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How Geopolitical Risk affect to Environmental Sustainability in Indonesia

Wahyu Aji Wijaya^{1*}, Khoirul An'am², Waldi Novi Yarsah³, Asrudi⁴, and Ismail⁵

^{1*,4,5}Department of Economic Development, Faculty of Economic and Business, Universitas
Musamus Merauke, Indonesia

²Department of Management, Faculty of Economics and Business, Universitas Musamus Merauke,
Indonesia

³Department of Economic Development, Faculty of Economics, Universitas Sriwijaya, Indonesia
Corresponding authors: wahyuajiwjy27@unmus.ac.id

Abstract: This study analyzes the influence of geopolitical risk (GPR), non-renewable energy consumption (NRE), trade liberalization (TR), and industrialization (IDS) on environmental sustainability (SDI) in Indonesia for the period 1980–2023 using the VECM model. The results show that NRE and IDS have a long-term negative effect on SDI, TR has a positive effect, while GPR is insignificant. Granger causality tests indicate a bidirectional relationship between NRE and SDI, while variance decomposition results show that SDI is most influenced by itself and NRE (20%). The IRF analysis reveals that shocks to the main variables can be stabilized around the 30th period, indicating the structural adaptability of the economy and the environment. This finding confirms the existence of a feedback effect between energy and the environment, where dependence on fossil fuels worsens environmental quality. This study recommends a transition to clean energy and strengthening green industrial policies to maintain environmental sustainability.

Keywords: Environmental Sustainability, Geopolitical Risk, Non-Renewable Energy Consumption, Trade Liberalization, Industrialization

Introduction

Indonesia faces complex challenges in achieving environmental sustainability, such as pressures from land conversion (plantations and mining), degradation of coastal ecosystems (including mangroves), land fires, and the impacts of urbanization and sea level rise on coastal areas and large cities. These conditions create a classic trade-off between rapid economic growth and natural resource protection—a problem that requires a cross-sectoral approach and evidence-based policies. Recent studies emphasize the critical role of coastal ecosystem restoration (e.g., mangroves) as a multi-benefit strategy for carbon mitigation, climate

resilience, and local well-being, but also highlight the challenges of implementation and large-scale success (Sasmito et al., 2023).

Econometrically and policy-wise, non-renewable energy consumption, industrial structure, and trade architecture play a dominant role in emissions patterns and environmental quality. Empirical evidence from various countries shows that trade liberalization and industrialization without adequate environmental mitigation can accelerate environmental degradation, including increased emissions and pollution, unless accompanied by technological shifts, strict environmental regulations, or incentives for clean energy. In the Indonesian context, this relationship is evident when the expansion of extractive sectors (such as palm oil, pulp, and nickel mining) has a direct impact on forest cover loss and increased CO₂ emissions (Xuan, 2024).

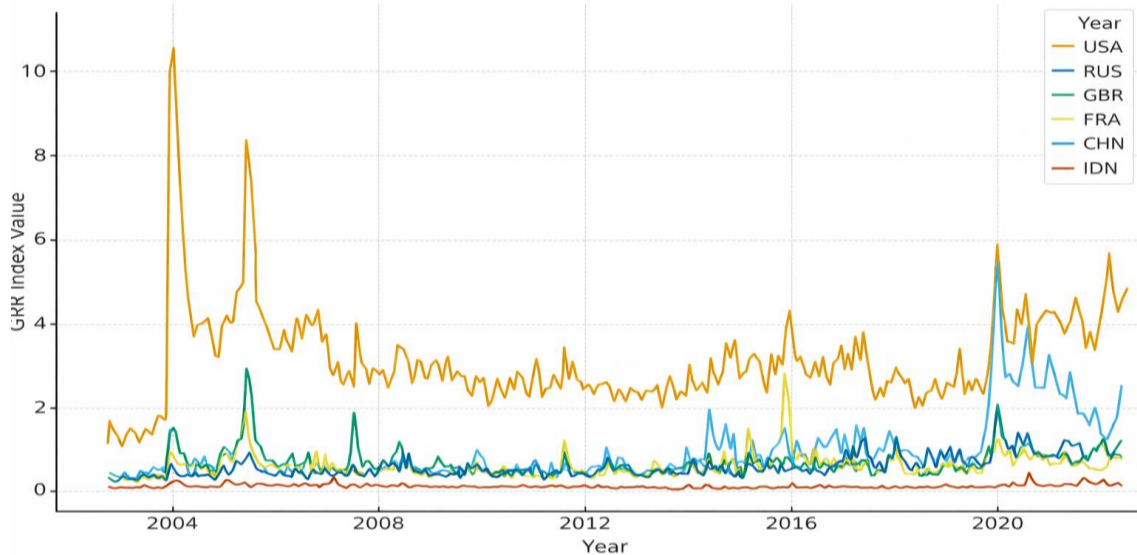
In the last decade, geopolitical risk has become an increasingly relevant variable for environmental and energy analysis. Geopolitical risks include regional tensions, disruptions in energy or commodity supply chains, and changes in global trade alliances and policies. These risks can influence energy investment decisions, national energy diversification, and environmental policies. Cross-country panel research shows that increased geopolitical uncertainty can significantly impact emissions through changes in industrial structure and investment decisions. Such changes may cause shifts to more carbon-intensive energy sources or delays in green investments. Thus, geopolitics serves as both a driver and a barrier to the green energy transition. This is relevant for Indonesia, a key player in the global energy mineral and agro-commodity supply chain (Li et al., 2025).

As a component of structural instability, geopolitical risk (later known as GPR) has attracted the attention of various academics. GPR is defined by Caldara & Iacoviell, (2022) as the potential political, economic, military, and social problems resulting from a country's participation in international affairs. These problems often arise after conflict, natural disasters, or significant changes in power. These dangers can have a significant impact on nations and the entire global community. Geopolitical risks can be caused by various factors, such as a country's military strength, its political relations with other countries, and its economic stability.

