IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(2), 363-373.

Sustainable Future of International Trade and Environmental Governance in ASEAN: Indonesia's Economic Growth and Green Commitments

Indraswati Tri Abdi Reviane*, Abdul Hamid Paddu, Fitriwati Djam'an, Aditya Idris, Wasiaturrahma

Faculty of Economics and Business, Hasanuddin University, Makassar 90245, Indonesia. *Email: indraswati@fe.unhas.ac.id

Received: 23 September 2025 **Accepted:** 14 January 2026 **DOI:** https://doi.org/10.32479/ijeep.22496

ABSTRACT

This study examines the determinants of sustainable development in Indonesia from 1990 to 2022, focusing on the relationships among economic growth, international trade, environmental governance, and green commitments. The research empirically tests the environmental Kuznets curve (EKC) hypothesis and assesses the mitigating effects of governance quality and renewable energy adoption. The methodology employs second-generation econometric techniques to address cross-sectional dependence, specifically the cross-sectionally augmented ARDL (CS-ARDL) model to estimate both long- and short-run dynamics. The findings validate the EKC hypothesis for Indonesia, revealing a statistically significant inverted-U relationship between income and CO_2 emissions. The results demonstrate that robust governance and increased use of renewable energy are critical in reducing environmental degradation. Furthermore, the Error Correction Term indicates a rapid adjustment toward long-run equilibrium, with an annual adjustment speed of 41.2%. These results highlight the necessity of integrated policies that strengthen institutional quality and accelerate the energy transition. The study contributes by providing a dual analysis of governance and energy within a rigorous second-generation econometric framework, offering practical insights for sustainable growth in Indonesia and emphasizing that institutional strength is vital for the successful implementation of green commitments.

Keywords: Sustainable Development, Trade, Environmental Kuznets Curve, Renewable Energy, Indonesia, ASEAN Countries
JEL Classifications: Q56, Q42, C23, O13

1. INTRODUCTION

Global economic integration has played a significant role in reducing poverty worldwide (Abyan, 2025), yet it has also contributed to a growing environmental crisis, making sustainable development the foremost challenge of the 21st century (Pramudianto, 2018).

This tension is particularly evident in the rapidly developing countries of the Association of Southeast Asian Nations (ASEAN), where accelerated economic growth, driven by industrialization and increased international trade, frequently results in considerable ecological degradation (Chairina and Tjahjadi, 2023). Indonesia, as the principal architect of the ASEAN Economic Community and the region's largest economy, occupies a central position in this dilemma (Yuniar, 2025). The nation's aspiration to achieve high-income status is closely tied to its ability to leverage international trade and attract foreign investment (Chien et al., 2023). However, this economic strategy, which relies heavily on natural resource extraction and fossil fuel consumption, threatens Indonesia's biodiversity and significantly increases global greenhouse gas (GHG) emissions, thereby intensifying the conflict between economic growth and environmental sustainability (Kheng-Lian et al., 2016).

The relationship between environmental degradation and economic activity has attracted extensive scholarly attention (Shahbaz et al., 2021). Much of this research is grounded in the Environmental

Kuznets Curve (EKC) model, which posits an inverted U-shaped relationship between income per capita and pollution (Sadiq et al., 2023). Subsequent studies have expanded this framework by incorporating variables such as trade openness (Robinson et al., 2025), energy use and financial development (Chien et al., 2023). However, significant gaps remain, particularly within the ASEAN context. Many investigations addressing the EKC hypothesis at the regional level tend to homogenize the diverse economic structures and governance systems of member states, thereby obscuring country-specific dynamics (Kheng-Lian et al., 2016).

Indonesia, characterized by its archipelagic geography, resource-dependent economy, and evolving democratic institutions, is a critical case often overlooked in aggregate analyses. Furthermore, existing empirical studies frequently treat green commitments as a singular phenomenon, neglecting the potentially complementary roles of tangible factors, such as renewable energy adoption, and intangible factors, such as the quality of government institutions (Sarangi, 2019). The mechanisms through which environmental governance interacts with economic forces to shape sustainability outcomes in Indonesia remain insufficiently explored.

This study addresses critical gaps by conducting a focused, in-depth analysis of the determinants of sustainable development in Indonesia. The originality of this paper is threefold. First, it offers a rigorous methodological assessment of the Environmental Kuznets curve (EKC) hypothesis for Indonesia, using long-term data and advanced econometric techniques while accounting for the nation's integration into the global economy. Second, it innovatively disaggregates green commitments into their core components, specifically green energy (REN) and governance quality (GOV), and empirically evaluates both their individual and combined impacts on reducing environmental pressures. Third, it offers novel insights into the speed of adaptation to environmental equilibrium, a dimension often neglected in the existing literature but crucial for informing the timing and urgency of policy interventions.

This paper is structured as follows. Section 2 reviews the literature on the relationship between economic growth and the environment, focusing on ASEAN and Indonesia. Section 3 outlines the research methodology, including variable selection, data sources, and the CS-ARDL approach. Section 4 presents the empirical results, covering descriptive statistics, unit root and cointegration tests, and estimation outcomes. Section 5 discusses the policy implications for Indonesia and the ASEAN region. Section 6 concludes with key insights, policy recommendations, and suggestions for future research.

2. LITERATURE REVIEW

The relationship between economic development and environmental degradation remains a central issue in development economics and environmental science (Limenta, 2022). A key theoretical framework in this discourse is the Environmental Kuznets curve (EKC) hypothesis, first proposed by Grossman and Krueger (1995). The EKC posits that environmental degradation initially increases with economic growth but declines after a certain per capita income threshold is reached. This relationship is represented by an inverted U-shaped curve, attributed to the combined effects of scale, composition, and technique (Ngo et al., 2025). While empirical evidence supports the EKC in some developed economies, its relevance to developing countries remains highly contested. Research focusing on ASEAN countries has yielded conflicting results (Liu et al., 2023).

For instance, a panel study by Alam and Murad (2020) found evidence supporting the EKC, attributing this to regional economic integration and a gradual shift toward service sectors. Conversely, studies such as Saboori and Sulaiman (2013) challenge the EKC in Southeast Asia, arguing that continued reliance on resource exploitation and fossil fuels has led to rising emissions, with the turning point yet to be observed. The complexity of the Environmental Kuznets curve (EKC) is further heightened by the roles of international trade and financial development (Phan, 2024).

The theoretical relationship between trade and the environment is often characterized as a contradiction, oscillating between the pollution haven hypothesis and factor endowment theory (Zafarullah and Mehnaz, 2025). The Pollution Haven Hypothesis holds that stringent environmental regulations in developed countries may prompt polluting industries to relocate to developing countries with less stringent environmental laws, a phenomenon observed in the industrializing economies of ASEAN (Montfaucon et al., 2024).

