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Research article

The Relationship between Poverty and Environmental Damage in Indonesia: A VECM Analysis

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ABSTRACT

This study investigates the relationship between poverty and environmental damage in Indonesia. This study consists time series data covering the period from 2000 to 2023, and utilized the vector error correction model. The short-run findings reveal that economic inequality exacerbates CO2 emissions, as affluent groups exploit resources and disadvantaged community resort to unsustainable practices. This is compounded by political and economic power weakening environmental regulations. Conversely, CO2 emissions exacerbate poverty, especially in rural areas reliant on natural resources, making them vulnerable to environmental shocks. A strong positive correlation exists between ecological footprint per capita and CO2 emissions, driven by resource consumption and fossil fuel reliance, though renewable energy adoption shows promise in mitigating emissions. In the long run, our findings align with the Environmental Kuznets Curve theory, suggesting that economic growth, supported by clean energy and sound environmental policies, ultimately leads to reduced environmental impact. These findings underscore the critical need for balanced strategies that simultaneously address poverty alleviation and promote ecological sustainability through inclusive policies and a transition to renewable energy.

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1. INTRODUCTION

Poverty remains a persistent and multifaceted challenge in Indonesia, particularly in underdeveloped rural and urban areas. High levels of poverty negatively impact quality of life, limit access to vital services such as education and health care, and increase the likelihood of social instability and conflict. Data from Statistics Indonesia shows that the number of poor people varies until early 2023. Until March 2023, the number of poor people in Indonesia reached 25.90 million people, compared to September 2022 and March 2022, the number of poor people decreased by 0.46 million people and 0.26 million people. To overcome this, the government has implemented various policies aimed at overcoming poverty, in line with the mission of the Sustainable Development Goals (SDGs) to end poverty by 2030.These poverty reduction policies encompass essential elements such as industry development, labor transfer, relocation, and improvements in education and healthcare. These measures have made significant contributions to economic development in poor areas, producing outcomes such as economic growth (Meng, 2013), reduced government expense (Zhu et al., 2021), and heightened political incentives (Li & Zhou, 2005).

Conversely, economic, and industrial growth has led to a rising demand for resource extraction and utilization, particularly in agriculture, deforestation, mining, and industrialization, all of which contribute to ecological degradation (Langnel et al., 2021). Meanwhile, several studies have shown that economic growth can alleviate pressures on ecological footprints (York et al., 2003; Moran et al., 2008; and Majeed et al., 2021). Below is data on Indonesia's carbon emissions, which showed a decline in 2020. Indonesia has set its Enhanced Nationally Determined Contribution (E-NDC) target, intending to reduce emissions from 2015 levels by 30-48% by 2030. Achieving this target will require a substantial increase in the renewable energy mix, from 13% in 2017 to approximately 74% by 2030 (Rajbhandari & Limmeechokchai, 2021). Analysis by the E-NDC Indonesia 1.5°C Pathways Explorer indicates that Indonesia's emissions should reach approximately 449 $MtCO_2e$ by 2030. Below is a projection of Indonesia's emissions (Gütschow et al., 2019).

Previous literature on the poverty-environment damage relationship presents two opposite perspectives. The first, known as the trade-off approach, posits that poverty alleviation and deterioration of the environment are interconnected (Shuai et al., 2019). This approach argues that impoverished communities rely on natural assets for living and surviving, and the overuse of resources damages the environment, exacerbating poverty. The second, known as the win- win approach, argues that poverty alleviation and environmental preservation can be handled concurrently. Masron & Subramaniam (2019) propose that poverty alleviation and environmental sustainability are like to "killing two birds with one stone." Empirical findings on the poverty-environment damage relationship present mixed results. The paradoxes or trade-offs arise when a country must choose between the two objectives. In other words, on one hand, efforts to eliminate poverty may result in environmental damage; on the other hand, policies aimed at preserving the environment could lead to an increase in poverty (Apergis et al., 2018). The study emphasized that achieving sustainable development goals is challenging in the face of climate change disasters and rising temperatures. As a result, it is recommended that climate change and poverty be treated as interconnected issues that need to be addressed simultaneously.

The claim that no systematic relationship exists between poverty and the environment is directly connected to Kuznets' hypotheses. According to these hypotheses, in the early stages of development (high poverty rate), a country may prioritize boosting the production of goods and services (e.g., increasing per capita GDP). This surge in industrialization and the high demand for various goods and services, which requires significant use of natural resources and energy, may lead to environmental damage. However, once the economy reaches a certain level of development (low level of poverty), environmental quality tends to improve. In contrast, studies examining the impact of environmental quality on poverty recognize SDG1 as a key objective. However, since the SDGs are interconnected, both dimensions should be pursued together. Additionally, carbon dioxida ($CO2$) emissions levels are commonly used as an indicator of environmental quality (Dhrifi et al., 2020). While this variable is a widely accepted proxy, it may not fully reflect the overall health of the natural environment (Yilanci et al., 2019).

According to the findings of Casillas & Kammen (2010); Jin et al. (2018); and Monyei et al., (2018) among the 17 Sustainable Development Goals (SDG13) are particularly critical concerns, especially for developing countries. As a result, this study focuses on the relationship between poverty and environmental damage, with two main objectives: (1) analyze the interlinkages between poverty and environmental damage, and (2) examine the impact of poverty on environmental damage. Despite extensive research on the poverty-environment nexus, the findings remain inconclusive, particularly in the context of developing countries like Indonesia. While existing studies often highlight either trade-offs or synergies between poverty alleviation and environmental sustainability, few have investigated the dynamic interplay between these dimensions using robust econometric models such as the Vector Error Correction Model (VECM). Additionally, limited attention has been given to the long and short-run relationships between poverty and environmental damage in Indonesia, a nation grappling with significant socio-economic disparities and environmental challenges.

