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RENEWABLE ENERGY CONSUMPTION AND CO_2 EMISSIONS IN INDONESIA: SHORT- AND LONG-RUN EVIDENCE FROM AN ARDL MODEL

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ABSTRACT
Indonesia must reconcile sustained economic and industrial expansion with increasingly stringent decarbonization commitments. Although recent studies generally find that renewable energy can reduce environmental pressure, Indonesia-specific evidence remains fragmented across different econometric designs, and the structural role of industrial value added is often treated only indirectly. This study therefore examines the short- and long-run effects of renewable energy consumption, GDP per capita, and industrial value added on CO_2 emissions in Indonesia using annual data for 1990–2021. The Autoregressive Distributed Lag (ARDL) bounds-testing framework is employed because it jointly estimates short-run adjustment and long-run equilibrium relationships and is suitable for a relatively small time-series sample provided that no variable is integrated of order two. The bounds test confirms cointegration ($F = 10.50$), while the error-correction coefficient is negative and significant (−0.6062), indicating that approximately 60.6% of disequilibrium is corrected within one year. Renewable energy consumption reduces CO_2 emissions in both the short run and long run (long-run elasticity = −0.6187), whereas industrial value added has a positive and significant long-run effect (1.2512). GDP per capita is positive and significant contemporaneously in the short run, but its long-run coefficient is not statistically significant in the baseline specification. The findings support the renewable-energy substitution mechanism and show that industrial structure can offset part of the environmental gains from cleaner energy. Policy should therefore combine faster renewable-energy deployment with industrial decarbonization, energy-efficiency improvements, and technology upgrading.
Keywords: Renewable energy consumption; CO_2 emissions; industrial value added; ARDL; energy transition; Indonesia

INTRODUCTION

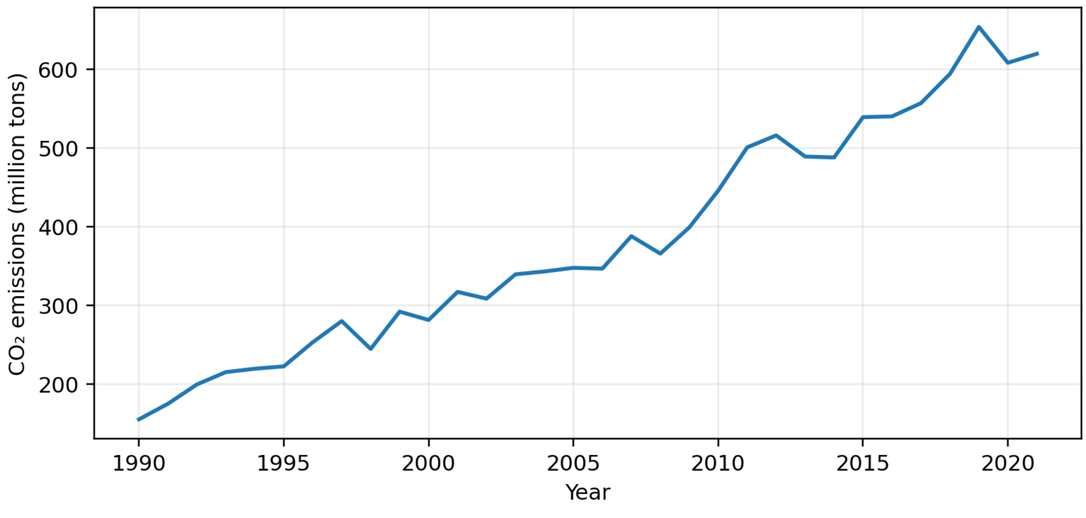
Climate change is increasingly inseparable from energy and development policy. The IPCC (2023) concludes that human activities, principally greenhouse-gas emissions, have unequivocally caused global warming, with average surface temperature in 2011–2020 around 1.1°C above the 1850–1900 level. Energy use remains central to this challenge: global energy-related CO_2 emissions reached a record 37.4 Gt in 2023, even as the expansion of clean-energy technologies slowed the pace of emissions growth (IEA, 2024). For emerging economies, the policy problem is therefore not simply to reduce energy use, but to change the composition and efficiency of energy supply without constraining productive transformation.