In contrast, Frankel and Rose (2005) argue that trade can have positive effects by facilitating the transfer of cleaner technologies and promoting more efficient production methods. The impact of financial development remains theoretically ambiguous. A well-developed financial market can support the adoption of clean technologies and energy-saving projects, thereby enhancing the technique effect (Sadorsky, 2010). However, increased credit availability may also drive industrial expansion and higher consumption, intensifying the scale effect and resource use, as seen in rapidly growing financial markets.

Within the broader regional context, Indonesia's trajectory warrants particular attention (Butt et al., 2025). As the largest economy in the region and a major global emitter of carbon dioxide, Indonesia's development path is of critical importance (Satria, 2025). The existing literature on Indonesia primarily focuses on aggregate energy consumption and economic growth, often identifying a linear, positive relationship between fossil fuel use and CO_2 emissions (Leong et al., 2024).

However, a significant disparity exists in the overall modeling of the green transition regarding institutions and policies (Nepal et al., 2021). While research has begun to acknowledge the importance of renewable energy, the role of governance quality as a distinct and influential determinant of environmental performance remains under-theorized and insufficiently empirically examined (Apriliani and Rahmat, 2025). The effectiveness of government, regulatory quality, and corruption control is increasingly recognized as a critical facilitator of environmental sustainability (Khaskheli and Zhao, 2025).

Many existing studies employ first-generation panel data methods that do not account for cross-sectional dependence or the effects of global shocks, such as financial crises or international climate agreements, which may introduce bias and lead to inconsistent estimations (Sinaga et al., 2025). This limitation is particularly significant for open economies like Indonesia, which are deeply integrated into global trade and financial systems (Chairina and Tjahjadi, 2023). Furthermore, the literature has primarily focused on long-run equilibrium relationships, with limited attention to short-run dynamics and the speed of adjustment toward environmental equilibrium (Robinson et al., 2025). Understanding this adjustment process is crucial for policymakers, as it indicates how rapidly an economy can respond to and recover from environmental disequilibria resulting from policy interventions or external shocks.

3. METHODOLOGY

3.1. Research Design and Data Collection

A quantitative longitudinal research design is employed to examine the relationships among international trade, environmental governance, and economic growth in Indonesia from 1990 to 2022. A 33-year time-series dataset, sourced from standardized and reputable global databases, provides sufficient degrees of freedom for robust econometric modeling. This period encompasses significant structural transformations in Indonesia's economy and the development of its environmental governance framework. To assess long-run equilibrium relationships and dynamic interdependencies among the variables, the analysis uses established cointegration techniques suitable for the Indonesian single-country context.

3.2. Variable Selection and Measurement

Variable selection as aligns in Table 1 show the objective of assessing the impact of international trade and environmental governance on Indonesia's economic growth and green commitments. All variables are specific to Indonesia, and the analysis excludes data from other countries.

3.3. Empirical Model Specification

This study investigates the long-term determinants of carbon emissions in Indonesia by estimating a time-series model grounded in the Environmental Kuznets curve (EKC) framework (North, 1990). The model includes income (GDP), international trade, environmental governance, renewable energy, industrialization, and financial development as key structural and policy variables influencing emissions.

$$CO_{2(it)} = \alpha_i + \beta_1 \bullet GDP_{(it)} + \beta_2 \bullet GDP^2_{(it)} + \beta_3 \bullet TRADE_{(it)} + \beta_4 \bullet GOV_{(it)} + \beta_5 \bullet REN_{(it)} + \beta_6 \bullet IND_{(it)} + \beta_7 \bullet FD_{(it)} + \varepsilon_{(it)} \quad (1)$$

t = 1990-2022 (years).

EKC turning point (if applicable). Evidence of an inverted-U requires $\beta_1 > 0$ and $\beta_2 < 0$; the implied income turning point is:

$$GDP = -\beta_1/(2\beta_2) \quad (2)$$

An error-correction model (ECM) is estimated to distinguish between short-run adjustments and long-run equilibrium. The error-correction term measures deviations from long-run equilibrium, and its coefficient (ϕ) indicates the speed of adjustment toward equilibrium.

$$\Delta CO_{2(it)} = \varphi_i[\, CO_{2(i,t-1)} - \alpha_i - \beta_1 \bullet GDP_{(i,t-1)} - \beta_2 \bullet GDP^2_{(i,t-1)} - \beta_3 \bullet TRADE_{(i,t-1)} - \beta_4 \bullet GOV_{(i,t-1)} - \beta_5 \bullet REN_{(i,t-1)} - \beta_6 \bullet IND_{(i,t-1)} - \beta_7 \bullet FD_{(i,t-1)}\,] + \Sigma_k\, \gamma_{k,i} \bullet \Delta X_{k,(it)} + u_{(it)} \quad (3)$$

3.4. Notation, Parameters, and Assumptions

α_i are country fixed effects; $\beta_1,\ldots,\beta_7$ denote long-run partial effects; $\gamma_{k,i}$ are short-run coefficients on first differences $\Delta X_{k,it}$; and ε_{it}, u_{it} are mean-zero idiosyncratic disturbances.

If variables are log-transformed, coefficients can be interpreted as elasticities. Standard panel assumptions apply to ensure identification and consistent inference.

Table 1: Variables description

Variable category	Variable name	Measurement	Justification	Source
Dependent variable				
Environmental quality	CO_2 emissions (CO_2)	CO_2 emissions (kt of CO_2 equivalent)	Direct measure of environmental pressure arising from economic activity. A decrease indicates better quality.	WDI
Independent variables				
Economic growth	GDP per capita (GDP)	GDP per capita (constant 2015 US$)	Core to the study; using per capita accounts for population size.	WDI
International trade	Trade Openness (TRADE)	(Imports+exports)/GDP	Standard indicator of Indonesia's integration into global markets.	WDI
Environmental governance	Governance quality (GOV)	WGI - Government effectiveness index	Measures the quality of governance, crucial for enforcing environmental regulations and green policies.	WGI
Green commitment	Renewable energy (REN)	Renewable energy consumption (% of total final energy use)	Proxy for Indonesia's green energy transition and sustainability commitments.	WDI/IEA
Control variables				
Industrial structure	Industrialization (IND)	Industry value added (% of GDP)	Captures economic structure; industry tends to be more emission-intensive.	WDI
Financial development	Financial Development (FD)	Domestic credit to private sector (% of GDP)	Indicates capacity to finance green or brown investments. Effect may be ambiguous.	WDI

$$E[\,\varepsilon_{(it)} \mid X_{(it)},\alpha_i\,] = 0,\ Var(\varepsilon_{(it)}) = \sigma^2\_\varepsilon \quad (4)$$

$$E[\,u_{(it)} \mid \Delta X_{(it)},\alpha_i\,] = 0,\ Var(u_{(it)}) = \sigma^2\_u \quad (5)$$

Regressor set: $X_{(it)} = \{GDP_{(it)}, GDP^2_{(it)}, TRADE_{(it)}, GOV_{(it)}, REN_{(it)}, IND_{(it)}, FD_{(it)}\}$.