This study addresses these gaps by analyzing the interlinkages between poverty and environmental damage in Indonesia, with a focus on identifying both immediate impacts and long-run trends. Most previous studies have either relied on cross-sectional data or case- specific qualitative assessments, which do not fully capture the temporal dynamics and causality between the variables (Barbier, 2010). Moreover, studies focusing on Indonesia often overlook region-specific heterogeneity. Study by Pujiati et al. (2022) addresses that gap by examining environmental quality determinants across different Indonesian islands, revealing that Java differs significantly from other regions due to variations in industrial structure, governance, and investment. The findings emphasize the need for regionally tailored policy responses to effectively address environmental and socio-economic challenges. There is also a lack of empirical study incorporating multiple environmental indicators (e.g., deforestation, carbon emissions, and waste generation) alongside poverty metrics, which is critical for designing integrative and effective policy intervention. The novelty of this study lies in its integrated approach, which combines both economic and environmental perspectives to offer a comprehensive understanding of these issues.

Specifically, this study aims to (1) analyze the dynamic relationship between poverty and environmental damage; and (2) examine the extent to which poverty contributes to environmental damage in Indonesia. By integrating economic and environmental perspectives, this study aims to provide valuable insights for policymakers in designing strategies that simultaneously tackle poverty alleviation and environmental sustainability. The second section of this article details the methodology used in this study, followed by the third section presenting the results and a comprehensive discussion of their implications. Finally, we present a conclusion summarizing the main findings of this study.

2. RESEARCH METHODS

2.1. Data

The data utilized in this study consists time series data covering the period from 2000 to 2023. This dataset includes several variables relevant to the study topic, such as CO_2 emissions (CO2), income inequality (GINI), poverty levels (POV), ecological footprint per capita (ECO), and energy consumption (ENC). By utilizing time series data, the analysis can capture dynamic changes that occur over time and examine how the relationships between variables evolve from year to year. Table 1 presents the variables, definitions, measurement methods, and data sources used in this study to explore the relationship between poverty, environmental damage, and other economic factors.

Table 1. Variables, Definitions, Measurements, and Data Sources

Variable	Definition	Measurement	Source
CO2	Environmental damage	CO2 emissions per capita (metric tons) and Ecological Footprint per capita	World Bank, Global Footprint Network
POV	Poverty	Ratio of population living below $1.90 per day (as a percentage of total population) or ratio of population living below the national poverty line (as a percentage of total population)	World Bank, and Indonesian Statistics
ECO	Ecological Footprint per capita	The amount of natural resources required to support an individual's consumption and absorb environmental impacts	Global Footprint Network
GINI	Income inequality (Gini Index)	income inequality within a population, with a value ranging from 0 (perfect equality) to 1 (maximum inequality).	World Bank, CIA World Factbook
ENC	Energy consumption	Energy consumption (kg of oil equivalent per capita)	International Energy Agency (IEA)

2.2. Model Specification

This study employs the VECM to analyze the relationship between poverty and environmental damage in Indonesia. VECM allows for the identification of both short and long-run dynamics among the variables, providing a comprehensive understanding of their causal interactions. By capturing the adjustment process toward long-run equilibrium, VECM offers a more nuanced view of how these relationships evolve over time. Moreover, this method addresses potential issues of multicollinearity commonly encountered in ordinary regression analyses, resulting in more reliable parameter estimates and robust conclusions regarding the influence of poverty on environmental damage and its broader implications for the well-being of the Indonesian population. According to Granger's representation theorem, cointegrated variables exhibit short-run relationships among them, which can be captured in an error correction model (ECM) or VECM. This model is a time series analysis used for variables that exhibit dependency, commonly referred to as cointegration. The VECM method is applied to balance short-run economic relationships among variables while ensuring long-run economic equilibrium (Mojanosski, 2022). The VECM model for this study can be represented as shown below:

$$\Delta CO2 = \alpha_0 + \alpha_1 \Delta POV + \alpha_2 \Delta GINI + \alpha_3 \Delta ECO + \alpha_4 \Delta ENC + \alpha_5 u_{t-1} + e_t \quad (1)$$

The notation of u_{t-1} represents the lag 1 cointegration error, which is mathematically written as:

$$u_{t-1} = \Delta CO2_{t-1} - \alpha_0 - \alpha_1 \Delta POV_{t-1} + \alpha_2 \Delta GINI_{t-1} + \alpha_3 \Delta ECO_{t-1} + \alpha_4 \Delta ENC_{t-1} \quad (2)$$

The VECM was chosen for this study due to its ability to capture both long and short-run relationships between the relevant variables, as demonstrated in the studies by Zafar et al. (2021), which explored the relationship between rainfall and poverty, and by Koondhar et al. (2021), which assessed the impact of agricultural carbon emissions on food production. The use of VECM is also aligned with the approach employed by Awolusi (2021), who examined the relationship between socio-economic inequality and economic growth, as it facilitates the identification of dynamic adjustments and long-run equilibrium between these variables.

The VECM is relevant for addressing the study question because many of the variables in the model are anticipated to have interdependent relationships, both in the short and long run. The VECM allows for the identification of long-run equilibrium among these variables and provides insights into how changes in one variable can influence others over time. The reliability of this model lies in its ability to handle non- stationary variables and offer insights into causal relationships between poverty and environmental damage, which can serve as a foundation for sustainable development policies.

3. RESULTS AND DISCUSSION

3.1. Results

This study found that all variables became stationary after first differencing, meeting the requirements for estimating the VECM. The Johansen cointegration test identified one stable long-run relationship among the variables. Post- estimation diagnostics confirmed the model's stability with no autocorrelation in the residuals, despite minor deviations from normality in some variables. These findings validate the reliability of the VECM in capturing the dynamic relationship between poverty and environmental damage, providing a foundation for sustainable development policies in Indonesia. Table 2 reports the descriptive statistics show that the CO2 variable has a mean of 1.804 with a standard deviation of 0.326. The GINI variable has a mean of 36.783 and a standard deviation of 3.202, while POV has a mean of 13.375 with a standard deviation of 3.37861. ECO has a mean of 1.494 with a standard deviation of 0.150, and ENC has a mean of 838.70 with a standard deviation of 121.97. The variations among these variables reflect the fluctuations within each data set.