Indonesia illustrates this tension particularly clearly. Economic growth, urbanization, transport demand, downstream industrialization, and expanding electricity consumption continue to raise energy requirements, while the power and industrial systems remain strongly exposed to fossil fuels. At the same time, Indonesia has substantial solar, hydro, geothermal, biomass, and wind potential, making renewable energy an important instrument for reducing carbon intensity and improving long-term energy security (Salsabila et al., 2023). Earlier assessments of Indonesia's energy policy also emphasize that renewable-energy targets require complementary reforms in investment, electricity-market governance, infrastructure, and institutional implementation (Maulidia et al., 2019; Santika et al., 2020).

The policy context has also become more demanding. Indonesia's Second Nationally Determined Contribution (Second NDC) maintains the pathway toward net-zero emissions by 2060 or sooner and aligns national climate targets with the RPJMN 2025–2029 and RPJPN 2025–2045. The Second NDC adopts emissions-level targets and emphasizes mitigation in the energy and industrial sectors, including accelerated renewable-energy development and stronger carbon-management instruments (Republic of Indonesia, 2025). This makes empirical evidence on the effectiveness of renewable energy especially relevant for the Indonesia Emas 2045 development agenda.

Indonesia's historical emissions trajectory, however, shows that the expansion of renewable energy has occurred alongside persistent growth in total CO_2 emissions. Figure 1 illustrates the marked increase in emissions over 1990–2021. The divergence suggests that cleaner energy can reduce emissions at the margin while broader structural forces, especially economic scale, industrial expansion, and continued fossil-fuel dependence, may partly offset those gains. Consequently, the relevant question is not whether renewable energy is environmentally beneficial in principle, but whether its observed expansion has been large enough to generate measurable emission reductions after controlling for economic and industrial dynamics.

Figure 1. Total CO_2 Emissions from Fossil Fuel and Industrial Sectors in Indonesia (1990–2021)



Source: World Bank, 1990–2021; figure reproduced from the submitted manuscript.

Recent empirical evidence provides an increasingly rich but still non-uniform picture. Idroes et al. (2024), using FMOLS, DOLS, and CCR, report that renewable and non-renewable energy have distinct long-run environmental effects in Indonesia. Wahyudi (2024) applies a VECM to the Indonesian energy–economy relationship, while Sari Saudi et al. (2024) employ QARDL to study renewable-energy adoption, technological factors, and carbon neutrality. Shodrokova et al. (2024) also use an ARDL framework for Indonesia but focus on the blue economy, renewable energy, and energy intensity. At the regional level, Claire and Widyawati (2023) and Mu'min et al. (2023) examine industrialization, renewable energy, economic growth, and emissions across ASEAN economies. These studies generally support the relevance of renewable energy, yet their model structures, samples, and environmental channels differ, and regional panel estimates may conceal Indonesia-specific adjustment dynamics.

The research gap is therefore more specific than a simple absence of studies on renewable energy and emissions. Indonesia still has limited country-specific evidence that simultaneously separates the short-run and long-run elasticities of renewable energy consumption, GDP per capita, and industrial value added in one parsimonious dynamic framework. The structural role of industrial value added is particularly important because industrial expansion can raise energy demand and fossil-fuel use even when the renewable share is increasing. This study addresses that gap by using an ARDL model to evaluate these three channels jointly, testing the existence of a long-run equilibrium relationship, and explicitly linking the estimated coefficients to pre-specified hypotheses.

Accordingly, the study makes three contributions. First, it updates the Indonesia-focused literature by treating industrial value added as a structural emissions channel rather than considering the energy mix alone. Second, it distinguishes immediate adjustment effects from long-run elasticities, which is important when renewable investment and industrial restructuring occur gradually. Third, it evaluates the empirical results against an explicit theoretical framework and a set of hypotheses, thereby clarifying which mechanisms are supported, partially supported, or rejected. The central objective is to determine whether renewable energy consumption has reduced Indonesia's CO_2 emissions over 1990–2021 after accounting for economic growth and industrial activity, and whether these variables share a stable long-run relationship.

Theoretical foundation and hypothesis development

The theoretical framework integrates three complementary mechanisms: energy substitution, the scale and composition effects associated with economic development, and the energy intensity of industrialization. Together, these mechanisms explain why renewable energy can reduce emissions while rising income and industrial output can simultaneously create upward pressure on carbon use.