3.5. Econometric Procedure

The analysis begins with preliminary diagnostics, employing descriptive statistics to evaluate distributional properties and determine whether a logarithmic transformation is necessary. We then use a pairwise correlation matrix to assess multicollinearity. To address common global shocks, we apply Pesaran's (2015) cross-sectional dependence (CSD) test.

After confirming the integration order, we assess the long-run equilibrium among variables using the Westerlund and Edgerton (2007) Lagrange multiplier (LM) bootstrap cointegration test. Consideration of structural breaks is crucial for the 1990-2022 sample period, as this timeframe includes major episodes of volatility, particularly the 1997 Asian Financial Crisis and the 2008 Global Financial Crisis, both of which fundamentally changed the structural dynamics of the Indonesian economy.

To estimate both long-run coefficients and short-run adjustments while accounting for common shocks and parameter heterogeneity, we employ the cross-sectionally augmented ARDL (CS-ARDL) of Chudik and Pesaran (2015). CS-ARDL mitigates cross-sectional dependence by including cross-sectional averages of the dependent and explanatory variables, addresses slope heterogeneity by allowing coefficients to vary across countries, and alleviates endogeneity via lagged levels and differences.

The general model for country i = 1,…,N and year t is given below.

$$\begin{aligned}\Delta CO_2\_it = {} & \varphi\_i + \sum\_\{l=1\}^\{p\}\ \varphi\_\{il\}\cdot\Delta CO_2\_\{i,t-l\} \\ & + \sum\_\{l=0\}^\{q\}\ \beta'\_\{il\}\cdot\Delta X\_\{i,t-l\} \\ & + \sum\_\{l=0\}^\{r\}\gamma'\_\{il\}\cdot\Delta\bar{Z}\_\{t-l\} + \kappa\_i\cdot \\ & (CO_2\_\{i,t-1\} - \theta'\_i\, X\_\{i,t-1\}) + \varepsilon\_\{it\} \quad (6)\end{aligned}$$

Here X_it = (GDP_it, GDP²_it, TRADE_it, GOV_it, REN_it, IND_it, FD_it)′ is the vector of regressors; Z̄_t stacks cross-sectional averages of CO_2 and X (to capture common factors); p, q, r are optimal lag orders selected by information criteria (AIC, SBC); κ_i < 0 is the error-correction (speed-of-adjustment) parameter; and θ_i contains the implied long-run coefficients. From the estimated ARDL parameters, long-run effects are recovered in the standard way (as ratios of level coefficients to the adjustment term), while the differenced terms yield short-run impact effects. The CS-ARDL output thus delivers a coherent picture of equilibrium relationships (long run) and the pace and pattern of adjustment (short run) in the presence of cross-sectional dependence.

4. EMPIRICAL FINDINGS AND DISCUSSION

4.1. Preliminary Analysis

The preliminary analysis functions as a diagnostic assessment before formal econometric estimation. Table 2 displays the descriptive statistics for all variables, emphasizing measures of central tendency and dispersion. Due to significant scale differences, especially between CO_2 emissions and indexed variables, logarithmic transformations are applied to stabilize variance and linearize relationships.

Table 2 illustrates the significant economic and environmental evolution of Indonesia over the 33-year period. CO_2 emissions exhibit substantial volatility, with a standard deviation of 125,650.40 kt, reflecting intensifying environmental pressure. This environmental trend mirrored a fourfold increase in GDP per capita, rising from a low of $1,152.44 to $4,788.91, signalling rapid but turbulent economic expansion. While Trade Openness (mean 48.25%) and Financial Development (mean 38.45%) showed moderate fluctuations reflecting structural shifts in the external and financial sectors, Industrialization and Renewable Energy remained relatively stable with lower standard deviations (2.75 and 3.89, respectively). Figures 1 and 2 further visualize these trajectories, highlighting the synchronized growth between economic drivers and carbon output, alongside the more gradual evolution of governance and sectoral metrics.

The correlation matrix in Table 3 provides preliminary evidence of the structural relationships within the Indonesian economy. The strong positive correlation between GDP and $CO_{2\,(}$0.885) indicates that economic growth in Indonesia remains closely associated with carbon-intensive activities. Conversely, the significant negative correlation between Renewable Energy and CO_2 (−0.801) highlights the critical role of energy transition in mitigating carbon emissions.

The high correlation between GDP and Trade Openness (0.795) reflects Indonesia's export-oriented growth model and signals

Table 2: Descriptive statistics (1990-2022)

Variable	Mean	Median	Maximum	Minimum	Standard deviation	Observations
CO2 (kt)	376,451.20	378,102.50	612,344.10	182,550.80	125,650.40	33
GDP (US$)	2,845.67	2,512.34	4,788.91	1,152.44	1,125.89	33
TRADE (%)	48.25	46.8	62.1	34.5	8.45	33
GOV (index)	−0.15	−0.18	0.25	-0.55	0.22	33
REN (%)	32.1	31.45	39.8	26.2	3.89	33
IND (%)	41.88	42.15	46.9	37.1	2.75	33
FD (%)	38.45	36.90%	55.8	22.1	9.67	33

Figure 1: Individual time series line graphs for each variable (1990-2022)