Table 2. The Result of Descriptive Statistics

Variables	N	Minimum	Maximum	Mean	Std. Deviation	Variance
CO2	24	1.30	2.60	1.8042	0.326	0.107
POV	24	9.40	19.10	13.375	3.378	11.415
ECO	24	1.29	1.71	1.4942	0.150	0.023
GINI	24	29.50	40.80	36.783	3.202	10.25
ENC	24	727.12	1,220.78	838.70	121.97	1,4876.14

Table 3 presents the unit root test, the data to ensure the reliability of the econometric model employed. This was assessed using the Dickey-Fuller test, which is specifically designed to detect the presence of unit roots in the data. The initial test results revealed that all variables were non-stationary at their level. Consequently, first differencing was applied to address the non-stationarity. Following this transformation, the Dickey-Fuller test was conducted again, with the results summarized in Table 3.

Table 3. The Result of Unit Root using Dickey-Fuller test

Variables	Test Statistics	MacKinnon approximate *p-value* for Z(t)	Dickey–Fuller Critical Value		
			1%	5%	10%
Δ(CO2)	-5.454	0.0000	-3.750	-3.000	-2.630
Δ(POV)	-4.262	0.0005	-3.750	-3.000	-2.630
Δ(ECO)	-4.918	0.0000	-3.750	-3.000	-2.630
Δ(GINI)	-3.70	0.0000	-3.750	-3.000	-2.630
Δ(ENC)	-4.703	0.0001	-3.750	-3.000	-2.630

The test results indicate that all variables became stationary after first differencing. The variable Δ(CO2) has a test statistic of -5.454 with a p-value of 0.000, which is smaller than the critical values at the 1%, 5%, and 10% significance levels. Similarly, the variables Δ(ECO) and Δ(GINI) are also stationary, with test statistics of -4.918 and -3.700, respectively, both showing significant p-values. Although Δ(GINI) test statistic slightly exceeds the critical value at the 1% significance level, it remains below the critical values at the 5% and 10% levels. Furthermore, the variables Δ(ENC) and Δ(POV), with test statistics of -4.703 and -4.262, also exhibit stationarity with significant p-values. Thus, all variables meet the requirements for further analysis.

Table 4. The Result of Lagrange-multiplier test

Lag	Chi^2	df	$Prob>Chi^2$
1	27.3601	25	0.33814
2	25.9478	25	0.41039

Table 4 reports the results of the residual autocorrelation was tested using the Lagrange Multiplier (LM) test to ensure that the model errors are not correlated, thus preventing estimation bias. The LM test results show that for lag 1 and lag 2, the chi-squared values are 27.3601 and 25.9478, with probabilities of 0.33814 and 0.41039, respectively. Since these probability values are greater than 0.05, there is no evidence of autocorrelation in the model.

Table 5 reports the residual normality test using the Jarque-Bera method, skewness, and kurtosis produced various results which are presented in Table 3. The residuals for the variable Δ(CO2) exhibit a non-normal distribution with the Chi.sq value of 26.721 (probability is 0.000), while the residuals for Δ(ECO), Δ(ENC), and Δ(POV) show distributions close to normal, with probabilities greater than 0.05. The skewness test identified asymmetry in Δ(CO2) and Δ(GINI), while the other variables showed no significant skewness. The kurtosis test revealed that the residuals for Δ(CO2) have a sharper distribution compared to normal, with a chi-squared value of 11.008 (probability 0.00091), while the other variables displayed kurtosis values close to normal.

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Table 5. The Result of Jarque-Bera, Skewness, and Kurtosis test

Jarque-Bera test				
Equation		**Chi²**	**df**	**Prob>Chi**
Δ(CO2)		26.721	2	0.000
Δ(POV)		4.463	2	0.107
Δ(ECO)		0.388	2	0.823
Δ(GINI)		5.862	2	0.053
Δ(ENC)		0.645	2	0.724
All		38.080	10	0.000
Skewness test				
Equation	**Skewness**	**Chi²**	**df**	**Prob>Chi²**
Δ(CO2)	2.070	15.712	1	0.000
Δ(POV)	-1.068	4.183	1	0.040
Δ(ECO)	-0.315	0.364	1	0.546
Δ(GINI)	1.113	4.543	1	0.033
Δ(ENC)	-0.230	0.194	1	0.659
All		24.997	5	0.000
Kurtosis test				
Equation	**Kurtosis**	**Chi²**	**df**	**Prob>Chi²**
Δ(CO2)	6.465	11.008	1	0.000
Δ(POV)	3.552	0.280	1	0.596
Δ(ECO)	3.163	0.024	1	0.875
Δ(GINI)	4.199	1.318	1	0.250
Δ(ENC)	2.298	0.451	1	0.501
All		13.082	5	0.022

Table 6 presents the cointegration test aims to identify long-run relationships among the analyzed variables. The Johansen cointegration test is employed to evaluate whether there exists a stationary linear combination of variables, even if the individual variables themselves are non-stationary. If the differences are significant, the null hypothesis of no cointegration can be rejected. Table 6 show that at a maximum lag of 1, the trace statistic of 47.186 is significant at the 5% critical value, leading to the rejection of the null hypothesis of no cointegration. However, the hypothesis that there is at most one cointegration equation is accepted, indicating the presence of one significant cointegration equation. Therefore, this model has one cointegration equation that can explain the long-run relationship between poverty and environmental damage in Indonesia.