Renewable energy consumption and CO_2 emissions (H1)

The energy-substitution mechanism predicts that replacing fossil-fuel-based energy with renewable sources reduces the carbon intensity of final energy use and electricity generation. Renewable technologies generally generate substantially lower direct emissions than coal, oil, and gas, and their wider adoption can also encourage complementary innovation and efficiency improvements (Genc & Kosempel, 2023; Raihan et al., 2023). Indonesia-specific evidence increasingly supports this mechanism. Idroes et al. (2024), Sari Saudi et al. (2024), and Shodrokova et al. (2024) all report emission-reducing effects associated with renewable energy under different specifications. Therefore, H1 states: renewable energy consumption has a negative and statistically significant effect on CO_2 emissions.

Economic growth and CO_2 emissions (H2)

The relationship between income and environmental pressure is commonly discussed through the Environmental Kuznets Curve (EKC). At earlier stages of development, the scale effect of rising production, transport, construction, and household energy demand can dominate improvements in technology and environmental regulation, causing emissions to increase with income. At higher income levels, structural change, cleaner technologies, and stronger institutions may weaken or reverse this relationship (Mardani et al., 2019). For Indonesia, earlier work has frequently found a positive link between economic expansion and carbon emissions (Hwang & Yoo, 2014; Raihan et al., 2022). Given the sample period and Indonesia's continued reliance on carbon-intensive energy, H2 states: GDP per capita has a positive and statistically significant effect on CO_2 emissions.

Industrial value added and CO_2 emissions (H3)

Industrial value added captures an important structural dimension of emissions. Manufacturing, mining-related processing, metallurgy, chemicals, construction materials, and other industrial activities require substantial heat, electricity, and material throughput. Where energy efficiency and low-carbon process technologies remain limited, greater industrial output tends to increase emissions (Fais et al., 2016). ASEAN evidence also shows that the environmental effect of industrialization depends critically on the penetration of renewable energy and cleaner technologies (Claire & Widyawati, 2023). H3 therefore states: industrial value added has a positive and statistically significant effect on CO_2 emissions, particularly in the long run as productive capacity and energy demand expand.

Long-run equilibrium relationship (H4)

Renewable-energy investment, economic development, and industrial transformation are persistent processes whose effects accumulate over time. Even when short-run coefficients fluctuate because of business cycles, energy-price changes, or adjustment lags, economic theory suggests that these variables can move around a common long-run equilibrium. The ARDL bounds-testing approach is designed to test this proposition directly (Pesaran et al., 2001). H4 states: CO_2 emissions, renewable energy consumption, GDP per capita, and industrial value added are cointegrated in Indonesia.

RESEARCH METHODOLOGY

This study uses annual time-series observations for Indonesia from 1990 to 2021 (32 observations). The dependent variable is CO_2 emissions (CO_2). The explanatory variables are renewable energy consumption (REC), GDP per capita (GDPC), and industrial value added (IND). The series are compiled from the World Bank's World Development Indicators for the study period and transformed into natural logarithms: $LNCO_2$, LNREC, LNGDPC, and LNIND. The logarithmic transformation reduces scale differences and allows the estimated slope coefficients to be interpreted approximately as elasticities.

The Autoregressive Distributed Lag (ARDL) bounds-testing framework is selected for three reasons. First, it estimates short-run dynamics and long-run relationships within a single-equation framework. Second, it is appropriate when regressors are integrated of order zero, I(0), or order one, I(1), provided that none is I(2). Third, ARDL is widely used for relatively small time-series samples, although the finite-sample nature of the present data requires cautious inference and attention to lag parsimony (Pesaran et al., 2001; Narayan, 2005). These properties make ARDL suitable for the study's 1990–2021 annual dataset and its focus on adjustment dynamics.

The empirical procedure has five stages. First, the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are used to determine the integration order of each series. Second, candidate lag structures are compared using the Akaike Information Criterion (AIC), subject to the limited number of annual observations. Third, the ARDL bounds F-test evaluates the null hypothesis of no long-run relationship. Because the sample is small, the cointegration decision is also checked against the small-sample logic discussed by Narayan (2005); the reported F-statistic is sufficiently above conventional upper bounds that the qualitative decision is unchanged. Fourth, once cointegration is established, the long-run elasticities and the error-correction representation are estimated. Fifth, model adequacy is assessed using serial-correlation, normality, heteroscedasticity, functional-form, and stability tests.