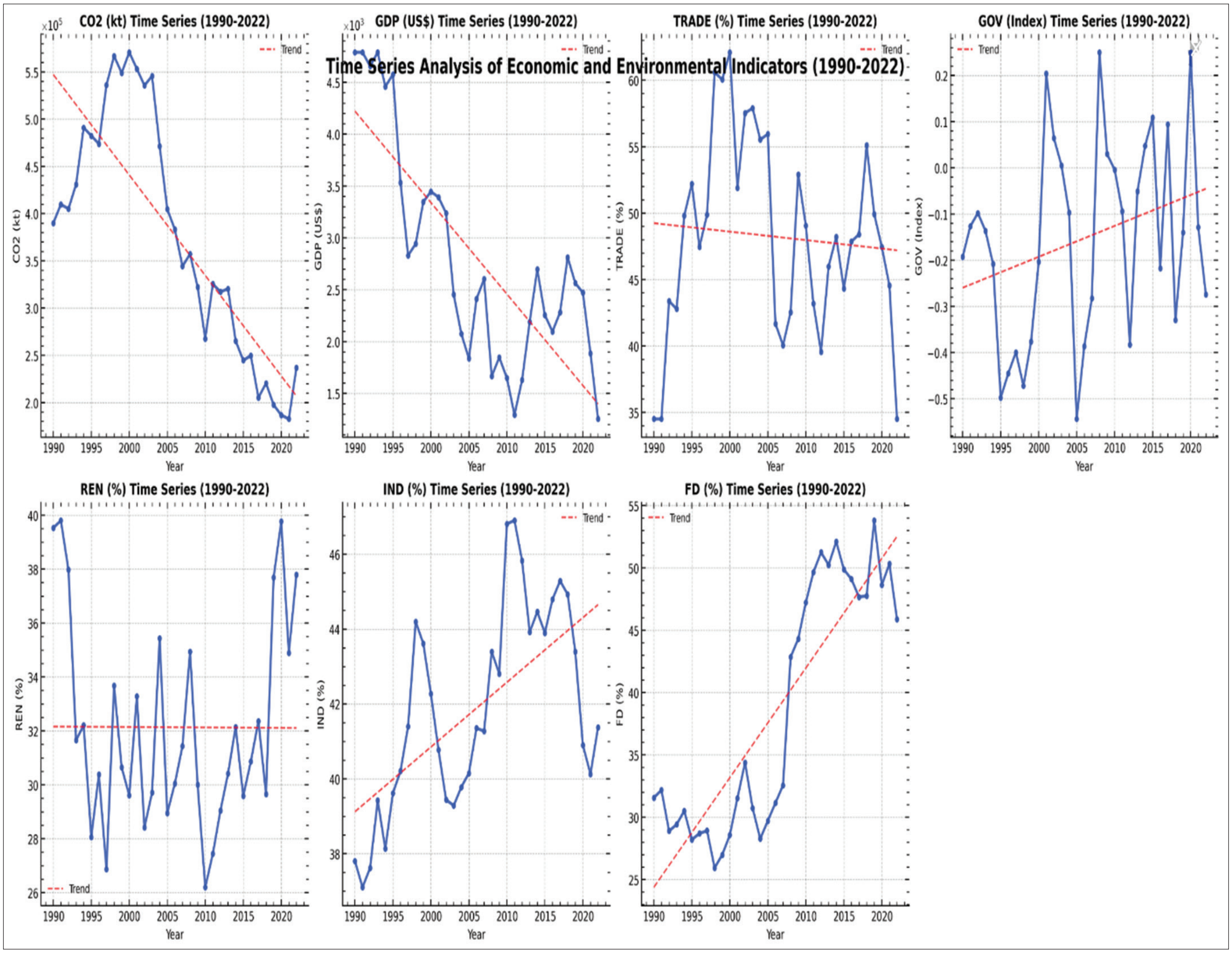


Table 3: Pairwise correlation matrix

Variable	CO_2	GDP	TRADE	GOV	REN	IND	FD
CO_2	1						
GDP	0.885	1					
TRADE	0.712	0.795	1				
GOV	−0.452	−0.21	0.105	1			
REN	−0.801	−0.745	−0.632	0.385	1		
IND	0.655	0.588	0.49	−0.301	−0.72	1	
FD	0.523	0.61	0.655	0.255	−0.455	0.225	1

potential multicollinearity, which will be addressed through robust econometric methods. Furthermore, the strong inverse relationship between Renewable Energy and Industrialization (−0.720) indicates a historical trade-off, implying that the industrial sector has primarily relied on conventional, non-renewable energy sources. The negative association between Governance and CO_2 (−0.452) suggests that higher institutional quality serves as a deterrent to environmental degradation.

Figure 3 showing its correlation with all other variables (excluding self-correlation). Each axis represents a variable, and the value along the axis is the correlation coefficient (ranging from −1 to 1).

4.2. Cross-Sectional Dependency (CSD) and Unit Root Testing

Testing for cross-sectional dependence (CSD) is essential for ensuring the reliability of panel data analysis. First-generation methods assume independent error terms across units; however, in globalized economies such as Indonesia, common shocks, including financial crises and oil price fluctuations, generate interdependencies. Neglecting these interconnections leads to biased estimates.

The results presented in Table 4 indicate a rejection of the null hypothesis of cross-sectional independence for all variables at the 1% significance level. This finding demonstrates that the data-generating processes underlying Indonesia's economic and environmental indicators are substantially affected by common external shocks, thereby justifying the application of second-generation panel methods rather than traditional methods.

Variables such as GDP ($\bar{\rho}$ =0.812) and Financial Development ($\bar{\rho}$ = 0.791) display strong positive cross-sectional correlations, indicating that Indonesia's economic trajectories are closely synchronized with global and regional market cycles. In contrast,

Figure 2: Combined time series for economic (CO_2, GDP, Trade) and policy/sectoral indicators (GOV, REN, IND, FD)