These risks have increased in recent years as a result of globalization, which has increased the interconnectedness of the world's economies and cultures. According to this argument, geopolitical risk is associated with warlike and violent actions. Geopolitical risk refers to international tensions caused by conflict, fanaticism, and poor relations. Geopolitical risk indirectly has significant economic and environmental consequences (Anser et al., 2021; Chen et al., 2024; Pata et al., 2024; Riti et al., 2022; Sweidan, 2023; Ulussever et al., 2023). Empirical findings show that increasing GPR consistently impairs environmental quality or sustainability (Khurshid, 2023). As a specific example, a study covering MENA (Middle East and North Africa) countries revealed that GPR negatively affects environmental sustainability, meaning that MENA countries face poor sustainability risks during periods of high GPR (Erdogan et al., 2025). The underlying mechanism is that geopolitical uncertainty shifts countries' focus from climate mitigation targets to economic security or military spending, which often increases fossil fuel use and exacerbates ecological degradation (Gu et al., 2020; Hill et al., 2019; Levy et al., 2010; Markandya et al., 2009; Nkuiya & Costello, 2016; Stettler et al., 2011). Furthermore, a quantile analysis of four vulnerable countries (Brazil, India, South Africa, and Turkey) found that GPR decreased ecological quality at

higher quantiles in all of them, indicating that higher risks in all of these countries consistently pose a threat to the environment (Pata et al., 2024). Another study of 38 developed and developing countries confirmed that GPR increases CO₂ emission inequality because the wealthy tend to respond to this risk by increasing resource consumption to secure their assets, thus widening the carbon gap (Chen et al., 2024; Lau et al., 2023).

Figure 1. GPR Index Trend over the last 25 years



Source: Processed data, 2025

Based on the Geopolitical Risk Index (GPR) trend for the 2000–2024 period, it can be seen that countries with high levels of political and economic tension, such as Russia (RUS) and China (CHN), show relatively fluctuating and increasing GPR values, while Indonesia (IDN) shows stability with a low GPR value throughout the observation period. Conceptually, the GPR reflects the intensity of global uncertainty stemming from conflict, diplomatic tensions, and foreign policy dynamics that have the potential to impact economic and social stability. Increased geopolitical risk is generally negatively correlated with environmental sustainability, as situations of political uncertainty often shift national policy priorities from sustainable development to efforts to maintain short-term security and economic stability.

The impact of rising GPR can be observed through several mechanisms. First, geopolitical uncertainty reduces investor interest in environmentally friendly and renewable energy projects, as increased financial risks reduce the attractiveness of long-term investments (Bouri et al., 2019). Second, international conflicts that trigger disruptions in the global energy supply chain, such as the Russia-Ukraine war, push countries back to relying on fossil fuels, thus slowing the transition to clean energy (Zhang et al., 2023). Third, high GPR can lead to a reallocation of national budgets from the environmental sector to the defense and security sector, which reduces the effectiveness of climate change mitigation policies (Anser et al., 2021).

Conversely, countries with high geopolitical stability, such as Indonesia, have a greater opportunity to maintain the continuity of environmental policies and strengthen the implementation of green development programs. Indonesia's low GPR supports a conducive investment climate and policy consistency in promoting a sustainable energy transition. Therefore, the relationship between geopolitical risk and environmental sustainability is

structurally negative. The higher a country's geopolitical risk, the greater the potential obstacles to achieving the Sustainable Development Goals (SDGs), particularly in the environmental dimension.

Consumption of non-renewable energy (NRE), such as oil and gas, is a major contributor to environmental problems due to its greenhouse gas emissions (Bhattacharya et al., 2016; Lau et al., 2023; Qin et al., 2021; Vural, 2020). Evidence from Pakistan shows that NRE has a significant negative impact on environmental sustainability, with a one-unit increase in NRE reducing environmental sustainability by 0.52 units (Khurshid, 2023). However, a more complex dynamic exists in the BRICS context, where an increase in GPR can significantly and negatively affect fossil fuel consumption and total energy consumption, while significantly and positively affecting renewable energy consumption. This result is consistent across FMOLS, DOLS, and ARDL models (Tabash et al., 2024). This suggests that geopolitical risks can drive a shift to more stable domestic energy sources (renewables) in an effort to improve energy security (Cai & Wu, 2021).

Trade liberalization (TR) has an impact on environmental sustainability, which is currently quite ambiguous. On the one hand, TR can help improve environmental quality through access to cleaner technologies, as found in studies covering Latin America and the Caribbean (LAC) countries, where trade liberalization can increase LCF in the long run (Cai & Wu, 2021; Pata et al., 2023; Wang et al., 2024). Similarly, in Pakistan, TR was found to have a positive and significant correlation with environmental sustainability, where a one-unit increase in TR can increase environmental sustainability by 0.040 units (Khurshid, 2023). However, on the other hand, empirical results can show the opposite effect, where a study focusing on five Southeast Asian countries (including Indonesia) found that trade liberalization negatively affects foreign direct investment (FDI), and a 1 percent increase in TR can reduce FDI by 0.203 percent according to the GMM model (Hossain et al., 2024; Nica et al., 2023; Zezethu & Phiri, 2018). This can occur due to the substitution effect, where foreign companies prefer exports rather than establishing local operations in highly open markets, which can slow the transfer of capital and technology necessary for sustainable development (Deb et al., 2023; Nica et al., 2023). Furthermore, global trade liberalization faces significant challenges because geopolitical risks have been shown to significantly stress trade openness (Yan & Piao, 2025).

The novelty of this research focuses explicitly on the Indonesian context. Previously, we adopted the concept developed by Khurshid (2023) on how geopolitical risk, non-renewable energy, and trade liberalization impact environmental sustainability in the case of Pakistan. We know that geopolitical risk in Pakistan is quite high. Therefore, by examining this concept, we as authors see Indonesia as a country with moderate geopolitical risk and a very significant level of dependence on non-renewable energy (especially coal). Consequently, it faces significant sustainability challenges and is in the midst of regional and global geopolitical turmoil (Pata et al., 2023). Although Indonesia has been part of a broad sample of studies on GPR and FDI (Liu et al., 2024), and its banking sector has been analyzed for its green regulations and geopolitical risk (Ariefianto et al., 2025), no study has systematically analyzed the tripartite relationship between geopolitical risk, non-renewable energy consumption, and trade liberalization on environmental sustainability specifically in Indonesia. This research fills this gap in the literature and provides crucial asymmetric insights for Indonesian policymakers in developing more resilient and integrated strategies to achieve sustainable development goals amidst increasing global geopolitical uncertainty.