The unrestricted error-correction representation of the ARDL model is written as:

$$\Delta LNCO_{2t} = c + \varphi LNCO_{2t-1} + \theta_1 LNREC_{t-1} + \theta_2 LNIND_{t-1} + \theta_3 LNGDPC_{t-1} + \Sigma\alpha_i \Delta LNCO_{2t-i} + \Sigma\beta_j \Delta LNREC_{t-j} + \Sigma\gamma_k \Delta LNIND_{t-k} + \Sigma\delta_l \Delta LNGDPC_{t-l} + \varepsilon_t \quad (1)$$

where Δ denotes the first-difference operator, c is the intercept, ε_t is the disturbance term, and the summation terms capture short-run dynamics. The joint significance of φ, θ_1, θ_2, and θ_3 is evaluated using the bounds F-test. When cointegration is confirmed, the short-run error-correction model is expressed as:

$$\Delta LNCO_{2t} = c + \Sigma\alpha_i \Delta LNCO_{2t-i} + \Sigma\beta_j \Delta LNREC_{t-j} + \Sigma\gamma_k \Delta LNIND_{t-k} + \Sigma\delta_l \Delta LNGDPC_{t-l} + \lambda ECT_{t-1} + \varepsilon_t \quad (2)$$

The coefficient λ is expected to be negative and statistically significant; its magnitude indicates the annual speed at which deviations from the long-run equilibrium are corrected. The long-run coefficients are interpreted as elasticities because all variables enter in logarithmic form. In addition to the baseline ARDL, a sensitivity specification introduces fossil-fuel energy consumption (FFEC) to examine whether the direction of the principal long-run coefficients is robust to explicit control for carbon-intensive energy use. This alternative specification is interpreted as a robustness check rather than as the primary model (Lu & White, 2014).

RESULTS AND DISCUSSION

The ADF and PP tests produce consistent evidence that the four baseline variables are non-stationary in levels but stationary after first differencing. As reported in Table 1, $LNCO_2$, LNREC, LNGDPC, and LNIND are all classified as I(1). Importantly, no variable is I(2), satisfying the principal integration-order requirement for the ARDL bounds procedure.

Table 1. Unit Root Test

Variable	ADF Level	ADF 1st Difference	PP Level	PP 1st Difference	Decision
$LNCO_2$	−1.86	−7.77***	−3.59**	−9.54***	I(1)
LNREC	0.70	−6.08***	2.35	−6.20***	I(1)
LNGDPC	−0.27	−4.15***	−0.27	−4.09***	I(1)
LNIND	−1.78	−5.93***	−1.82	−5.83***	I(1)

*Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Source: EViews 13, processed data (2025).*

The AIC selects the reported lag configuration (4,4,4,3) for $LNCO_2$, LNIND, LNREC, and LNGDPC, respectively. The bounds-test F-statistic is 10.50, which is higher than the upper bound at the 1% level in Table 2. The null hypothesis of no cointegration is therefore rejected. Given the relatively small sample, this conclusion is also robust to the use of stricter small-sample critical-value logic because the F-statistic is far above the relevant upper bounds. H4 is consequently supported: emissions, renewable energy consumption, industrial value added, and GDP per capita share a long-run equilibrium relationship.

Table 2. ARDL Bounds Cointegration Test

Model / significance	Lag / I(0)	F-stat. / I(1)	Decision
$LNCO_2$ = f(LNIND, LNREC, LNGDPC)	4,4,4,3	10.50***	Cointegrated
10% critical bounds	2.67	3.58	
5% critical bounds	3.27	4.30	
1% critical bounds	4.61	5.96	

*Note: *** denotes significance at the 1% level. Reported bounds follow the submitted EViews output. Source: EViews 13, processed data (2025).*

Table 3 reports the short-run, long-run, and diagnostic estimates. The error-correction term is −0.6062 and statistically significant at the 1% level. Thus, approximately 60.6% of a deviation from the long-run equilibrium is corrected within one year, implying relatively rapid convergence after a shock. Renewable energy consumption has a negative contemporaneous short-run coefficient (−0.7830; p = 0.0002), and selected lagged REC effects are also negative. By contrast, the contemporaneous GDP-per-capita effect is positive and significant (0.9480; p = 0.0004), although the lagged coefficients alternate in sign, indicating short-run adjustment rather than a uniformly monotonic response. Industrial value added exhibits negative short-run coefficients in the reported baseline model, with the contemporaneous term significant at 10% and the first lag significant at 5%.