Table 6. The Result of Johansen Cointegration test

Maximum Rank	**Params**	**LL**	**Eigenvalue**	**Trace Statistics**	**Critical Value (5%)**
0	30	205.911	.	82.785	68.52
1	39	223.711	0.802	47.186*	47.21
2	46	236.588	0.689	21.431	29.68
3	51	242.289	0.404	10.028	15.41
4	54	247.213	0.360	0.181	3.76
5	55	247.304	0.008	-	-

Table 7 reports the determining the optimal lag length is a crucial step in time series modeling, particularly in the VECM framework. Selecting the correct lag ensures that the dynamic relationships between variables are estimated accurately, without introducing efficiency issues into the model. In this study, the optimal lag length is evaluated using various criteria, including the likelihood-ratio (LR), final prediction error (FPE), Akaike information criterion (AIC), Hannan-Quinn information criterion (HQIC), and Schwarz Bayesian information criterion (SBIC). The analysis results, as shown in Table 7, indicate that all criteria consistently recommend two lags as the optimal lag length. This is marked by the asterisk symbol in the output, which signifies the selection of lag based on the minimum value or highest significance of each criterion. Therefore, this study adopts two lags to ensure that the VECM model effectively captures the dynamic relationship between poverty and environmental damage in Indonesia.

Table 7. The Result of Optimal Lag Length Criterion

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	150.064	-	-	-	1.3 e-12	-13.188	-13.129	-12.939
1	217.883	135.64	25	0.000	2.8e-14	-17.080	-16.729	-15.59
2	247.304	58.842*	25	0.000	2.9e-14*	-12.48*	-16.939*	-14.76*

Table 8 presents the eigenvalue stability test is used to ensure that the model remains stable and returns to equilibrium after experiencing shocks in the variables. The test results show that all eigenvalues, except for four with a modulus of 1 (which are characteristic of cointegration), lie within the unit circle. This indicates that the estimated VECM model is stable and valid for long-run analysis, without exhibiting explosive behavior.

Table 8. The Result of Eigenvalue Stability Condition

Eigenvalue		Modulus
1.000	-	1.000
1.000	-	1.000
1.000	-	1.000
1.000	-	1.000
-0.155	0.750	0.766
-0.155	-0.750	0.766
0.543	-	0.543
-0.124	0.320	0.343
-0.124	-0.320	0.343
0.184	-	0.184

Table 9 reports the VECM results in the short run, changes in the ECO positively and significantly impact on CO2, with a coefficient of 1.3679 (*p*-value = 0.001). Conversely, the ENC has a negative and significant effect, with a coefficient of -0.4668 (*p*-value = 0.006). However, past changes in CO2, the GINI, and POV insignificantly affect current on the CO2 changes. The error correction coefficient (ECT) of -0.6702 shows that 67% of long-run deviations in the CO2 are corrected each period, indicating an adjustment mechanism toward equilibrium. For ECO, the error correction coefficient of -0.572 suggests that 57% of long-run deviations in the ECO are corrected each period. Changes in the CO2 have a significant positive impact on ECO, with coefficient of 0.376 (*p*-value = 0.016), while the ECO itself also has a positive impact, with a coefficient of 0.5457 (*p*-value = 0.006). Both the GINI and POV positively affect ECO, with coefficients of 0.4406 (*p*-value = 0.027) and 0.3037 (*p*-value = 0.024), respectively. However, ENC has a negative impact on ECO with a coefficient of -0.1833, significant at the 10% level).

The short-run VECM result reveals findings regarding the dynamics of poverty and the environment in Indonesia. First, economic activity puts significant pressure on the environment. The increase of 1% in the ECO leads to a 1.37% rise in the CO2, highlighting the substantial environmental impact of economic growth. Interestingly, however, The ENC shows a negative effect on CO2 (-0.47%), which may reflect improvements in energy efficiency or a transition towards cleaner energy sources in recent years. In terms of poverty, it implies that economic growth is important in reducing poverty throughout Indonesia. The increase of 1% in economic growth is associated with a 0.70% decrease in the poverty rate. This finding aligns with the general trend observed over the past two decades, during which sustained economic expansion has significantly reduced poverty levels in the country. Notably, environmental variables such as CO2 and ENC do not exhibit a significant short-run effect on poverty, suggesting that environmental impacts on poverty are more cumulative in nature and become apparent over the long-run. Furthermore, increases in the POV, GINI, and CO2 are all found to contribute positively to the rise in the ecological footprint, each with statistically significant effects at the 5% level. This indicates that social and economic pressures—particularly poverty and inequality—intensify environmental damage in the short run. However, when examining the short-run dynamics of income inequality, no variable is found to have a statistically significant influence at the 5% level, although CO2 exhibit a near positive and significant effect.

Table 9. The Result of Short-run Estimation

Variables	Coefficient	Std. error	z	P>|z|	[95% conf. interval]	
Δ(CO2)						
Δ(CO2)	0.352	0.275	1.28	0.040	-0.186	0.889
Δ(POV)	0.342	0.236	1.45	0.148	-0.121	0.804
Δ(ECO)	1.368	0.352	3.89	0.000	0.678	2.058
Δ(GINI)	0.424	0.352	1.21	0.228	-0.265	1.113
Δ(ENC)	-0.467	0.171	-2.73	0.006	-0.802	-0.131
ECT	-0.670	0.175	-3.84	0.000	-1.013	-0.328
Δ(POV)						
Δ(CO2)	-0.127	0.282	-0.45	0.652	-0.679	0.425
Δ(POV)	0.0782	0.242	0.32	0.747	-0.397	0.553
Δ(ECO)	-0.699	0.361	-1.94	0.053	-1.407	0.009
Δ(GINI)	-0.381	0.361	-1.06	0.291	-1.088	0.326
Δ(ENC)	0.055	0.176	0.31	0.753	-0.289	0.399
ECT	0.131	0.179	0.73	0.464	-0.220	0.483
Δ(ECO)						
Δ(CO2)	0.376	0.157	2.41	0.016	0.069	0.682
Δ(POV)	0.304	0.134	2.26	0.024	0.041	0.567
Δ(ECO)	0.546	0.200	2.73	0.006	0.154	0.938
Δ(GINI)	0.441	0.199	2.21	0.027	0.049	0.832
Δ(ENC)	-0.183	0.097	-1.89	0.059	-0.374	0.007
ECT	-0.572	0.099	-5.76	0.000	-0.766	-0.378
Δ(GINI)						
Δ(CO2)	0.316	0.182	1.73	0.083	-0.041	0.673
Δ(POV)	0.102	0.157	0.65	0.517	-0.206	0.409
Δ(ECO)	0.187	0.234	0.80	0.423	-0.271	0.645
Δ(GINI)	0.240	0.233	1.03	0.304	-0.217	0.698
Δ(ENC)	-0.067	0.114	-0.59	0.555	-0.289	0.156
ECT	-0.186	0.116	-1.61	0.108	-0.414	0.041
Δ(ENC)						
Δ(CO2)	0.688	0.479	1.44	0.151	-0.250	1.626
Δ(POV)	0.416	0.412	1.01	0.313	-0.391	1.223
Δ(ECO)	0.740	0.613	1.21	0.228	-0.462	1.942
Δ(GINI)	-0.181	0.613	-0.30	0.767	-1.382	1.019
Δ(ENC)	-0.275	0.298	-0.92	0.357	-0.859	0.309
ECT	-0.263	0.304	-0.86	0.387	-0.859	0.333