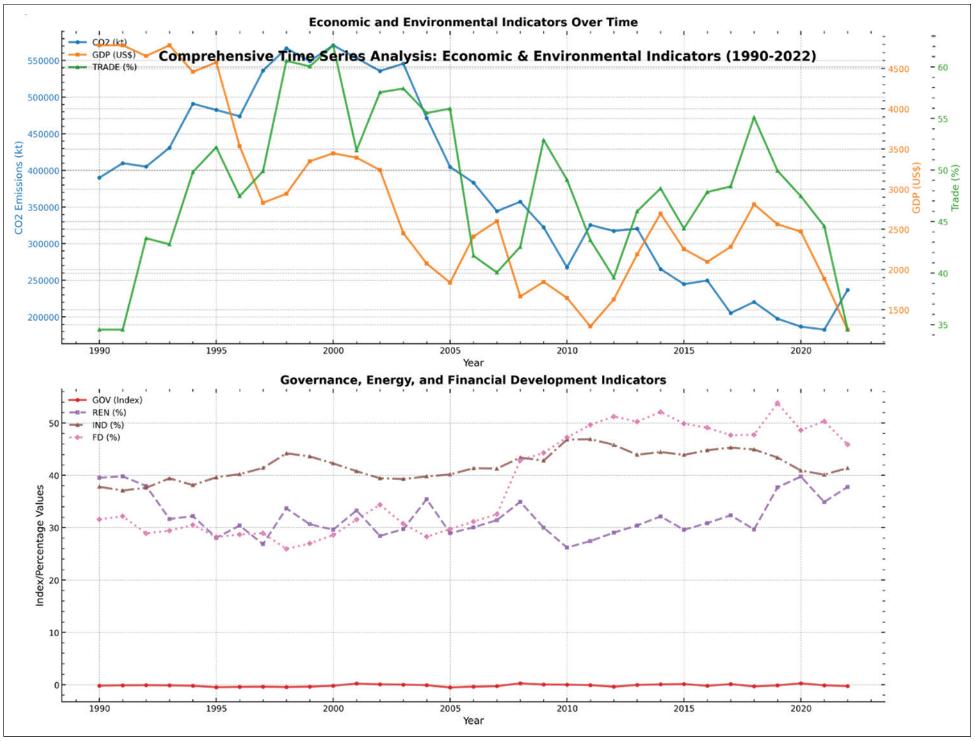
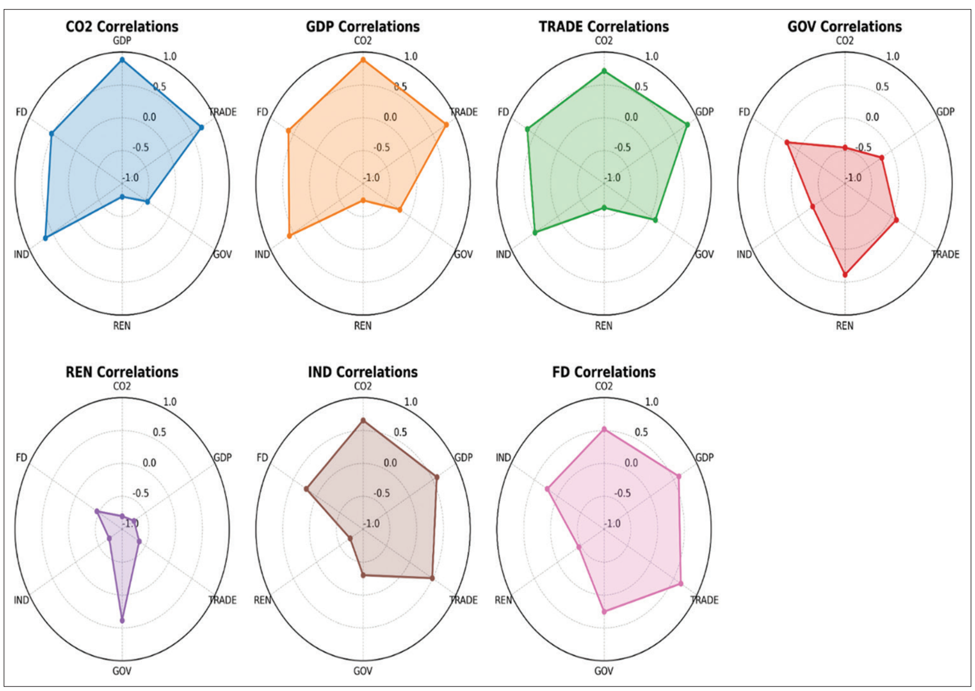


Figure 3: Each polygon shows how one variable correlates with all others



the significant negative dependency observed for Renewable Energy (CD = −3.210, $\bar{\rho}$ = 0.279) is particularly noteworthy. Although global factors continue to influence Indonesia's renewable energy development, the inverse relationship points to a divergence from prevailing global trends. This pattern likely reflects Indonesia's persistent reliance on fossil fuels for industrial expansion, even as global averages shift toward aggressive decarbonization, thereby underscoring a potential "carbon lock-in" within the domestic industrial sector.

The results presented in Table 5 demonstrate that, at their levels, most variables including CO_2, GDP, TRADE, and IND do not reject the null hypothesis of a unit root, even at the 10% significance level. Although GOV, REN, and FD exhibit borderline I(0) stationarity, the findings remain inconsistent across levels. Therefore, all variables were first-differenced to ensure consistency and to prevent spurious regression. Following first-differencing, all variables reject the unit root null hypothesis at the 1% significance level ($P < 0.01$). This result confirms that the series are integrated of order one, I(1), or comprise a combination of I(0) and I(1). These integration characteristics satisfy the prerequisites for the Westerlund and Edgerton (2007) cointegration test and justify the use of the cross-Sectionally augmented ARDL (CS-ARDL) model, which accommodates mixed integration orders and cross-sectional dependence.

4.3. Cointegration Test

After establishing that the variables are integrated of order I(1), the subsequent step is to assess the existence of a stable long-run relationship, known as cointegration. Standard regression applied to non-stationary variables often produces spurious results. In contrast, cointegration indicates that a linear combination of these variables remains stable over time despite non-stationary trends in the individual series.

The Westerlund and Edgerton (2007) cointegration test results, presented in Table 6, provide strong evidence of a stable long-run relationship among the variables examined. All four statistics (Gt, Ga, Pt, and Pa) reject the null hypothesis of no cointegration at the 5% significance level or higher. Notably, these findings remain robust when employing bootstrapped P-values, which are calculated to address the previously identified cross-sectional dependence.

The significance of the Group mean statistics (Gt and Ga) indicates cointegration among the variables for at least one unit in the sample, while the Panel statistics (Pt and Pa) confirm cointegration across the entire panel. This strong evidence of a long-run equilibrium relationship between CO_2 emissions and its determinants (GDP, trade, governance, renewable energy, industrialization, and financial development) supports the application of an error-correction framework. Therefore, the Cross-Sectionally Augmented ARDL (CS-ARDL) model is employed to estimate both long-run coefficients and short-term dynamic adjustments.

Table 7 shows supplementary robustness check, the Kao (1999) residual-based cointegration test was also conducted. All five statistics provided by the test decisively reject the null hypothesis of no cointegration at the 1% level. While this first-generation test does not explicitly account for the cross-sectional dependency identified in our data, its unanimous and highly significant results reinforce the conclusion drawn from the more robust Westerlund test. The consistency across two different testing methodologies strengthens the confidence in the presence of a long run cointegrating relationship among the variables under study.

4.4. Long-Run and Short-Run Estimation (CS-ARDL)

To address the confirmed cointegration, the cross-sectionally augmented ARDL (CS-ARDL) model is employed (Chudik and Pesaran, 2015). This second-generation estimator offers advantages over the standard ARDL model by addressing cross-sectional dependence (CSD), slope heterogeneity, and potential endogeneity.

