 6. Short-run relationships

	Coeff.	Std. Err.	t-stat.	p-value
ΔLnYPC	-3.927	1.357	-2.89	0.007
$\Delta LnYPC^2$	0.261	0.085	3.08	0.004
ΔLnCRD	0.062	0.020	3.03	0.005
ΔLnREU	1.166	0.155	7.54	0.000
ΔLnENC	-0.043	0.020	-2.18	0.036
ECT	-0.801	0.082	-9.77	0.000

Other short-run estimates demonstrate that renewable energy holds a pivotal position in promoting sustainable development since it is negatively associated with emissions, consistent with the long-run estimates. Conversely, per capita total energy consumption has a detrimental impact on the environment, given that it is positively linked with CO_2, as predicted. These results imply that clean energy can be applied as a key instrument for pollution reduction. Thus, it can be stated that promoting RET is a crucial scheme for reducing the level of emissions.

The ECT parameter is confirmed to be negative, consistent with theoretical expectations. It is statistically significant at a 1% level. The estimated parameter of ECT is -0.801. This result suggests that short-run shocks that cause deviations are adjusted by around 80% within a year toward the long-run equilibrium. This evidence corroborates the evidence of cointegration as reported by the Bounds test.

Diagnostic and stability test results

This study includes diagnostic tests to ensure reliable findings derived from the ARDLBT. **Table 7** jointly displays the outcomes of the diagnostic tests. Following the Breusch-Godfrey and Breusch-Pagan analyses, issues regarding serial correlation and heteroskedasticity are not evident. Instead, error terms are not serially correlated and are homoscedastic. Furthermore, the Ramsey RESET test signifies no clear signs of model misspecification. The JB test signifies that error terms exhibit a normal distribution. Therefore, these diagnostic results provide strong statistical support that the estimated ARDLBT model is robust and reliable for inference.

Table 7. Diagnostic test results

Test	H0	Stat.	p-value
Breusch-Godrey	No serial correlation	1.063	0.303
Breusch–Pagan-Godfrey	Constant variance	2.690	0.101
Ramsey RESET	No omitted variable	0.360	0.779
Jaeque-Bera	Normality residuals	0.335	0.846

In addition to diagnostic tests, this study includes the stability parameter test by employing the cumulative sum (CUSUM) test of recursive residuals. The null hypothesis of parameter consistency is proposed. As shown in **Figure 3**, the cumulative sums (red plots) fluctuate within the critical lines at a 95% level. Thus, it can be stated that the ARDLBT (1,0,0,0,0,0) model is stable during the period of analysis. In other words, a structural break is not evident.

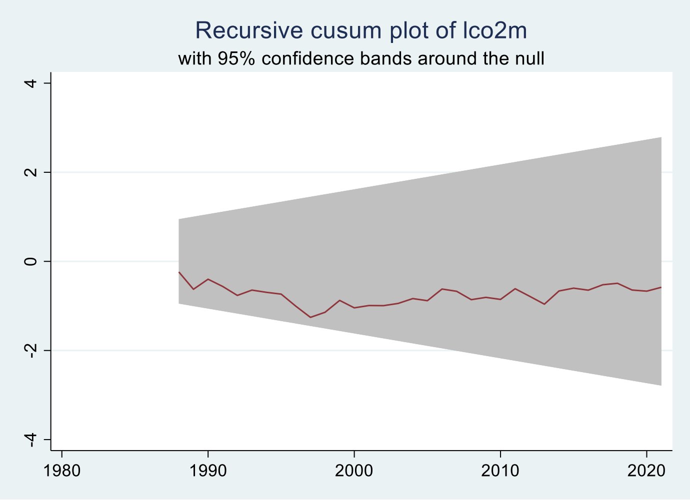


Figure 3. cumulative sum test results

Robustness check

To check the robustness of the estimated parameters obtained from ARDLBT, this study employs the Fully Modified OLS (FMOLS). The FMOLS estimator is chosen given that it has the power to tackle serial correlation and endogeneity [64]. Furthermore, it is more relaxed in terms of the order of integration and nonstationary series. **Table 8** displays the results of the FMOLS estimation. The computed coefficients from FMOLS exhibit consistency with the long-run estimates obtained from the ARDLBT procedure. There is a U-shaped pattern for the linkage between income and emissions, suggesting the absence of the EKC hypothesis. Other findings denote a positive connection between private credit, per capita energy consumption, and CO_2, as well as an adverse association between clean energy and CO_2. Hence, it can be inferred that the empirical findings in this study are robust and reliable.