Literature Review

GPR-Environmental Sustainability Nexus

Geopolitical risk (GPR) has emerged as a component of global structural instability that has increased dramatically in recent years and has had a detrimental impact on the environment (Khurshid, 2023). GPR is defined as the potential for political, economic, military, and social problems arising from a country's involvement in international events, often related to interstate tensions, extremism, or conflict (Caldara & Iacoviell, 2022). The impact of GPR on environmental sustainability (ES) has shown mixed and complex results. In a study using VECM analysis, GPR was found to have a negative and significant effect (0.234 units) on ES (Khurshid, 2023). This negative impact is supported by the finding that increasing GPR can reduce research, development, innovation, and sustainable practices, thereby exacerbating ecological degradation (Wang et al., 2022). Furthermore, higher GPR can increase inequality in CO₂ emissions because instability can encourage wealthier populations to increase resource consumption (Lau et al., 2023; Wu et al., 2022). GPR also creates uncertainty in financial markets, leading primarily to increased volatility (not returns) in climate-related stocks, particularly during extreme conflicts such as the Russian invasion of Ukraine (Demiralay et al., 2024; Sohag et al., 2022). However, there is a "mitigation effect" view that argues that GPR can reduce non-renewable energy (NRE) consumption and economic development, ultimately resulting in lower CO₂ emissions (Anser et al., 2021). In an analysis using the load capacity factor (LCF), GPR was found to increase LCF at lower and middle quantiles in some fragile states (BRA, ZAF, TUR), but to decrease ecological quality at higher quantiles in all countries studied (Pata et al., 2024). Causality-wise, GPR is a Granger cause of environmental sustainability (Chen et al., 2024). Because GPR is often closely linked to resource and energy issues, these geopolitical risks often directly impact non-renewable energy consumption and the clean energy transition. Based on the literature, we can assume that several countries with high levels of geopolitical risk tend to have a long-term impact on environmental sustainability, or in other words, geopolitical risk with a high GPR level will have a substitution effect on the shift in their priority policies by reducing or reallocating their national budget from the environmental sector to their defense and security sector, thus having a short-term environmental effect and ultimately threatening long-term environmental sustainability.

Energy-Environmental Sustainability Nexus

The role of energy consumption, especially non-renewable energy (NRE), is a major determinant recognized for its impact on environmental sustainability as it contributes to increased CO₂ emissions (Awodumi & Adewuyi, 2020; Azam et al., 2023; Shabbir Alam et al., 2023). The use of NRE (such as coal, oil, and natural gas) has a significant negative impact (0.052 units) on ES, as the combustion of fossil fuels produces emissions that contribute to greenhouse gases, pollution, and ecosystem disruption (Khurshid, 2023). Empirical findings confirm a substantial relationship between NRE and increased CO₂ emissions (Ozturk & Acaravci, 2010; Vural, 2020). Conversely, increased use of renewable energy (RECs) has been shown to reduce carbon dioxide emissions and improve environmental quality, promoting sustainable development (Sharif et al., 2020; Usman et al., 2020; Wijaya, 2021). An important aspect of energy sustainability is Energy Security Risk (ESR), which measures the risk to a consistent and cost-effective energy supply (Cui et al., 2023). Increasing ESR can pose a threat to the environment because when energy shortages occur, countries may prioritize

economic growth by inefficiently utilizing existing energy resources and neglecting environmentally friendly technologies (Azwardi et al., 2023; Kartal & Pata, 2023). This is shown in studies that at higher quantiles, ESR lowers the LCF (an ecological indicator that considers both the demand and supply sides of the environment) in India and South Africa (Kartal & Pata, 2023; Pata et al., 2023). Thus, geopolitical and energy-related risks collectively increase pressure on natural resources (Doğan et al., 2023; Dogan & Seker, 2016; Lin & Raza, 2020; Sun et al., 2021). To achieve sustainability goals amidst these risks, many countries must shift from non-renewable energy to clean energy sources (Azwardi et al., 2024; Shittu et al., 2021), a process that is heavily influenced by trade policies. So we can assume that the use of energy, especially non-renewable energy, will have a negative effect on environmental sustainability in the long term.

Trade-Environmental Sustainability Nexus

Trade liberalization (TR) acts as a driving force for economic development, but its impact on environmental sustainability raises concerns due to its potentially multifaceted nature, as evidenced by several studies (Onwachukwu et al., 2021; Pachiyappan et al., 2022). On the one hand, it has a positive and significant effect (0.040 units) on ES (Khurshid, 2023). The benefits of trade liberalization include enabling the exchange of environmentally friendly practices and information between countries (Alam, 2022; Hamid et al., 2023; Saqib et al., 2023), ultimately driving efficiency and innovation in industrial operations and increasing access to breakthrough technologies that can reduce resource consumption and other harmful elements. Furthermore, globalization is more broadly negatively associated with CO₂ emission inequality because it promotes the diffusion of energy-efficient technologies (Gozgor et al., 2020; Liu et al., 2020; Rahman, 2020; Shahbaz et al., 2018; Wijaya et al., 2025; Yang et al., 2021). On the other hand, concerns arise because it can lead to increased resource consumption, pollution, and greenhouse gas emissions (Hertel, 1997). Empirically, trade liberalization and non-renewable energy have been found to both increase carbon emissions Arzova & Sahin (2023), and trade openness can degrade global environmental quality. Furthermore, imports have been found to play a larger role in consumption-based carbon emissions (CBEs) than exports (Vo et al., 2022). Given this relationship, while GPR can drive resource-intensive consumption, it also offers a pathway to sustainable energy solutions. It is therefore crucial for governments to design and implement trade policies that integrate environmental clauses to ensure that trade supports, rather than hinders, sustainable development. So in our perception, trade liberalization will increase local output while reducing the consumption of goods that damage the ecology, so that a pollution-free idea can be created, and ultimately trade can contribute to environmental sustainability by increasing knowledge about environmentally friendly technologies.

Methods

In the concept, it is indicated that trade liberalization, non-renewable energy, and geopolitical risks are interconnected with environmental sustainability. In response to geopolitical issues, nations tend to favour renewable energy options to lessen their reliance on fossil fuels. This transition has the potential to promote more sustainable environmental practices. Additionally, geopolitical conflicts can adversely affect the environment by leading to the destruction of natural ecosystems and pollution resulting from warfare. The use of non-renewable energy sources is shown to detrimentally affect environmental sustainability. The burning of fossil fuels, including coal, oil, and natural gas, generates emissions which lead to

the accumulation of greenhouse gases, environmental pollution, and acid rain. Such outcomes can cause climate change, disrupt ecosystems, damage soil and water resources, and negatively impact human health. Furthermore, the extraction and transportation processes of non-renewable energy sources can damage ecosystems and interfere with wildlife habitats.

Trade liberalization has two distinct effects on environmental sustainability. Firstly, its implementation can lead to increased production and consumption, which may result in adverse environmental impacts such as higher emissions of carbon dioxide, methane, and nitrous oxide. Additionally, the expansion of trade might encourage the over-exploitation of natural resources, deforestation, and destruction of habitats, threatening biodiversity and endangering the long-term viability of ecosystems. On the other hand, it is essential to acknowledge that enhanced trade can also yield positive outcomes. Trade liberalization can empower governments to enhance their role in environmental stewardship by fostering economic growth, aiding development efforts, and improving social welfare. Moreover, open markets have the potential to facilitate access to innovative technologies that can refine local production methods and diminish the use of natural resources like energy and water while minimizing reliance on environmentally damaging materials.