Table 3. ARDL Short-Run, Long-Run, and Diagnostic Results

Variable/Test	Coefficient/F-stat.	t-statistic	Probability
Panel A. Short-run estimates			
ECT_{t-1}	−0.6062	−8.7105	0.0000***
D(LNREC)	−0.7830	−6.0922	0.0002***
D(LNREC(−1))	−0.4942	−2.9923	0.0151**
D(LNREC(−2))	−0.3180	−1.7066	0.1221
D(LNREC(−3))	−0.5904	−0.7081	0.0142**
D(LNGDPC)	0.9480	5.4626	0.0004***
D(LNGDPC(−1))	−0.8115	−4.1721	0.0031***
D(LNGDPC(−2))	0.5968	3.2661	0.0115**
D(LNGDPC(−3))	−0.5575	−2.6335	0.0300**
D(LNIND)	−0.3871	−1.9852	0.0784*
D(LNIND(−1))	−0.5684	−2.6675	0.0257**
D(LNIND(−2))	−0.1997	−1.0042	0.3415
Panel B. Long-run estimates			

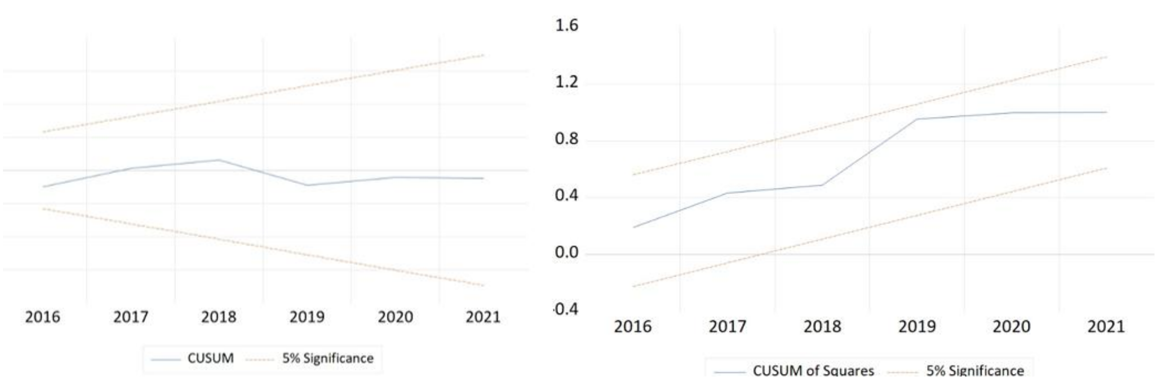
Variable/Test	Coefficient/F-stat.	t-statistic	Probability
LNREC	−0.6187	−2.8919	0.0178**
LNGDPC	0.3958	1.8278	0.1008
LNIND	1.2512	7.2871	0.0000***
C	14.156	5.9432	0.0002***
Panel C. Diagnostic tests			
LM test	0.4434	—	0.9272
Jarque–Bera normality test	0.7979	—	0.6710
Heteroscedasticity test	0.2447	—	0.9946
Ramsey RESET test	0.8203	—	0.3916

*Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.*
Source: EViews 13, processed data (2025).

In the long run, renewable energy consumption has a coefficient of −0.6187 and is significant at the 5% level. Holding the other factors constant, a 1% increase in renewable energy consumption is associated with an approximately 0.62% reduction in CO_2 emissions. This is the clearest result of the model and provides direct support for H1. GDP per capita has the expected positive sign (0.3958), but the p-value of 0.1008 is above conventional significance thresholds. H2 is therefore only partially supported: economic expansion raises emissions in the contemporaneous short run, but the baseline model does not establish a statistically significant long-run income elasticity. Industrial value added has a large positive long-run coefficient (1.2512; $p < 0.01$), supporting H3 in the long run even though its short-run coefficients are negative. This difference suggests that temporary efficiency or cyclical effects may dominate in the short run, whereas the cumulative expansion of industrial capacity and energy demand raises emissions over longer horizons.