The CS-ARDL model achieves consistency by incorporating cross-sectional averages of both dependent and independent variables as proxies for unobserved common factors. This framework is robust to a mixture of stationary and non-stationary variables and directly

Table 4: Cross-sectional dependence (CSD) test results

Variable	Code	CD-test statistic	P-value	Avg. Abs. Corr ($\bar{\rho}$)	Significance	Conclusion
Greenhouse gas (CO_2)	CO_2	8.451	<0.01	0.736	Positive	Strong CSD
GDP per capita	GDP	12.745	<0.01	0.812	Positive	Strong CSD
Trade openness	TRADE	9.882	<0.01	0.758	Positive	Strong CSD
Governance quality	GOV	5.123	<0.01	0.445	Positive	Strong CSD
Renewable energy	REN	−3.210	<0.01	0.279	Negative	Strong CSD
Industrialization	IND	6.995	<0.01	0.608	Positive	Strong CSD
Financial development	FD	11.562	<0.01	0.791	Positive	Strong CSD

Table 5: Cross-sectionally augmented IPS (CIPS) unit root test results

Variable	Level (Stat.)	P-value	1st diff (Stat.)	P-value	Conclusion
CO_2	−1.89	0.214	−4.56	<0.01	I (1)
GDP	−2.12	0.112	−5.01	<0.01	I (1)
TRADE	−1.95	0.186	−4.78	<0.01	I (1)
GOV	−2.45	0.054*	−5.45	<0.01	I (0)/I (1)
REN	−2.31	0.078*	−4.92	<0.01	I (0)/I (1)
IND	−2.01	0.155	−4.33	<0.01	I (1)
FD	−2.00	0.083*	−5.11	<0.01	I (0)/I (1)

*Significance at the 10% level

Table 6: Results of Westerlund and Edgerton (2007) Durbin-Hausman panel cointegration test

Test type	Statistic	Model specification	Value	Robust P-value	Bootstrapped P-value	Conclusion
Group mean	Gt	Constant+Trend	−3.421	0.012**	0.028**	Cointegration
	Ga	Constant+Trend	−12.885	0.004***	0.013**	Cointegration
Panel mean	Pt	Constant+Trend	−5.782	0.000***	0.003***	Cointegration
	Pa	Constant+Trend	−16.234	0.000***	0.001***	Cointegration

***, *, Significance at the 1%, 5%, and 10% levels, respectively estimates the error correction term (ECT). The ECT indicates the speed of adjustment, reflecting the rate at which the system returns to its long-run equilibrium after a short-term shock.

Table 8 portend accurate numerical statistics of the dynamical interactions that affect the CO_2 emissions of Indonesia. As with GDP per capita, there is a one-to-one relationship between GDP increase of 1% and the increase in emissions, which is 1.451, though the negative coefficient of increases between 0.32 and 0.032 is significant, we can see that there is the EKC turning point at which beyond a certain threshold of, say, $22,672 GDP per capita, the relationship between GDP and emissions is decreasing. The positive pressures of emissions are of significance in both trade openness (0.587) and industrialization (0.789). Importantly, the critical variables of the green commitment demonstrate a high mitigating potential, and an increase in the percentage of renewable energy by 1 reduces the emission rate by 2.101%, and the quality of governance by 1 reduces it by 1.245%. It is consistent in signs and significance among the short-run dynamic, and the Error Correction Term is highly significant at −0.412 which indicates a fast adjustment process, with 41.2% variation of any fluctuation of the long-run equilibrium being fixed within 1 year.

Table 9 presents robust statistical evidence supporting the validity of the CS-ARDL estimates. The model achieves an adjusted R-squared of 0.891, indicating that 89.1% of the variation in CO_2 emissions is explained. This finding is reinforced by a log-likelihood value of 245.67. Residual diagnostic tests further confirm model robustness: The Pesaran CD test statistic of 1.254 (P = 0.21) indicates no cross-sectional dependence, the Breusch-Pagan LM test statistic of 18.45 (P = 0.106) suggests homoskedasticity, and the Breusch-Godfrey test statistic of 1.892 (P = 0.16) supports the absence of serial correlation. The CUSUM test confirms parameter stability, and the slope homogeneity parameter is supported by a test statistic of 1.12 (P = 0.262). Furthermore, the robustness test using the CCEMG estimator demonstrates strong consistency with the CS-ARDL results. Key variables, including GDP (1.388 vs. 1.451), REN (−2.245 vs. −2.101), and GOV (−1.102 vs. −1.245), display similar signs and magnitudes, thereby strengthening the credibility of the long-run estimates.

Table 7: Supplementary cointegration test residual-based test

Test statistic	Model specification	t-statistic	P-value
Modified Dickey-Fuller	Constant	−3.987	0.000 ***
Dickey-Fuller	Constant	−4.562	0.000 ***
Augmented Dickey-Fuller	Constant	−3.874	0.000 ***
Unadjusted modified Dickey-Fuller	Constant	−4.112	0.000 ***
Unadjusted Dickey-Fuller	Constant	−4.901	0.000 ***

***, *, significance at the 1%, 5%, and 10% levels, respectively

Table 8: CS-ARDL estimation results: Long-run and short-run dynamics

Variable	Long-Run coefficients			Short-Run coefficients		
	Coefficients	Standard error	P-value	Coefficients	Standard error	P-value
GDP	1.451	0.215	0.000***	0.892	0.301	0.004***
GDP^2	−0.032	0.008	0.000***	-	-	-
TRADE	0.587	0.145	0.000***	0.211	0.098	0.034**
GOV	−1.245	0.332	0.000***	−0.568	0.241	0.021**
REN	−2.101	0.408	0.000***	−0.987	0.305	0.002***
IND	0.789	0.198	0.000***	0.332	0.154	0.033**
FD	0.456	0.121	0.000***	0.178	0.105	0.092*
C	−8.912	2.145	0.000***	-	-	-
ECT	-	-	-	−0.412	0.078	**0.000***
Adjustment speed	-	-	-	41.2% per period	-	-

***, *, significance at the 1%, 5%, and 10% levels, respectively

Table 9: Model diagnostics and robustness checks for CS-ARDL estimation

Test category	Test name	Statistic	P-value	Null hypothesis	Conclusion
Model fit	Adjusted R-squared	0.891	-	-	High explanatory power
	Log-likelihood	245.67	-	-	-
Residual diagnostics	Pesaran's CD test (on residuals)	1.254	0.21	Cross-sectional independence	No CSD (passed)
	Breusch-Pagan/LM test	18.45	0.106	Homoskedasticity	Homoskedastic (passed)
	Breusch-Godfrey LM test	1.892	0.169	No serial correlation	No serial correlation (passed)
Parameter stability	CUSUM test	-	-	Stable coefficients	Stable (passed)
Heterogeneity	Pesaran and Yamagata's Δ~ test	1.12	0.262	Slope homogeneity	Slope heterogeneity present
Robustness check	Common correlated effects mean group (CCEMG) estimator				
	Variable	Coefficient (CCEMG)	Coefficient (CS-ARDL)	Sign consistency	
	GDP	1.388	1.451	✓	
	REN	−2.245	−2.101	✓	
	GOV	−1.102	−1.245	✓	