Similarly, changes in energy consumption do not appear to be significantly driven by other variables in the short run. Regarding poverty, the ecological footprint shows a nearly negative and significant effect, with a coefficient of -0.699 (*p*-value = 0.053), suggesting that increased environmental pressure may be linked to poverty reduction in the short run, potentially through development interventions or redistributive economic policies—though this finding warrants further investigation. These findings carry important policy implications for Indonesia. The government must sustain economic growth to continue reducing poverty. On the other hand, there is an urgent need to mitigate the environmental pressures generated by economic activities. Several policy recommendations emerge from this analysis: (1) strengthening low-emission green growth policies, (2) improving energy efficiency across economic sectors, and (3) developing social protection programs that can buffer the poor from environmental shocks.

Table 10. The Result of Parameter Estimation Validity

Equation	Parms	Chi^2	$Prob>Chi^2$	Identification
(β)	4	4,584.62	0.000	Exactly identified

The next estimation, Table 10 presents the results of the cointegration vector (β), which illustrates the long-run relationship between the variables in the model. The estimation in Table 10 shows the cointegration vector (β), representing the long-run relationship between the variables in the model. The result is "Identification: beta is exactly identified" indicates that the model has sufficient information to uniquely determine the parameter values, ensuring clear interpretation of the cointegration coefficients. The cointegration analysis results indicate a significant long-run relationship between the variable of CO2, ECO, GINI, ENC, and POV, with the Chi-square statistic of 4,584.61 and a p-value of 0.000, the model significantly rejects the null hypothesis of no long-run relationship.

Table 11. The Result of Long-run Estimation

Variables	Coefficient	Std. error	z	P>|z|	[95% conf. interval]	
CO2	1.000	-	-	-	-	-
POV	1.452	0.136	10.70	0.000	1.186	1.718
ECO	2.656	0.403	6.580	0.000	1.864	3.447
GINI	-0.375	0.403	-2.600	0.000	-0.658	-0.092
ENC	-0.595	0.079	-7.550	0.000	-0.749	-0.440

The long-run equilibrium relationship shows the all variables significantly correct towards equilibrium (p-value < 0.01). The negative coefficient indicates that the direction of adjustment in ECO shows the strongest error correction effect - a 1% imbalance triggers a 2.66% correction. The POV follows with 1.45% correction for each 1% deviation from equilibrium. The last, ENC and GINI show moderate correction effects (0.60% and 0.58%, respectively. The CO2 coefficient is normalized to 1 as the reference variable. All variables move inversely to correct disequilibrium, consistent with theoretical expectations. The significant negative coefficients confirm the system's stable return to equilibrium after the shocks. The adjustment speeds suggest economic growth and poverty levels are most responsive to CO2-related disequilibria, while energy and inequality factors adjust more gradually. This aligns with the ECT framework where variables adjust proportionally to the degree of disequilibrium.