The diagnostic results strengthen confidence in the baseline specification. The LM test does not indicate serial correlation, the Jarque–Bera statistic does not reject residual normality, the heteroscedasticity test does not detect non-constant variance, and the Ramsey RESET test provides no evidence of functional-form misspecification. Figure 2 further shows that the CUSUM and CUSUM of Squares statistics remain within the 5% significance bands over the reported period, indicating stable estimated parameters.

Figure 2. Stability Test Using CUSUM and CUSUM of Squares



Source: EViews 13, processed data (2025).

Robustness check

A sensitivity specification adds fossil-fuel energy consumption (LNFFEC) to the long-run model. The purpose is to determine whether the principal coefficient directions persist when the carbon-intensive energy channel is controlled explicitly. Table 4 shows that LNREC remains negative and statistically significant, while LNIND and LNGDPC are positive; LNFFEC is also positive and significant, as expected. The renewable-energy and industrialization results are therefore directionally robust. However, GDP per capita becomes statistically significant in this expanded specification, indicating that the long-run income effect is more specification-sensitive than the renewable-energy and industrial coefficients. The diagnostic probabilities remain above 5%, including the RESET probability of 0.0532. These results support the baseline findings while also cautioning against over-interpreting the exact magnitude of the GDP effect.

Table 4. Long-Run Robustness Check with Fossil-Fuel Energy Consumption

Variable/Test	**Coefficient/F-stat.**	**t-statistic/decision**	**Probability**
Panel A. Long-run estimates			
LNREC	−0.8025	−37.1823	0.0000**
LNGDPC	0.3981	18.4240	0.0000***
LNIND	0.8962	13.0750	0.0000***
LNFFEC	0.7674	8.30367	0.0002***
C	12.7888	52.5168	0.0000***
Panel B. Diagnostic tests			
LM test	0.1957	—	0.9957
Jarque–Bera normality test	0.1856	—	0.9113
Heteroscedasticity test	0.6886	—	0.7576
Ramsey RESET test	6.3520	—	0.0532
CUSUM	—	Stable	—
CUSUM of Squares	—	Stable	—

*Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. The robustness table focuses on the long-run coefficients and diagnostics to avoid duplicating short-run output. Source: EViews 13, processed data (2025).*

Discussion and hypothesis evaluation

The negative renewable-energy coefficient is consistent with the substitution mechanism and with recent Indonesia-specific evidence. Idroes et al. (2024) find that renewable and non-renewable energy have distinct long-run environmental consequences, while Sari Saudi et al. (2024) report lower CO_2 emissions across several quantiles as renewable-energy adoption and related technologies expand. Shodrokova et al. (2024) similarly find that renewable energy reduces Indonesia's emissions in both short- and long-run ARDL estimates. The present study adds to this literature by showing that the emission-reducing effect remains visible even after industrial value added is introduced as a structural control. In policy terms, renewable deployment is not merely correlated with a cleaner energy mix; it is associated with a statistically measurable reduction in aggregate emissions.

The GDP result requires a more nuanced interpretation than the original manuscript's claim of a uniformly positive and significant effect. The contemporaneous short-run coefficient is strongly positive, which is consistent with the scale effect: stronger economic activity raises energy use and emissions before technology and structural adjustment occur. Yet the long-run coefficient is not statistically significant in the baseline model. This means the data do not provide sufficient evidence to conclude that income alone is a stable long-run driver of emissions after renewable energy and industrial structure are controlled. The robustness model makes GDP significant, suggesting that the estimated income effect depends partly on how fossil-fuel use is represented. This finding is compatible with the mixed EKC evidence documented in broader reviews and ASEAN research (Mardani et al., 2019; Mu'min et al., 2023).

Industrial value added displays the strongest positive long-run elasticity in the baseline model. This supports the view that Indonesia's industrial transition remains materially and energetically intensive. The negative short-run coefficients should not be interpreted as evidence that industrialization is inherently emission-reducing; rather, they may reflect temporary production adjustments, efficiency changes, or timing differences between output and energy use. Over the longer horizon, the positive coefficient indicates that expansion of industrial capacity can offset part of the environmental benefit produced by renewable energy unless low-carbon process technologies, electrification, and energy-efficiency standards improve simultaneously. This conclusion is consistent with ASEAN evidence showing that renewable energy can moderate, but not automatically eliminate, the environmental cost of industrialization (Claire & Widyawati, 2023).