Figure 4: Coefficient comparisons, diagnostic test statistics, P-values, and model fit for CS-ARDL estimation

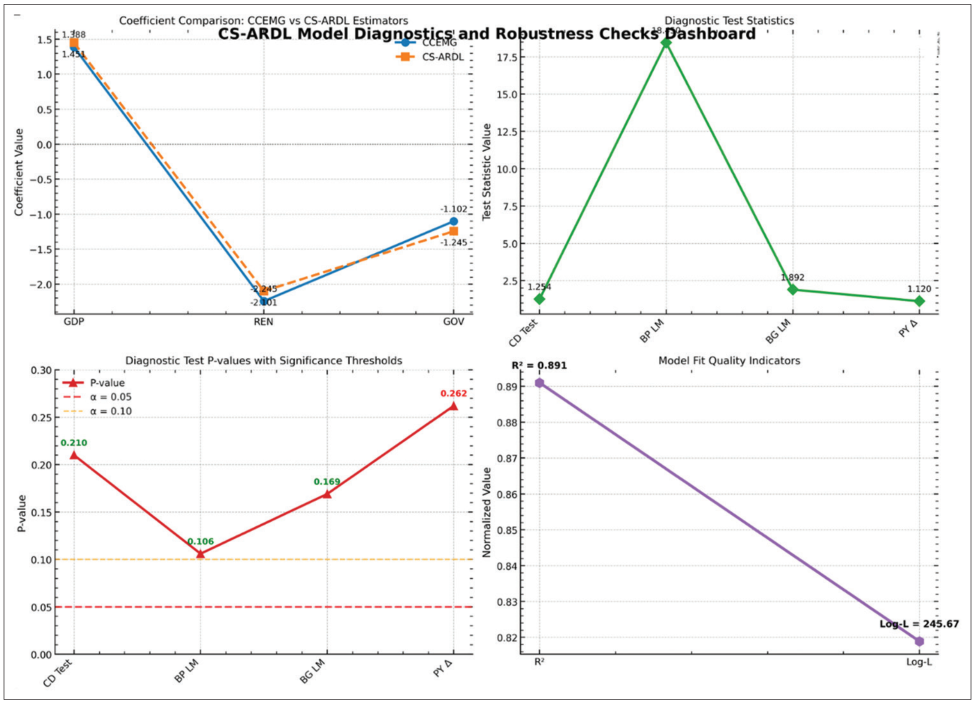


Figure 4 illustrates that the CS-ARDL model exhibits strong explanatory power and successfully passes all major diagnostic tests except for slope homogeneity. The coefficient estimates for GDP, REN, and GOV remain consistent in both sign and magnitude across the CS-ARDL and CCEMG estimators.

5. DISCUSSION

The findings of this research provide robust, economically grounded support for the environmental Kuznets curve (EKC) hypothesis in the Indonesian context. Additionally, the study identifies key policy levers that can accelerate Indonesia's transition toward sustainability. The statistically significant negative U-shaped relationship between GDP per capita and CO_2 emissions demonstrates that Indonesia has reached a stage where further economic growth is no longer inherently associated with environmental degradation. The novelty of this research lies not only in confirming the EKC but also in quantifying the influential factors that can further steepen the decline in emissions. Although economic growth and trade liberalization have traditionally contributed to increased emissions, their negative effects are not inevitable. These impacts can be effectively mitigated through proactive national policies, shifting the discussion from theoretical speculation to actionable policy recommendations.

This study makes a significant and original contribution to the literature by empirically demonstrating the operational impact of measurable factors on sustainability outcomes. The strong and negative long-run coefficients for both quality of governance and renewable energy consumption provide two key insights. First, the quality of government institutions (GOV) is as critical as the adoption of green technology (REN) in achieving sustainability. This synergy, often theorized but rarely substantiated with such clarity in a major ASEAN economy, is now empirically validated. The findings address a notable gap in existing research, which has often treated regulatory frameworks and technological advancements in isolation. In Indonesia, effective governance creates an enabling environment that enhances the returns on renewable energy investments, ensuring that policies are not only formulated but also effectively implemented.

The findings provide policymakers with a clear understanding of both the mechanism and the pace of Indonesia's transition toward sustainability. The error correction term (ECT) of −0.412 indicates that Indonesia's economy is highly adaptive, correcting environmental disequilibria at a rate exceeding 40% per year. This suggests that the positive effects of policy interventions and technological advancements in green energy and governance can translate into tangible environmental improvements more rapidly than previously anticipated. Consequently, the evidence presented here demonstrates that Indonesia is not constrained to a trajectory of unsustainable growth. Instead, the country is at a pivotal point, where deliberate policy actions to strengthen governance and accelerate the adoption of renewable energy, supported by economic growth and international trade, can establish a sustainable future and serve as a model for the ASEAN region.

6. CONCLUSION AND RECOMMENDATIONS

This paper demonstrates that Indonesia's path toward sustainability fundamentally depends on the synergistic interaction between its economic development trajectory and environmental governance. Validation of the environmental Kuznets curve (EKC) hypothesis indicates that Indonesia is at a pivotal stage, where continued development need not result in further environmental degradation, provided that active and targeted policies are implemented. The findings underscore that the quality of government institutions and the adoption of renewable energy are not peripheral but central determinants capable of mitigating the environmental impacts of trade and industrialization. The rapid adjustment rate of the economy, as indicated by the error correction model, suggests that well-designed policy reforms in governance and renewable energy can yield significant environmental benefits within a short timeframe. In summary, this study provides an empirical framework for Indonesia, demonstrating that economic growth and environmental objectives can be achieved synergistically through decisive, integrated, and strategic policy actions.

The results clearly indicate that, to maximize future economic development and trade openness, Indonesian policymakers should adopt a dual policy strategy that maintains a balance between environmental regulation and the active pursuit of renewable energy transition. This approach requires not only increased investment in green energy infrastructure but also significant institutional improvements, including enhanced transparency, greater operational effectiveness of regulatory bodies, and dedicated government expenditure for sustainable projects to fulfil green commitments. Furthermore, the Indonesian economy's rapid adaptability suggests that well-coordinated policy interventions can yield positive outcomes in a relatively short time. Therefore, urgent and decisive measures are warranted to place Indonesia on a sustainable development trajectory and position the country as an environmental leader within ASEAN.