Table 8. Fully Modified Ordinary Least Squares estimation results

	Coeff.	Std. Err.	t-stat.	p-value
LnYPC	-3.751	1.647	-2.277	0.029
$LnYPC^2$	0.263	0.102	2.583	0.014
LnCRD	0.062	0.030	2.063	0.046
LnREU	-0.102	0.031	-3.304	0.002
LnENC	0.906	0.124	7.316	0.000
Constant	6.167	5.714	1.079	0.288
R-square	0.991			

Causality test

The ARDLBT analyses do not imply the causal direction between the variables. Therefore, with the lag order set to one, this study performs the GC test, and the corresponding results are collectively presented in **Table 9**. This study focuses on the causal relationships related to CO_2. There is a bidirectional causality between CO_2 and YPC. In practical terms, this implies that variations in per capita income significantly influence the level of CO_2, as higher income levels are often associated with increased fossil fuel consumption, industrial activities, and shifts in consumption patterns that lead to greater emissions.

Table 9. Causality test results

(x Granger Causes y)	Chi-square	p-value
$LnCO_2 \leftarrow lnYPC$	12.655	0.005
$LnYPC \leftarrow LnCO_2$	8.936	0.030
$LnCO_2 \leftarrow LnCRD$	6.311	0.097
$LnCRD \leftarrow LnCO_2$	11.130	0.011
$LnCO_2 \leftarrow LnENC$	15.401	0.002
$LnENC \leftarrow LnCO_2$	5.927	0.115
$LnCO_2 \leftarrow LnREU$	6.661	0.084
$LnREU \leftarrow LnCO_2$	0.252	0.969
LnYPC←LnCRD	11.729	0.008
LnCRD←LnYPC	81.562	0.000
LnYPC←LnENC	15.278	0.002
LnENC←LnYPC	8.014	0.046
LnYPC←LnREU	24.391	0.000
LnREU←LnYPC	6.355	0.096
LnCRD←LnENC	8.732	0.033
LnENC←LnCRD	13.326	0.004
LnCRD←LnREU	21.935	0.000
LnREU←LnCRD	4.903	0.179
LnENC←LnREU	10.470	0.015
LnREU←LnENC	1.9346	0.586

Another novel finding denotes the presence of a bidirectional causal nexus between CO_2 and CRD, as expected. The feedback relationship between emissions and total private credit to nonfinancial firms demonstrates that the past value of emissions impacts the amount of loans accessed by firms. This evidence is relevant since pollutions are associated with transactional, physical, and reputational risks.

Furthermore, the results of the GC test signify a unidirectional causal linkage moving from per capita energy consumption toward CO_2. This finding emphasizes that energy consumption is a significant driver of environmental deterioration by increasing emissions, corroborating the evidence obtained from the ARDLBT model. Higher per capita energy usage corresponds to a greater release of CO_2.

Last of all, there is unidirectional causality moving from primary energy consumption from renewable resources toward CO_2. This evidence implies that clean energy exerts a measurable influence in facilitating CO_2 reduction, whereas changes in CO_2 levels do not have a reciprocal effect on the utilization of clean energy. In this regard, advancing green energy infrastructure, in conjunction with promoting energy efficiency and implementing low-carbon technologies, constitutes an essential prerequisite for facilitating Indonesia’s transition toward a sustainable development trajectory.

CONCLUSION

Whether private credit is necessary for supporting emissions reduction is a pivotal question to be addressed, simultaneously with the impact of energy consumption and economic growth. This study augments the EKC model, taking a unique perspective by integrating the impact of total credit to private non-financial sectors and renewable energy consumption in the context of Indonesia by employing annual data over the period 1980 to 2020. The ARDLBT approach is utilized to provide the dynamic and cointegration relationships, followed by the GC test for unraveling causal directions.

The results from regressions convey that the validity of the EKC hypothesis is not verified; instead, there is a ball-shaped association between income and CO_2, suggesting that economic growth cannot be solely considered an instrument for emission reduction. Total credit to non-financial sectors is found to significantly influence environmental degradation by raising CO_2, indicating that emissions are expected to arise from financial developments. Primary energy use from renewable sources is confirmed to be negatively associated with CO_2, emphasizing the significance of the clean energy transition in promoting sustainable development. The GC test suggests a feedback relationship between economic growth, private credit, and CO_2, as well as a unidirectional causality flowing from per capita energy consumption toward CO_2. In light of the findings, the promotion of green financial products and the reduction of dependence on fossil fuel consumption through the adoption of renewable energy are pivotal.

Abbreviations

GDP	Gross Domestic Product
GHG	Greenhouse Gas
CO_2	Carbon Dioxide Emissions
ARDLBT	Autoregressive Distributed Lag Bounds Testing
ADF	Augmented Dickey-Fuller
GC	Granger Causality
PP	Phillips Perron
AIC	Akaike Information Criterion
EKC	Environmental Kuznets Curve
YPC	GDP per capita

CRD	Private credit
REC	Renewable Energy Consumption
EN	Energy Consumption

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Paper submitted: 11.12.2024
Paper revised: 11.06.2025
Paper accepted: 15.06.2025