Finally, the significant bounds test and negative error-correction coefficient provide an important dynamic interpretation. The variables are not simply correlated contemporaneously; they exhibit a long-run equilibrium, and deviations are corrected relatively quickly. This supports the use of a coordinated policy framework in which energy transition, industrial strategy, and economic planning are treated jointly rather than as separate policy domains. The hypothesis decisions are summarized in Table 5.

Table 5. Summary of Hypothesis Evaluation

Hypothesis	Expected relationship	Key evidence	Decision
H1: REC → CO_2	Negative	Short run: −0.7830***; Long run: −0.6187**	Supported
H2: GDPC → CO_2	Positive	Short run: +0.9480***; Long run: +0.3958 (p = 0.1008)	Partially supported
H3: IND → CO_2	Positive	Short-run coefficients negative/mixed; Long run: +1.2512***	Supported in long run
H4: Cointegration	Long-run equilibrium	Bounds F = 10.50***; ECT = −0.6062***	Supported

Source: Authors' synthesis based on the ARDL estimates in Tables 2 and 3.

CONCLUSION AND SUGGESTIONS

This study re-examines the relationship between renewable energy consumption and CO_2 emissions in Indonesia by integrating GDP per capita and industrial value added within an ARDL framework for 1990–2021. Four conclusions emerge. First, renewable energy consumption has a statistically significant emission-reducing effect in both the short run and the long run, with a long-run elasticity of −0.6187; H1 is supported. Second, GDP per capita raises emissions significantly in the contemporaneous short run, but its long-run baseline coefficient is not statistically significant; H2 is therefore only partially supported. Third, industrial value added has a positive and highly significant long-run elasticity, supporting H3 in the long run and demonstrating that productive transformation remains an important structural source of emissions. Fourth, the variables are cointegrated and the error-correction coefficient indicates that about 60.6% of disequilibrium is corrected within a year, supporting H4.

The policy implication is that renewable-energy expansion is necessary but not sufficient for Indonesia's low-carbon transition. Faster deployment of renewables should be paired with industrial decarbonization through energy-efficiency standards, electrification of industrial processes where feasible, cleaner heat technologies, green-technology investment, and stronger incentives to reduce fossil-fuel intensity. The results also caution against assuming that economic growth will automatically improve environmental quality: the long-run income effect is specification-sensitive, while the industrial structure remains clearly carbon-intensive. These priorities are consistent with the Second NDC's emphasis on integrating energy, industrial, and national development planning toward net-zero emissions by 2060 or sooner (Republic of Indonesia, 2025).

The study has several limitations. The annual sample contains only 32 observations and ends in 2021, so recent policy shifts and post-2021 energy shocks are not captured. The analysis is aggregate and cannot distinguish the emissions effects of different renewable technologies or industrial subsectors. In addition, the linear ARDL specification may not fully capture structural breaks, threshold effects, or asymmetric responses. Future research should extend the sample as comparable data become available, test for structural breaks, compare linear ARDL with NARDL or QARDL specifications, and incorporate energy efficiency, fossil-fuel composition, technological innovation, carbon-pricing variables, and sector-level industrial data.

REFERENCES

Claire, B., & Widyawati, D. (2023). Impact of industrialization and renewable energy on carbon dioxide emission in 9 ASEAN countries. Economic Journal of Emerging Markets, 15(2), 183–198. https://doi.org/10.20885/ejem.vol15.iss2.art6

Fais, B., Sabio, N., & Strachan, N. (2016). The critical role of the industrial sector in reaching long-term emission reduction, energy efficiency and renewable targets. Applied Energy, 162, 699–712. https://doi.org/10.1016/j.apenergy.2015.10.112

Genc, T. S., & Kosempel, S. (2023). Energy transition and the economy: A review article. Energies, 16(7), 2965. https://doi.org/10.3390/en16072965

Hwang, J. H., & Yoo, S. H. (2014). Energy consumption, CO_2 emissions, and economic growth: Evidence from Indonesia. Quality & Quantity, 48(1), 63–73. https://doi.org/10.1007/s11135-012-9749-5

Idroes, G. M., Hardi, I., Rahman, M. H., Afjal, M., Noviandy, T. R., & Idroes, R. (2024). The dynamic impact of non-renewable and renewable energy on carbon dioxide emissions and ecological footprint in Indonesia. Carbon Research, 3, 35. https://doi.org/10.1007/s44246-024-00117-0

Intergovernmental Panel on Climate Change. (2023). Climate Change 2023: Synthesis Report. IPCC.