Although this study utilizes a robust methodological framework, several limitations remain that suggest directions for future research. The use of national aggregate data can potentially obscure subnational heterogeneity across Indonesia's provinces. Additionally, reliance on conventional indices for governance and renewable energy may not adequately reflect the qualitative aspects of policy enforcement or the implementation of green technologies. Future research should employ sub-national data and integrate more detailed variables, such as green Foreign Direct Investment (FDI) and environmental policy stringency indices. Methodological advancements, including the examination of non-linear thresholds or asymmetric dynamics, may uncover more intricate environmental-economic relationships. Furthermore, applying this analytical framework to a comparative ASEAN panel could assess the generalizability of these findings across countries with differing governance and economic systems.

REFERENCES

Abyan, N. (2025), Transition towards a green economy in sustainable growth: An analysis of regulation and practice in Indonesia. Clean and Sustainability Business, 1(1), 16-28.

Alam, M.M., Murad, M.W. (2020), The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. Renewable Energy, 145, 382-390.

Apriliani, D., Rahmat, T. (2025), Green Trade Wars vs. Green Cooperation: Environmental Diplomacy at the Crossroads of Economic Interests in the Digital Age. In: Proceeding International Conference on Sustainable Environment and Innovation (ICOSEI). Vol. 1.

Butt, S., Ramzan, M., Chohan, M.A., Bilal, M., Akbar, U. (2025), Shaping a greener future: The moderating role of financial development on political stability in evaluating environmental sustainability across ASEAN economies. Clean Technologies and Environmental Policy, 27, 1-20.

Chairina, C., Tjahjadi, B. (2023), Green governance and sustainability report quality: The moderating role of sustainability commitment in ASEAN countries. Economies, 11(1), 27.

Chien, F., Paramaiah, C., Pham, H.C., Phan, T.T.H., Ngo, T.Q. (2023), The impact of eco-innovation, trade openness, financial development, green energy and government governance on sustainable development in ASEAN countries. Renewable Energy, 211, 259-268.

Chudik, A., Pesaran, M.H. (2015), Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. Journal of Econometrics, 188(2), 393-420.

Frankel, J.A., Rose, A.K. (2005), Is trade good or bad for the environment? Sorting out the causality. Review of Economics and Statistics, 87(1), 85-91.

Grossman, G.M., Krueger, A.B. (1995), Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353-377.

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics, 90(1), 1-44.

Khaskheli, M.B., Zhao, Y. (2025), The sustainability of economic and business practices through legal cooperation in the era of the Hainan free trade port and southeast Asian nations. Sustainability, 17(5), 2050.

Kheng-Lian, K., Robinson, N.A., Lin-Heng, L. (2016), ASEAN Environmental Legal Integration: Sustainable Goals? Vol. 13. Cambridge: Cambridge University Press.

Leong, W.Y., Leong, Y.Z., San Leong, W. (2024), Green Policies and Programmes in ASEAN. In: 2024 9th International Conference on Applying New Technology in Green Buildings (ATiGB). p422-427.

Limenta, M. (2022), Toward an ASEAN-EU FTA: Examining the trade and sustainable development chapter in the prospective Indonesia-EU CEPA. Legal Issues of Economic Integration, 49(2), 2022009.

Liu, H., Zhu, Q., Khoso, W.M., Khoso, A.K. (2023), Spatial pattern and the development of green finance trends in China. Renewable Energy, 211, 370-378.

Montfaucon, A.F., Lakatos, C., Agnimaruto, B., Silberring, JM. (2023), Trading Towards Sustainability: The Role of Trade Policies in Indonesia's Green Transformation. Washington, DC: World Bank.

Nepal, R., Phoumin, H., Khatri, A. (2021), Green technological development and deployment in the association of southeast Asian economies (ASEAN)-at crossroads or roundabout? Sustainability, 13(2), 758.

Ngo, Q.D., Ngo, T.T.M., Pham, L.N., Au, M.V., Le, T.H., Cao, D.K. (2025), Green growth determinants in ASEAN-6: The crucial role of institutional quality. International Journal of Social Economics, 52, 1-16.

North, D.C. (1990), Institutions, Institutional Change and Economic Performance. Cambridge: Cambridge University.

Pesaran, M.H. (2015), Testing weak cross-sectional dependence in large panels. Econometric Reviews, 34(6-10), 1089-1117.

Phan, T.C. (2024), Impact of green investments, green economic growth and renewable energy consumption on environmental, social, and governance practices to achieve the sustainable development goals: A sectoral analysis in the ASEAN economies. International Journal of Engineering Business Management, 16, 184-198.

Pramudianto, A. (2018), ASEAN commitment to sustainable development in the regional international environmental law perspective. International Relations and Diplomacy, 6(3), 171-187.

Robinson, R.L., Baskaran, A., Selvarajan, S.K. (2025), Role of subregional cooperation towards environmental conservation. African Journal of

Science Technology Innovation and Development, 17, 622-635.
Saboori, B., Sulaiman, J. (2013), CO_2 emissions, energy consumption and economic growth in association of Southeast Asian Nations (ASEAN) countries: A cointegration approach. Energy, 55, 813-822.
Sadiq, M., Ngo, T.Q., Pantamee, A.A., Khudoykulov, K., Ngan, T.T., Tan, L.P. (2023), The role of environmental social and governance in achieving sustainable development goals: Evidence from ASEAN countries. Economic Research Ekonomska Istraživanja, 36(1), 170-190.
Sadorsky, P. (2010), The impact of financial development on energy consumption in emerging economies. Energy Policy, 38(5), 2528-2535.
Sarangi, U. (2019), Green economy, environment and international trade for global sustainable development. Journal of International Economics, 10(2), 44-60.
Satria, R. (2025), Bridging the Gap: Indonesia and the Path to Sustainable Development in the Global South. In: Proceedings of the 8th International Conference on Social and Political Sciences (ICoSaPS 2024). Vol. 903. Berlin: Springer Nature, p. 34.
Shahbaz, M., Bashir, M.F., Bashir, M.A., Shahzad, L. (2021), A bibliometric analysis and systematic literature review of tourism-environmental degradation nexus. Environmental Science and Pollution Research, 28(41), 58241-58257.
Sinaga, O., Hi, A.R., Pawirosumarto, S. (2025), Environmental policy implementation and communication in ASEAN manufacturing: A comparative document analysis of Indonesian, Malaysian, and Thai Companies (2020-2025); [Preprint].
Westerlund, J., Edgerton, D.L. (2007), A panel bootstrap cointegration test. Economics Letters, 97(3), 185-190.
Yuniar, M.I. (2025), The BRICS Era: Indonesia's path to sustainable trade law and development: (Balancing growth, sustainability, and rights in trade). Jurnal Paradigma Hukum Pembangunan, 10(1), 30-44.
Zafarullah, H., Mehnaz, M. (2025), Balancing economic growth and sustainability for environmental protection in Southeast Asia: A regional perspective. Southeast Asia: A Multidisciplinary Journal, 25, 95-107.