To address this concept, we use the Vector Error Correction Model (VECM) to analyze the effects of geopolitical risk (GPR), non-renewable energy consumption (NRE), trade liberalization (TR), and industrialization (IDS) on environmental desirability (SDI) based on macroeconomic characteristics that are generally non-stationary but cointegrated. The VECM allows researchers to capture the long-run relationship between economic structures such as energy intensity, depth of trade integration, and level of industrialization on environmental quality, while also estimating the short-run impact of shocks such as the formation of geopolitical risk. This model is also economically sound because these variables have strong reciprocal relationships and endogeneity, making the error correction-based VAR approach more appropriate than conventional linear regression. Furthermore, the VECM allows for impulse response analysis and variance decomposition to examine how shocks to the GPR or NRE are transmitted to the SDI over different time horizons. The empirical literature also shows that the cointegration-VECM approach is standard in energy, environmental, and international trade studies, as demonstrated by recent studies such as Khurshid (2023) and Gyamerah & Gil-Alana (2023) applied the VECM to assess the long-term dynamics between trade, energy, geopolitical risk, and environmental desirability. We will technically outline this approach in the "model specifications" section below.

The present study seeks to explore the relationship between environmental sustainability, geopolitical risks, and trade liberalization in Indonesia. The dataset utilized encompasses key variables such as geopolitical risk (GPR), non-renewable energy (NRE), industrial development score (IDS), and trade liberalization (TR), all of which are essential for a comprehensive analysis. GPR refers to the potential political, economic, military, and social threats arising from a country's participation in global affairs, drawing on the research conducted by Husnain et al., (2022). On the other hand, TR relates to the elimination or reduction of obstacles to the unrestricted exchange of goods among countries, based on an extensive investigation by (Wijaya et al., 2023). NRE is derived from the significant findings of Li & Haneklaus (2021), estimating fossil fuel energy consumption as a proportion of total energy use. Likewise Tufail et al., (2021) developed natural resource rents (NR), calculated as total natural resource rents relative to GDP. The urbanization rate (UR) is defined as the

share of the urban population within the total population and is informed by detailed studies conducted by Saqib & Dincă (2024). The temporal range of our data covers 1980 to 2023, facilitating a thorough examination of these factors. Complete information regarding the data and its sources can be seen in table 1 below.

Table 1. **Description and Definitions of Variables**

Variables	Definitions	Data Source
Environmental Sustainability (SDI)	The Sustainable Development Index was created by incorporating economic (GDP), social (life expectancy), and environmental (ecological footprint) dimensions of sustainable development.	Global Footprints Network
Geopolitical Risks (GPR)	Index	https://www.matteoiacoviello.com/gpr.htm
Non-renewable energy consumption (NRE)	Fossil fuel energy consumption (% of total)	WDI
Trade Liberalization (TR)	Trade globalization index	Koff Index
Industrialization (IDS)	Manufacturing, Value Added (% of GDP)	WDI

The main objective of this research is to explore the relationships between SDI, GPR, NRE, TR, and IDS. Following this analysis, a model will be created to achieve the goals outlined in this study.

$$SDI = f(GPR, NRE, TR, IDS) \quad (1)$$

To examine the enduring relationship between the study variables, Equation (1) is reformulated as shown in Equation (2):

$$SDI = \omega_0 + \omega_1 GPR_t + \omega_2 NRE_t + \omega_3 TR_t + \omega_4 IDS_t + \varepsilon_t \dots \dots \dots (2)$$

Causal Relationship

To investigate the presence of a causal relationship among the studied variables, the Granger Causality approach was employed. To elucidate the methodology for evaluating Granger causality, the subsequent models as represented in Eq. (3) and Eq. (4) are taken into account:

$$Y_t = \sum_{i=1}^p a_i Y_{t-i} + \sum_{i=1}^p b_i X_{t-i} + \mu_t \dots \dots \dots (3)$$

$$X_t = \sum_{i=1}^p a_i X_{t-i} + \sum_{i=1}^p b_i Y_{t-i} + \mu_t \dots \dots \dots (4)$$

The Long-Run Relationship

Johansen Cointegration employed the Maximum Eigenvalue test and the Trace test to ascertain the quantity of cointegration vectors. For $r = 0, 1, 2, \dots, n-1$, the maximum

eigenvalue assesses the null hypothesis concerning r cointegrating relationships against the alternative hypothesis of $r+1$ cointegrating relationships. These test statistics can be calculated based on the formula presented in Eq. (5):

$$\lambda_{trace} = -T \sum_{i=r+1}^k \log(1 - \lambda_i) \dots \dots \dots (5)$$

Where λ denotes the maximum eigenvalue and T represents the sample size. Trace statistics evaluate the null hypothesis concerning r cointegrating relationships in contrast to the alternative hypotheses of n cointegrating relationships, where n indicates the number of variables in the system, with r being 0, 1, 2, ..., $n-1$. The subsequent equation (6) is utilized for conducting the maximum eigenvalue test:

$$\lambda_{max} = -T \log(1 - \lambda_{r+1}) \dots \dots \dots (6)$$

Short-Run Dynamics testing

The VAR model is a statistical framework that posits each endogenous variable within the system as dependent on its past values. When a co-integration relationship exists among the variables, the autoregressive distributed lag model can facilitate the formation of an error correction model. The VEC model essentially functions as a VAR model that incorporates cointegration constraints, capturing a range of short-term dynamic variations. Since the VEC model encompasses these fluctuations, its formulations can impose limitations on the long-term dynamics of endogenous variables, guiding them towards their co-integration relationship.

Given that $Y_t = (Y_{1t}, Y_{2t}, \dots, Y_{kt})$ represents a k -dimensional stochastic time series, where $t = 1, 2, \dots, T$, and with $y_{it} \sim I(1)$, each $y_t \sim I(1)$, for $i = 1, 2, \dots, k$, which is influenced by exogenous time series of d -dimension ($x_t = x_{1t}, x_{2t}, \dots, x_{dt}$), the VAR model can be expressed in the format of Eq. (7):

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \dots, A_m y_{t-m} + B x_t + \mu_t \dots \dots \dots (7)$$

Where, $t = 1, 2, \dots, T$.