International Energy Agency. (2024). CO_2 Emissions in 2023. IEA.

Lu, X., & White, H. (2014). Robustness checks and robustness tests in applied economics. Journal of Econometrics, 178, 194–206. https://doi.org/10.1016/j.jeconom.2013.08.016

Mardani, A., Streimikiene, D., Cavallaro, F., Loganathan, N., & Khoshnoudi, M. (2019). Carbon dioxide (CO_2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. Science of the Total Environment, 649, 31–49. https://doi.org/10.1016/j.scitotenv.2018.08.229

Maulidia, M., Dargusch, P., Ashworth, P., & Ardiansyah, F. (2019). Rethinking renewable energy targets and electricity sector reform in Indonesia: A private sector perspective. Renewable and Sustainable Energy Reviews, 101, 231–247. https://doi.org/10.1016/j.rser.2018.11.005

Mu'min, M. S., Susilowati, I., Qudsyina, H., Wahyuni, H. A., Rismawati, S., Kusumawardhani, H. A., & Miah, M. R. (2023). Nexus between economic growth, renewable energy, industry value added and CO_2 emissions in ASEAN. Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi dan Pembangunan, 24(2), 265–281. https://doi.org/10.23917/jep.v24i2.23165

Narayan, P. K. (2005). The saving and investment nexus for China: Evidence from cointegration tests. Applied Economics, 37(17), 1979–1990. https://doi.org/10.1080/00036840500278103

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 16(3), 289–326. https://doi.org/10.1002/jae.616

Rahman, A., Richards, R., Dargusch, P., & Wadley, D. (2023). Pathways to reduce Indonesia's dependence on oil and achieve longer-term decarbonization. Renewable Energy, 202, 1305–1323. https://doi.org/10.1016/j.renene.2022.11.051

Raihan, A., Muhtasim, D. A., Pavel, M. I., Faruk, O., & Rahman, M. (2022). An econometric analysis of the potential emission reduction components in Indonesia. Cleaner Production Letters, 3, 100008. https://doi.org/10.1016/j.clpl.2022.100008

Raihan, A., Pavel, M. I., Muhtasim, D. A., Farhana, S., Faruk, O., & Paul, A. (2023). The role of renewable energy use, technological innovation, and forest cover toward green development: Evidence from Indonesia. Innovation and Green Development, 2(1), 100035. https://doi.org/10.1016/j.igd.2023.100035

Republic of Indonesia. (2025). Second Nationally Determined Contribution. Submitted to the United Nations Framework Convention on Climate Change.

Salsabila, M. S., Suharno, & Sukatiman. (2023). Renewable energy in Indonesia: Current status, potential, and future development. Sustainability, 15(3), 2342. https://doi.org/10.3390/su15032342

Santika, W. G., Urmee, T., Simsek, Y., Bahri, P. A., & Anisuzzaman, M. (2020). An assessment of energy policy impacts on achieving Sustainable Development Goal 7 in Indonesia. Energy for Sustainable Development, 59, 33–48. https://doi.org/10.1016/j.esd.2020.08.011

Sari Saudi, N. D., Abdi Reviane, I. T., Paddu, A. H., Agustin, G., Djam'an, F., & Sabbar, S. D. (2024). Carbon neutrality and sustainable development: An empirical study of Indonesia's renewable energy adoption. International Journal of Energy Economics and Policy, 14(4), 526–537. https://doi.org/10.32479/ijeep.15953

Shodrokova, X., Yulianita, A., Bashir, A., Asngari, I., & Hidayat, A. (2024). The impact of the blue economy and renewable energy on CO_2 emissions in Indonesia: An ARDL approach. Jurnal Perspektif Pembiayaan dan Pembangunan Daerah, 12(3), 255–270. https://doi.org/10.22437/ppd.v12i3.34183

Wahyudi, H. (2024). The relationship between the renewable energy and CO_2 emissions to the Indonesian economy. International Journal of Energy Economics and Policy, 14(3), 349–357. https://doi.org/10.32479/ijeep.15903

World Bank. (2025). World Development Indicators [Data set]. World Bank.