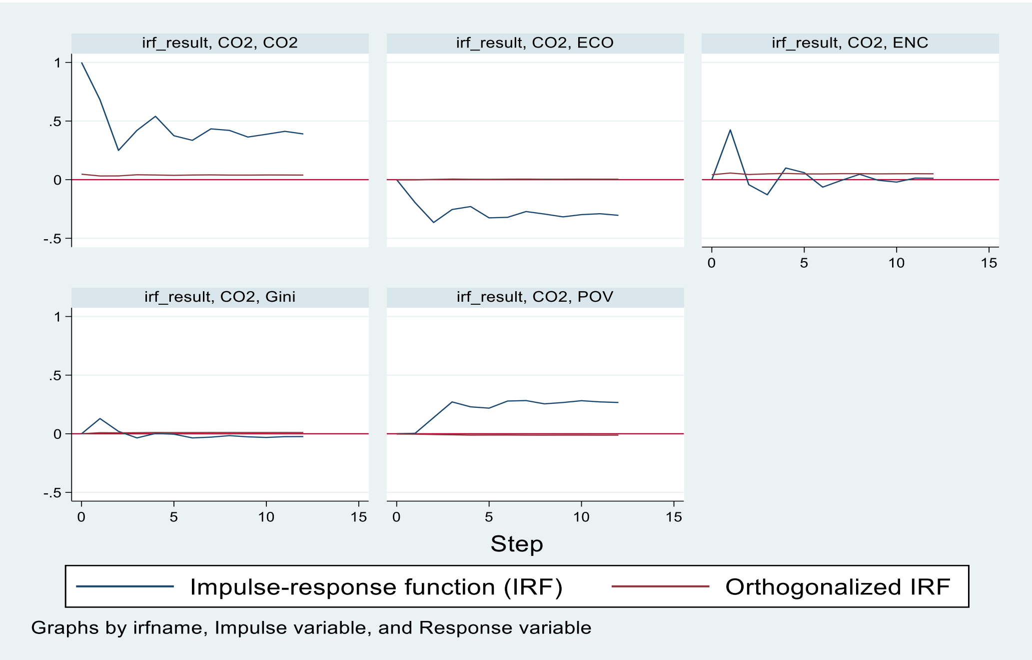

Figure 1. The Result of Impulse Response Function

Figure 1 reports the impulse response function (IRF) is used to analyze the dynamic response of dependent variables to shocks in independent variables. Figure 1 shows the responses of several variables to shocks in CO2 emissions. The blue line in the IRF illustrates how variables such as the ECO, ENC, GINI, and POV react to shocks in CO2 over multiple periods. The red line represents the baseline or zero point, showing the condition without any shocks to the triggering variable. If the blue line is above the red line, the response to the shock is positive (an increase), while if it is below the red line, the response is negative (a decrease). The response of CO_2 emissions to shocks in CO_2 itself shows a significant initial increase, with the effect remaining positive but diminishing over time. Meanwhile, the response of ECO to CO_2 shocks is initially negative; however, this negative impact gradually decreases, indicating that the effect is temporary. For ENC, the response initially fluctuates, indicating that the effect of CO_2 shocks on energy consumption is mixed, with no clear long-run impact. The response of GINI is nearly zero, with a small and insignificant long-run effect. However, the most significant response is observed in the POV, which shows a long-run increase following CO_2 shocks. This response remains positive and stable, suggesting that the impact of CO_2 shocks on poverty is more sustained compared to other variables. Despite some initial fluctuations, poverty tends to rise and does not diminish, indicating a long-run effect. Overall, while CO_2 shocks have temporary impacts on variables like ECO and ENC, their effect on poverty is more significant and persistent, suggesting that increased CO_2 emissions can worsen poverty in the long run.

3.2. Discussion

3.2.1. Poverty Rate and Environmental Damage

The results in the short run show a direct relationship between environmental damage, measured through CO_2 shocks, and poverty levels. When CO_2 emissions increase, poverty rises directly. This finding is consistent with the poverty-environment trap theory explained by Duraiappah (1998) which suggests a feedback loop between poverty and environmental damage. The poor are heavily reliant on natural resources for their daily livelihoods, but extreme poverty forces them to exploit the environment in unsustainable ways, such as deforestation, illegal mining, or farming on marginal lands. This further degrades the environment, which in turn worsens their poverty. In the long run, although fluctuations in impact are initially observed, the increase in poverty due to CO_2 shocks does not return to zero. This indicates that the impact of environmental damage on poverty is sustained. Several factors contribute to this, including the accumulation of negative effects, the inability to adapt, and increasing inequality. Ongoing environmental damage leads to the deterioration of physical and natural assets, worsening the living conditions of the poor, such as crop failures caused by climate change. Moreover, communities are required to constantly adapt to environmental changes, especially in rural areas, where access to technology, education, and capital is still limited, making it difficult to innovate ways to reduce the impacts of environmental damage. Additionally, inequality plays a role, where vulnerable groups become even poorer, while wealthier groups can protect themselves from environmental impacts more effectively.

Our finding that environmental damage measured by CO_2 emissions shocks increases poverty is consistent with study by Dhrifi et al. (2020), who emphasized that environmental damage disproportionately affects the poor in developing countries by reducing access to clean resources and increasing vulnerability. However, Wagle et al. (2016) found that in certain contexts—particularly in informal sectors like artisanal mining—environmental exploitation by the poor may temporarily raise their incomes, although this effect is short-lived and ultimately leads to deeper environmental damage. This suggests the existence of a trade-off between short-run income gains and long-run sustainability, reinforcing the Poverty-Environment Trap as theorized by Duraiappah (1998). Study by Dinga (2023) shows that key macroeconomic indicators influencing ecological poverty are GDP per capita, domestic investment, foreign direct investment (FDI), trade openness, structural changes (value-added in agriculture, manufacturing, and services), and democracy. According to Dioikitopoulos et al. (2020), psychological factors such as impatience play an important role in driving the ecological and poverty trap by influencing individual consumption and saving behaviors. In environments with low environmental quality, individuals tend to have higher impatience levels, causing them to allocate increased income to consumption rather than saving. This behavior further exacerbates environmental damage, as consumption increases pollution, reinforcing the poverty trap. High impatience levels are linked to lower growth rates, creating a vicious cycle of low environmental quality and low economic growth, trapping the economy in poverty.

3.2.2. Ecological Footprint and Environmental Damage

The ecological footprint explains the direct and indirect impacts of production and consumption activities on the environment, capturing environmental characteristics and the effects of human activity (Ulucak & Bilgili, 2018). Environmental damage becomes a major focus, triggered by the current economic growth patterns in N-11 countries, and the large consumption of fossil fuels due to economic growth, which leads to an increase in the Ecological Footprint (Sinha, Shahbaz, & Balsalobre, 2017). The short-run estimation results show that the ecological footprint per capita significantly positively affects CO2 changes. This means that an increase in the per capita ecological footprint significantly raises CO2 emissions. This finding is consistent with York et al. (2003), where the ecological footprint is closely related to CO2 emissions. The larger use of natural resources without sustainable management increases pressure on the environment and exacerbates degradation. The finding that energy consumption has a negative effect on CO_2 emissions in the short run suggests increasing energy efficiency or a transition to cleaner energy sources. This is consistent with Salari et al. (2021), who showed that energy transition in U.S. states significantly reduces emissions. However, Acheampong et al. (2019) found that in Sub-Saharan Africa, even renewable energy consumption still contributes to CO_2 emissions due to inefficient infrastructure and limited access to advanced technologies. This discrepancy highlights the importance of context—namely, the energy mix and technological readiness—in determining the environmental outcomes of energy consumption.