If y_t is not influenced by exogenous time series of d -dimensions ($x_t = x_{1t}, x_{2t}, \dots, x_{dt}$), then the VAR model presented in equation (7) can be expressed as shown in equation (8):

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \dots, A_m y_{t-m} + \mu_t \dots \dots \dots (8)$$

By applying the cointegration transformation from formula (8), we are able to express it as illustrated in equations (9) through (11):

$$\Delta y_t = \Omega y_{t-1} + \sum_{i=1}^{m-1} \Pi_i \Delta y_{t-i} + \mu_t \dots \dots \dots (9)$$

Where:

$$\Omega = \sum_{i=1}^m A_i - 1 \dots \dots \dots (10)$$

$$\Pi_i = \sum_{j=i+1}^m A_j \dots \dots \dots (11)$$

If y_t has cointegration relationship, then $\Omega y_{t-1} \sim I(0)$ and formula (9) can be written in the form of Eq. (12):

$$\Delta y_t = \alpha \beta y_{t-1} + \sum_{i=1}^{m-1} \Pi_i y_{t-1} + \mu_t \dots \dots \dots (12)$$

In the equation, $\alpha \beta / y_{t-1} = ecm_{t-1}$ represents the error correction term, indicating reflects the long-term equilibrium relationship that exist among the variables, and the above formula can be reformulated in the manner of Eq. (13):

$$\Delta y_t = a ecm_{t-1} + \sum_{i=1}^{m-1} \Pi_i y_{t-1} + \mu_t \dots \dots \dots (13)$$

Findings

Table 2 shows descriptive statistics for the variables used in this study. Using the descriptive statistics table, we analyzed the properties of each index, from the SDI to the IDS. The mean and median of the SDI variable are 0.653 and 0.6565, respectively (very small differences), and it has a moderately concentrated, symmetric distribution (with an interquartile range of $IQR = 0.531-0.768$). This is also consistent with a small standard deviation of 0.082. In contrast to the SDI, the GPR distribution is strongly skewed to the right (mean = 0.087, median = 0.044). With a maximum value of 0.358 and a minimum of only 0.016, the histogram shows that there are a few large values that increase the mean, but most of the data falls below this level.

Simultaneously, both the NRE and TR variables appear negatively skewed. In the NRE, the mean (71.127) is smaller than the median (76.065), indicating that there are many low values in this dataset that lower the mean. The large data range (51.85–82.09) indicates that observations vary substantially from each other. In the TR, a comparable pattern is observed between the median (59.336) and mean (54.253), along with a range from low (38.938) to high (62.980) values. Finally, the IDS variable is well distributed, with a mean (21.645) and median (21.051) being nearly identical. This relatively scattered range of values (12.596 to 31.953) reflects considerable variability in the data, but with little distortion. Therefore, we can conclude that there is a unique distribution for each variable. SDI and IDS tend to be symmetrical, while GPR, NRE, and TR show deviations influenced by extreme values.

Table 2. Descriptive Statistics

	SDI	GPR	NRE	TR	IDS
Mean	0.653	0.087	71.127	54.253	21.646
Median	0.656	0.044	76.065	59.336	21.051
Maximum	0.768	0.357	82.090	62.980	31.953
Minimum	0.531	0.015	51.850	38.938	12.596
Std. Dev.	0.082	0.081	9.833	8.761	4.802
Skewness	-0.096	1.550	-0.678	-0.688	0.059
Kurtosis	1.551	4.800	2.027	1.815	2.429
Jarque-Bera	3.915	23.570	5.109	6.045	0.623
Probability	0.141	0.000	0.077	0.048	0.732

Source: Author's Calculation, 2025

Table 3 presents the correlation matrix of the variables used in this study. The results indicate a strong, though slightly varying, relationship among all measured variables. The SDI variable is highly positively correlated (NRE 0.93 and TR 0.94), although weakly negatively correlated (GPR -0.64). NRE and TR also have a strong positive relationship (0.98). Meanwhile, IDS remains only moderately correlated with the other indicators (weak to moderate), with IDS having a higher estimate with NRE (0.63) and TR (0.61), while lower for SDI (0.36) and GPR (-0.43). Overall, GPR has a negative relationship with all other variables, particularly with TR (-0.70) and NRE (-0.66). Therefore, when any of the NRE, SDI, and TR variables increase, there will be a significant effect on GPR (or vice versa).

Table 3. Correlation matrix

	SDI	GPR	NRE	TR	IDS
SDI	1				
GPR	-0.642	1			
NRE	0.930	-0.662	1		
TR	0.938	-0.702	0.975	1	
IDS	0.363	-0.425	0.631	0.607	1

Source: Author's Calculation, 2025

Prior to estimating the empirical model intended for examination, it is essential to confirm that the variables exhibit stationarity. In order to evaluate stationarity, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are employed. The results of the ADF and PP tests are displayed in Table 4. The test findings indicate that all study parameters are in first difference, i.e., I(1). We can test the long-run equilibrium relationship between variables using the ADF and PP results at the I(1) level by applying Johansen's (1988) cointegration test.

Table 4. Unit root test results

	PP (Prob).		ADF (Prob).	
	I(0)	I(1)	I(0)	I(1)
	Without Trend	Without Trend	Without Trend	Without Trend
SDI	0.80	0.00	0.77	0.00
GPR	0.23	0.00	0.29	0.00
NRE	0.11	0.00	0.17	0.00

PP (Prob).			ADF (Prob).	
	I(0)	I(1)	I(0)	I(1)
	Without Trend	Without Trend	Without Trend	Without Trend
TR	0.42	0.00	0.39	0.00
IDS	0.32	0.00	0.32	0.00

Source: Author's Calculation, 2025

We additionally evaluated the study series for the occurrence of a single point by utilizing the Zivot-Andrews Structural Break Unit Root test. The outcomes of the Zivot-Andrews examination are illustrated in Table 5. With the exception of SDI and GPR, the findings from this research suggest that all variables demonstrate stationarity at the first difference. This finding signifies a consistent level of integration throughout the series. This supplementary test enhances the credibility and reliability of our results.

Table 5. Zivot-Andrews Structural Break Unit Root test result

	I(0)		I(1)	
	t-stat	Break Points	t-stat	Break Points
SDI	-3.889*	1989	-5.711***	2019
GPR	-5.363*	1989	-9.652***	1990
NRE	-3.077	1987	-10.220***	2000
TR	-3.730	1990	-6.804**	1998
IDS	-2.184	2008	-8.532**	2003

Source: Author's Calculation, 2025

The VAR model is used to calculate the lag duration requirements after checking the stationarity level among the research parameters. The appropriate lag must be selected because it provides an overview of the total amount of time required for a data parameter to respond to changes in other parameters. Based on Table 6, it shows that the optimal lag is at lag 4, guided by the lowest AIC value among the other lag periods. Based on these results, the obtained model is also tested using the AR Roots Table output; the result is that the modulus value of the output is less than 1 (one), which means the model is stable.

Table 6. Lag Length Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	2.414846	NA	7.86e-07*	0.132572	0.345849*	0.209094*
1	20.65448	30.86707	1.12E-06	0.479257	1.75892	0.938389
2	47.49471	38.53981*	1.09E-06	0.384887	2.730935	1.226629
3	67.52184	23.62174	1.69E-06	0.639906	4.05234	1.864258
4	106.6263	36.09646	1.19E-06	-0.083402*	4.395418	1.52356

Source: Author's Calculation, 2025

Once the model is stable, the next step is to conduct a cointegration test, which will determine which analysis method to use. If cointegration is present, a VECM analysis will be used; otherwise, a VAR analysis will be used.

Table 7. Johansen Co-Integration test results

Hypothesized	Trace		0.05	Max-Eigen		0.05
No. of CE(s)	Statistic	Critical Value	Prob.**	Statistic	Critical Value	Prob.**
None *	119.227	69.819	0.000	53.084	33.877	0.000
At most 1 *	66.143	47.856	0.000	42.454	27.584	0.000
At most 2	23.689	29.797	0.214	15.559	21.132	0.252
At most 3	8.130	15.495	0.452	6.038	14.265	0.608
At most 4	2.093	3.841	0.148	2.093	3.841	0.148

Trace test and Max-Eigen indicate 2 and 2 cointegrating eqn(s) at the 0.05 level.

* denotes rejection of the hypothesis at the 0.05 level.

** MacKinnon-Haug-Michelis (1999) *p*-values.

The results of table 7 compare the cointegration alternatives with the null hypothesis, namely the absence of cointegration, using the Trace and Max-Eigen statistical tests. The results above show two cointegration links, each of which has a significant long-term influence, as indicated by the five percent significance level of the null hypothesis. Because the variables in the study exhibit a balanced relationship and similar movements over time, it is possible that there is a single cointegration equation. In the next phase, we can run long-term estimation using the VECM technique.

The short-run findings are presented at the bottom of Table 8. The coefficient representing the "adjustment speed" in the error correction component is negative, which is positive because it indicates movement toward long-run equilibrium. Specifically, this adjustment term implies that the deviation from the long-run equilibrium for the current year is corrected at a rate of 0.74%. For a meaningful causal relationship to be established in the VECM, both the t-statistics for the regressors and the error correction term must be significant. The top of Table 7 illustrates the normalized coefficients associated with the long-run performance of the cointegrating vector. The formula for calculating these normalized coefficients is as follows:

the equation as follows:

$$SDI = 0.0037 \text{ GPR} - 0.0017\text{NRE} + 0.0044\text{TR} - 0.0034\text{IDS}$$

The long-term results of the VECM model illustrate that NRE, IDS, and TR influence environmental sustainability, except for GPR. Our research findings indicate that geopolitical risk (GPR) conceptually refers to the uncertainty resulting from international conflict, political tension, and threats to global stability that can impact a country's economic and social strength. The GPR index by Caldara & Iacoviell (2022), published in the American Economic Review, is a global indicator for measuring geopolitical risk across countries by analyzing international news texts. In an ideal world, GPR would also discourage foreign investment, change the direction of trade, and make public policy more focused on maintaining environmental issues or more focused on the economic status quo. However, in the case of Indonesia, empirical results indicate that the effect of GPR on environmental sustainability is insignificant in the long run because domestic factors are much more controlling the direction and quality of national environmental sustainability.

Table 8. Results of VECM model

Variables	Coefficient	Std.Error	t-stat
Long Run Results			
D(GPR(-1))	-0.00375	0.02238	-0.16788
D(NRE(-1))	0.00173	0.00085	2.03039
D(TR(-1))	-0.00448	0.00079	-5.6651
D(IDS(-1))	0.00343	0.00056	6.12651
Short Run Result			
CointEq1	-0.7489	0.41758	-1.79345
D(GPR(-1),2)	-0.0073	0.01971	-0.3704
D(GPR(-2),2)	-0.03249	0.02557	-1.2711
D(GPR(-3),2)	-0.02662	0.02966	-0.89765
D(GPR(-4),2)	0.00222	0.02157	0.10335
D(NRE(-1),2)	-0.00154	0.00161	-0.96133
D(NRE(-2),2)	-0.0005	0.00169	-0.29991
D(NRE(-3),2)	0.00012	0.0018	0.06684
D(NRE(-4),2)	0.00026	0.00129	0.20141
D(TR(-1),2)	-0.00307	0.00168	-1.82858
D(TR(-2),2)	-0.00261	0.00133	-1.96298
D(TR(-3),2)	-0.00244	0.00127	-1.93091
D(TR(-4),2)	-0.00152	0.00104	-1.46516
D(IDS(-1),2)	0.0016	0.0011	1.4587
D(IDS(-2),2)	0.00067	0.00124	0.54758
D(IDS(-3),2)	0.0004	0.00092	0.44144
D(IDS(-4),2)	0.00064	0.0006	1.06342
C	-2.23E-05	0.00086	-0.02592

Source: Author's Calculation, 2025

Recent studies have shown that GPR has varying effects across countries, depending on economic structure, governance, and energy policies. Husnain et al., (2022) found that geopolitical risk can increase the ecological footprint in some developing countries through increased energy consumption and reliance on fossil fuels. However, this effect is temporary and highly dependent on the stability of domestic policies. Similarly, a cross-country study by Anser et al., (2021) revealed that the effect of GPR on the ecological footprint is inconsistent, with positive effects in some countries (increasing degradation) while negative in others due to declining economic activity caused by global damage. Thus, there is no strong evidence that GPR systematically determines ecotourism trends, especially in the context of a developing country like Indonesia, whose economy relies on primary commodities.

In the case of Indonesia, domestic factors have been shown to be the primary drivers of environmental degradation and land-use change. Research by Gaveau et al., (2021) shows that the expansion of palm oil plantations, the pulp and paper industry, and mining are the largest contributors to deforestation and forest degradation. This process is not a direct response to global geopolitical dynamics, but rather a combination of economic incentives, lax land-use policies, and weak environmental law enforcement. The same conclusion is

confirmed by Gaveau et al., (2022), who show that Indonesia's decline in deforestation in recent years is due more to a moratorium on new forest clearing permits and improved governance than to geopolitical changes. This means that the dynamics of environmental sustainability in Indonesia are largely determined by internal policies and commodity market forces, rather than fluctuations in international geopolitical risks. Weak environmental governance and overlapping land ownership also weaken the influence of geopolitics on sustainability. Amidst global uncertainty, domestic economic actors continue land expansion due to pressure from demand for palm oil and mining exports, which are the main sources of foreign exchange. Therefore, even though the GPR temporarily discouraged foreign direct investment, this pressure was not strong enough to halt the large-scale land conversion process that has become institutionalized economically and politically. This reinforces the argument that geopolitical risks only have a short-term impact on macroeconomic indicators but are incapable of changing the production structure and land use practices that are the primary sources of environmental degradation in Indonesia.