According to the Global Footprint Network's report, Indonesia's per capita ecological footprint in 2020 was recorded at 1.7 gha (global hectares), indicating high resource consumption compared to the Earth's regeneration capacity. With a large population and continually increasing economic activities, Indonesia faces significant challenges in managing natural resources and curbing environmental damage. Deforestation is a major contributor to the increase in the ecological footprint in Indonesia. As previously discussed, the deforestation rate in Indonesia was quite high, reaching more than 450,000 hectares in 2021 (KLHK, 2021). Additionally, the Ministry of Energy and Mineral Resources (ESDM) reported in 2022 that more than 60% of Indonesia's electricity is still generated from coal-fired power plants. Although there has been an increase in the use of renewable energy, its proportion remains relatively small compared to fossil energy sources.

The long run, both Ecological Footprint per capita (ECO) and energy consumption (ENC) respond to CO2 shocks, but the impact tends to be temporary and dissipates over time. This indicates that, although there is an effect, in the long run, the response of both variables to CO2 shocks does not last or continue to increase. The finding that in the long run, the impact of ecological footprint and energy consumption on CO2 emissions dissipates aligns with the environmental Kuznets curve (EKC).

3.2.3. Inequality and Environmental Damage

Based on short-run results, inequality has a positive impact on environmental damage. Economic inequality significantly affects environmental damage by causing imbalances in access to and use of natural resources. In highly unequal societies, wealth tends to be concentrated in the hands of a small group with significant purchasing power, allowing them to exploit natural resources. These small groups may invest capital in economically profitable projects that, at times, also harm the environment, such as large-scale mining and deforestation. As a result, ecosystems that were once sustainable experience environmental damage. According to data from Indonesian statistics (2023), in its Indonesian environmental statistics publication, the area of land used for mining activities has been increasing year by year. Additionally, this finding aligns with Ulucak & Apergis (2018), who found that wealth concentration tends to increase the ecological footprint in European countries. Similarly, Langnel et al. (2021) discovered that income inequality exacerbates the overexploitation of natural resources in ECOWAS member states. However, Akpan et al. (2019) report contrasting evidence in Nigeria, where the relationship between inequality and environmental damage becomes statistically insignificant when institutional quality and public participation are accounted for. These inconsistencies suggest that strong governance and environmental regulations can moderate the adverse effects of inequality on the environment.

On the other hand, low-income groups, who are economically disadvantaged, tend to exploit natural resources without implementing green economy practices in their daily lives. For example, without access to environmentally friendly technologies and practices, these groups often resort to cheap methods that negatively impact the environment, such as burning wood or overusing chemical fertilizers in agricultural land. Additionally, the lack of environmental awareness leads to further damage. This aligns with the study by Nurrachmi et al. (2024) which states that collaboration between ASEAN-6 countries is needed, with wealth distribution, technology transfer, and knowledge sharing from high-income countries to low- and middle-income countries in the ASEAN region to reduce the negative impacts of the highest income inequality and environmental issues. Furthermore, economic inequality has political implications, where capitalist groups tend to influence environmental policies to serve their interests. For instance, this can result in the relaxation of environmental regulations or the granting of easier permits for large-scale projects that contribute to environmental damage. Meanwhile, lower-income groups generally lack access to eco-friendly technologies and practices and are underrepresented in decision-making processes. This contributes to environmental damage. Therefore, it is essential to implement green economy practices within society, with further support from the government. This view is supported by Lange et al. (2018), who argue that the best solution is to decouple economic growth from environmental impacts by developing a green economy.

In the long run, the response of the GINI to shocks in environmental damage is shown. Initially, the response is close to zero, and although there are slight fluctuations, the impact of CO2 shocks on income inequality appears negligible in the long run. This may be because society can adapt or shift to alternative sources of income that are not directly dependent on degraded environments. For example, emerging economic sectors such as services, technology, or the service industry, and the public perspective on vegetable oil plantations, which are depicted in the figure below as environmentally friendly. The positive attitude of Indonesian society toward plantations is not surprising, considering that this sector is a major source of income and employment for the country. According to data from the Ministry of Agriculture, 59% of palm oil plantations are owned by private companies, while 41% are owned by smallholder farmers. Smallholder palm oil plantations have supported approximately 2.3 million jobs.

3.2.4. Energy Consumption and Environmental Damage

The energy consumption has a significant negative impact on CO2 changes. This result reflects more efficient energy use or a shift to cleaner energy sources. Although energy consumption has increased, if the energy comes from more environmentally friendly sources like renewable energy (solar, wind, or hydro), CO2 emissions can decrease. Additionally, this result also indicates that increased efficiency in energy use can contribute to a reduction in CO2 emissions, even if overall energy consumption increases. The use of more energy-efficient technologies (such as electric vehicles, more efficient heating systems, or environmentally friendly industrial technologies) can help reduce CO2 emissions. This study is supported study by Saragi et al. (2021) found that high energy consumption in Indonesia, particularly in the industrial and transportation sectors, is strongly correlated with increased CO2 emissions. According to the 2021 report from the Indonesian statistics, energy consumption in Indonesia continues to increase, particularly in the industrial, transportation, and household sectors. The majority of energy consumption in Indonesia still relies on fossil fuels such as coal and petroleum, which are the primary sources of CO2 emissions. The energy transition theory supports the finding that energy consumption can negatively impact CO2 emissions in the short run if the energy comes from cleaner sources. Energy transition refers to the shift from fossil fuel energy use to renewable energy sources like solar, wind, and biomass. The significant negative effects of energy consumption on CO2 emissions in this study suggest that more efficient and cleaner energy use can significantly reduce carbon emissions.

The findings of the study supporting the Environmental Kuznets Curve theory are similar to those in Salari et al. (2021), which found an inverted U-shaped relationship between CO2 emissions and GDP in U.S. states, providing sufficient evidence to validate the EKC hypothesis across the states. Therefore, policymakers need to use cost-benefit principles to find the optimal point for energy consumption. By using tax incentives or reduction efforts, authorities can then guide the economy toward an optimal level of energy consumption. Further, according to the environmental Kuznets curve theory, higher levels of economic development will eventually reduce pollution. This is an important finding for policymakers attempting to determine the optimal level of reduction efforts and design tax incentives. For example, the optimal carbon tax is based on the benefits in terms of pollution reduction and the costs in terms of reductions in output and GDP per capita. In designing optimal policies, policymakers must consider that after a certain threshold, economic growth and development will reduce pollution without any policy intervention. At later stages of development, clean energy technologies and more environmentally friendly policies are likely to be applied to reduce emissions.