Furthermore, Indonesia's economic structure, which remains reliant on the extractive sector, makes it relatively resilient to geopolitical shocks. Villanthenkodath & Pal (2024) note that in developing countries with a dominant primary sector, GPR fluctuations have no long-term relationship with sustainability indicators because the main determinants are industrial transformation and domestic policy capacity. In this context, the relationship between GPR and environmental sustainability in Indonesia tends to be indirect, mediated by commodity prices, energy policies, and national political stability. When domestic policies are more oriented toward exploiting natural resources for economic growth, sensitivity to external changes is low.

Further findings show that NRE use has a negative and significant relationship with SDI in the long run. A one-unit increase in NRE use decreases SDI by 0.0017 units. This indicates that the consumption of non-renewable energy sources has a significant negative impact on environmental sustainability due to their high carbon intensity and pollutant emissions. The combustion of fossil fuels such as coal, oil, and natural gas produces large amounts of greenhouse gases that accelerate global warming, degrade air quality, and disrupt ecosystem integrity. Furthermore, the extraction and exploitation of these resources often lead to deforestation, land degradation, and water pollution, thus exacerbating ecological pressures. Empirical evidence consistently shows that increasing consumption of non-renewable energy sources worsens key environmental indicators such as ecological footprint and carbon emissions. For example, Idroes et al., (2024) revealed that the use of non-renewable energy in Indonesia from 1965 to 2022 was positively correlated with CO₂ emissions and ecological footprint, implying a long-term decline in environmental quality. Similarly, Depren et al., (2022) found that the consumption of coal and oil had the most detrimental long-term impact on environmental performance compared to other energy sources. At the global level, Ghose et al., (2024) and Çatık et al., (2024) assert that countries reliant on fossil fuels exhibit weaker environmental sustainability outcomes and slower transitions to green growth. Collectively, these findings indicate that non-renewable energy consumption remains a key driver of environmental degradation, underscoring the urgent need for accelerated clean energy transitions, carbon reduction policies, and sustainable energy governance frameworks to ensure long-term environmental sustainability.

Our research also shows that TR has a positive and significant relationship with SDI, where a one-unit increase in TR increases SDI by 0.0048 units. Simply put, this means that trade

liberalization has a positive relationship with environmental sustainability when accompanied by strong environmental governance, green technology innovation, and effective green economic policies. Theoretically, this relationship is explained through the Porter Hypothesis and the Environmental Kuznets Curve (EKC), which emphasizes that trade openness encourages increased production efficiency, clean technology transfer, and the adoption of better environmental standards globally (Antweiler et al., 2001; Frankel & Rose, 2005). In an open economy, countries can import environmentally friendly technologies from developed countries and export more energy-efficient products, thereby reducing emission intensity and improving overall environmental quality.

Empirical evidence supports the view that trade liberalization plays a role in improving environmental quality, particularly in developing countries with adequate institutional systems. A study by Hasan et al., (2025) showed that trade openness in the Asian region contributed to increased renewable energy consumption and reduced carbon emissions through technology transfer and energy efficiency mechanisms. Similar results were found by Hassan et al., (2023), who revealed that trade liberalization encouraged investment in green innovation and accelerated the decoupling effect between economic growth and environmental degradation.

In Indonesia, trade liberalization, initiated in the 1990s through tariff reforms, participation in the ASEAN Free Trade Area (AFTA), and membership in the WTO, has positively impacted industrial transformation towards sustainable practices. Research by Ling et al., (2020) found a long-term causal relationship between trade openness and improved environmental performance in Indonesia. This process is reinforced by the adoption of environmental certification standards such as the Indonesia Sustainable Palm Oil (ISPO) and the implementation of green industrial policies that promote energy efficiency in the manufacturing sector. Furthermore, Chien et al., (2023) explain that trade openness accelerates the adoption of clean innovations and improves national sustainability performance through global market integration and technological collaboration. However, the positive effects of trade liberalization on sustainability are highly dependent on domestic environmental regulatory capacity. In Indonesia, policies such as Government Regulation No. 46 of 2017 concerning Environmental Economic Instruments have been crucial in ensuring trade activities align with sustainable development goals. Therefore, trade liberalization can be a significant catalyst for environmental sustainability if accompanied by strong environmental governance, clean energy transition policies, and government and industrial sector commitment to implementing a green economy. Thus, Indonesia's experience shows that trade openness not only expands markets and economic growth, but can also strengthen long-term environmental performance through the diffusion of green innovations and increased resource efficiency.

Finally, we found that a one-unit increase in IDS leads to a 0.0034 unit decrease in SDI. This suggests that, in the long term, industrialization can have a positive impact on environmental sustainability if guided by technological innovation and the application of green industry principles. Although it is often associated with increased emissions and environmental degradation in the initial stages, industrialization processes oriented towards energy efficiency and clean technology can reduce carbon footprints and increase resource efficiency (Dinda, 2004; Zhang et al., 2023) consistent with the Environmental Kuznets Curve (EKC) theory, as economies grow, countries have a greater capacity to invest in green innovation and environmental regulation (Grossman & Krueger, 1995).

In Indonesia, the transformation toward a green industry through the Making Indonesia 4.0 policy has encouraged the use of environmentally friendly technologies and low-emission production. Elfaki & Heriqbaldi (2023) state that industrial modernization and increased investment in technological innovation contribute to improved energy efficiency and reduced carbon emissions. Thus, innovation-driven industrialization and strong environmental policies not only accelerate economic growth but also serve as key drivers of long-term environmental sustainability (Jiang et al., 2024).