This finding is also supported by Akmalia (2022), whose study on the impact of climate change in Indonesia shows that rising temperatures and changes in rainfall patterns have led to crop failures and reduced agricultural productivity in various regions, particularly in Java and Sumatra. The farming communities most affected are generally poor groups that lack access to modern agricultural technology or proper irrigation systems. As a result, poverty among these farmers increases due to environmental shocks. Bappenas (2010) adds that disasters such as earthquakes, floods, and landslides can damage infrastructure that supports the livelihoods of the poor, worsening poverty by destroying productive assets such as: agricultural land and trade facilities, and disrupting access to markets and jobs. Furthermore, according to data from the Ministry of Environment and Forestry, deforestation rates in Indonesia reached approximately 462,000 hectares per year in 2021. Many of these degraded lands are in rural areas inhabited by poor communities. The loss of forests not only results in the loss of livelihoods from forest resources but also causes ecological disasters such as floods and landslides, further exacerbating poverty in those regions. The Indonesian statistics reports that agriculture contributes about 13.5% to Indonesia's GDP and is the primary livelihood for more than 28% of the workforce, especially in rural areas. With climate change leading to unpredictable weather patterns, the agricultural sector is heavily affected, particularly among small farmers who are highly dependent on rainfall. The Indonesian statistics (2020) also notes that the poverty rate in rural areas is 12.82%, higher than in urban areas, indicating greater vulnerability to environmental damage.

4. CONCLUSIONS

The findings reveal a direct link between environmental damage in the short run, as measured by CO_2 shocks, and poverty levels. An increase in CO_2 emissions directly leads to a rise in poverty. Over the long run, although there are some initial fluctuations in the impact, the poverty levels driven by CO_2 shocks do not return to their original state. This suggests that the effects of environmental damage on poverty persist over time. Additionally, the study examines the impact of poverty on environmental damage, showing that extreme poverty often compels individuals and communities to exploit natural resources in unsustainable ways. The poor, heavily reliant on natural resources for their livelihoods, engage in activities such as deforestation, illegal mining, and over-farming, which degrade the environment. This, in turn, worsens their living conditions, creating a vicious cycle where poverty drives environmental harm, and environmental damage further entrenches poverty. The lack of access to education, technology, and capital in impoverished areas limits the ability to adopt more sustainable practices, exacerbating the ongoing degradation of the environment.

The findings indicate that income inequality has a positive impact on environmental damage, particularly in the short run. This is driven by two main factors: the concentration of wealth in the hands of a small elite, which leads to large-scale resource exploitation, and the reliance of low-income groups on unsustainable resource use due to a lack of access to environmentally friendly technologies. The implications of these findings suggest that addressing wealth disparity alongside environmental concerns is critical to fostering sustainable development. Policymakers should promote green economy practices, such as incentivizing eco-friendly technologies and implementing resource-sharing policies. Additionally, the shift towards more sustainable sectors like technology and services could help mitigate the effects of inequality-driven degradation in the long run. The findings align with the EKC, which suggests that while economic growth initially increases environmental harm, it can later lead to environmental improvement as economies mature.

The study also reveals that environmental damage, particularly from CO2 emissions, exacerbates poverty, confirming the Poverty-Environment Trap Theory. Poor communities are forced to exploit natural resources unsustainably for survival, which further damages the environment and traps them in a cycle of poverty. Immediate intervention is necessary to break this feedback loop, with policies that focus on both poverty alleviation and environmental sustainability. Climate adaptation strategies and improved access to technology can help mitigate the effects of environmental damage, especially in rural, agriculture-dependent areas. This finding is consistent with study by Duraiappah (1998) Poverty-Environment Trap Theory, which emphasizes the cyclical relationship between poverty and environmental damage. The study findings align with key theories such as the EKC and the poverty-environment trap theory. The EKC suggests that early economic development leads to higher pollution, but as economies mature, they adopt greener technologies, reducing emissions. The Poverty-Environment Trap Theory emphasizes the need for sustainable development models that address both poverty and environmental harm. However, the study also highlights contradictions with some previous study. For instance, some studies argue that well-managed institutions and policy frameworks can mitigate the environmental damage caused by inequality, which contrasts with the study’s findings that inequality directly drives environmental damage, particularly in contexts with weak environmental governance. Similarly, while the need for energy transitions to cleaner sources is widely supported, some studies challenge the assumption that energy consumption always leads to increased environmental damage, especially in countries investing in renewable energy.

The several policy recommendations are put forward to analyze and impact between poverty and environmental damage: (1) sustainable environmental management policies should be prioritized. In this regard, the government needs to encourage the adoption of environmentally friendly technologies in agriculture and forestry to reduce exploitative practices that harm the environment. Providing subsidies and incentives for modern agricultural technologies and efficient irrigation methods can assist small farmers in increasing productivity while safeguarding the environment. The government should strengthen efforts to enforce laws against illegal deforestation and support reforestation programs; (2) the government should develop an early warning system for natural disasters to minimize economic losses. Furthermore, specific insurance schemes can be developed for farmers and vulnerable communities who are at risk from climate change, such as those affected by crop failure due to extreme weather events; (3) to address poverty and inequality, the government can implement higher environmental taxes (such as carbon taxes or emission taxes) on large corporations or high-income individuals who significantly contribute to environmental damage. The proceeds from these taxes could be allocated to poverty reduction and environmental protection programs in marginalized or ecologically deteriorated regions. This would help balance economic growth with the reduction of environmental damage; (4) the government should provide green skills training for low-income workers, enabling them to take up jobs in environmentally friendly sectors such as recycling, renewable energy, or sustainable construction.

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