Table 9. **Granger Causality test**

Null Hypothesis:	F-Statistic	Prob.
GPR # SDI	0.663	0.6224
SDI # GPR	2.78926	0.0435
NRE # SDI	3.37627	0.021
SDI # NRE	2.90133	0.0378
IDS # SDI	2.1505	0.0981
SDI # IDS	2.58411	0.0564
TR # SDI	1.76573	0.161
SDI # TR	1.76294	0.1615
NRE # GPR	2.12456	0.1014
GPR # NRE	0.44563	0.7747
IDS # GPR	1.55187	0.2118
GPR # IDS	0.47443	0.7541
TR # GPR	1.89271	0.1367
GPR # TR	0.59306	0.6702
IDS # NRE	2.38204	0.0729
NRE # IDS	5.00468	0.0031
TR # NRE	1.11107	0.369
NRE # TR	1.60787	0.1971
TR # IDS	4.48016	0.0057
IDS # TR	1.69616	0.176

Source: Author's Calculation, 2025

Cointegration analysis indicates that each indicator exhibits a long-run equilibrium relationship; however, further investigation is needed to establish a causal relationship. If parameter A proves effective in predicting B, meaning that the regression of B combines its past values with the previous values of A, the explanatory power of this regression can be significantly improved. A is classified as a non-Granger cause if it does not meet the criteria to be considered a Granger cause of B. The P-value should be below 5%, indicating that the null hypothesis (which states the existence of Granger causality) should be rejected. As presented in Table 9, most variables show unidirectional causality except for the relationship between NRE and SDI or vice versa. Overall, these results illustrate that environmental sustainability in Indonesia is more influenced by economic and energy factors than geopolitical risks. The bidirectional causality between energy consumption and sustainability emphasizes the importance of the transition to clean energy, while the interaction between trade and industrialization strengthens the long-term structure of the green economy.

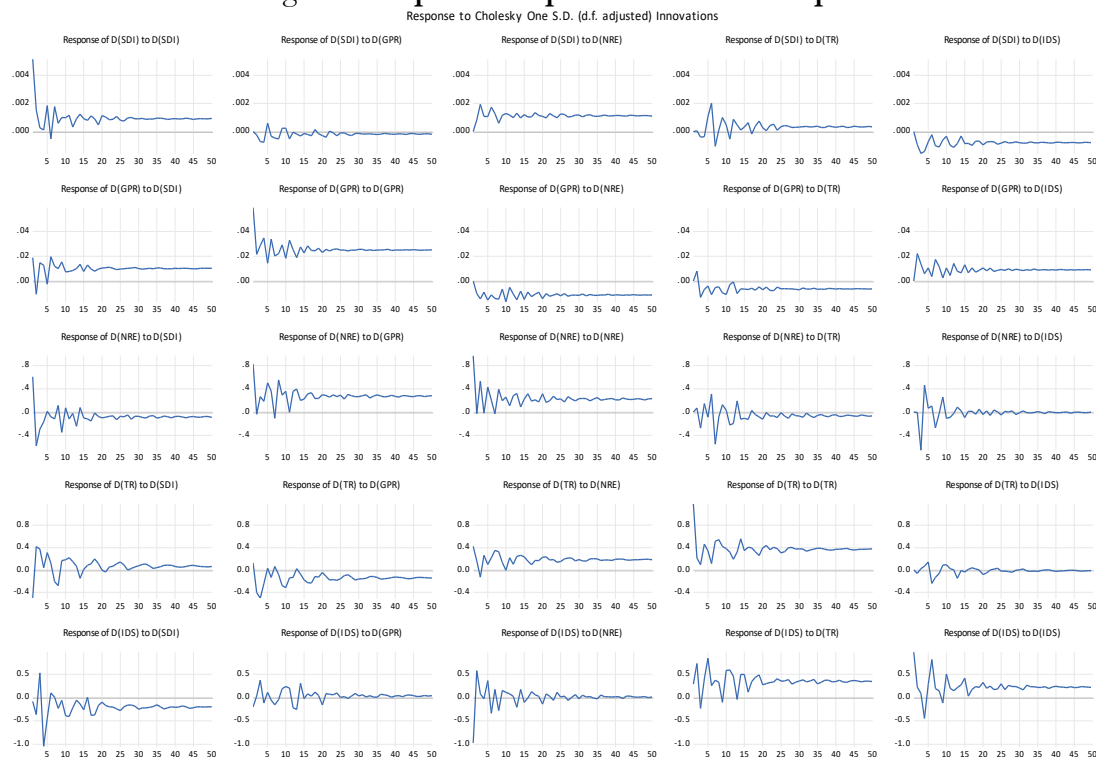
To determine whether the resulting model exhibits heteroscedasticity, serial correlation, autocorrelation, and normality, a test must be performed. The results in Table 10 show that the p-value from the LM test indicates that all lags have values greater than 0.05, indicating no correlation between the variables. Furthermore, the data are normally distributed, as indicated by the Jarque-Bera test value of 6.063 (as seen from the normality test) and a p-value greater than the significance level. Finally, the heteroscedasticity test results show that the p-value is also greater than the 5 percent significance level.

Table 10. Results of diagnostic test

Part A: Serial correlation LM Test			
Lag	LM stat	d.f	Prob.
1	21.064	25	0.724
2	15.517	25	0.939
3	27.145	25	0.396
4	21.386	25	0.707
Partl B: Normality test			
Statistics	X ²	d.f	p-Value
Skewness	3.137	5	0.678
Kurtosis	2.925	5	0.711
Jarque-Bera	6.063	10	0.809
Part C: Heteroscedasticity test			
White	X ²	d.f.	p-Value
Statistics	470.45	480	0.613

Source: Author's Calculation, 2025

Figure 1. Impulse Response Function Graph



Source: Author's Calculation, 2025

The impulse response function (IRF) results indicate that shocks to the SDI generate a consistently positive and relatively stable response over 50 periods. The response peaks in the initial period at 0.005140 and then gradually declines, remaining within the range of 0.0008–0.0012 thereafter. This suggests strong internal dynamics in the sustainability index, whereby an initial improvement in SDI continues to reinforce sustainable development over time. In contrast, shocks to the Geopolitical Risk Index (GPR) lead to a persistent negative response of SDI, particularly in periods 3 and 4, with values of –0.000710 and –0.000759. Although the magnitude is modest, the negative impact persists throughout the observation horizon, indicating that rising geopolitical risk consistently undermines sustainable development performance. Meanwhile, shocks from trade liberalization (TR) exert a notably positive effect, peaking in period 6 at 0.002475 and remaining stable within the range of 0.0006–0.0009 in later periods. This highlights the positive role of trade openness in promoting sustainable development through greater efficiency, technological diffusion, and deeper global economic integration.

Meanwhile, the shock to the non-renewable energy consumption (NRE) variable responded positively to the SDI, with a relatively large value in early periods, such as period 3 (0.001960) and remaining positive throughout the 50 periods. Although theoretically, non-renewable energy consumption should depress sustainability, this empirical result can be explained by the short-term contribution of fossil fuels to productivity, economic growth, and institutional capacity, which, to some extent, are still included in the sustainability index measurement. This also reflects the fact that the energy transition to renewable sources has not yet been optimal, so increasing fossil fuel consumption still has a positive macroeconomic effect in the short term. Finally, the shock from industrialization (IDS) had a negative and stable impact on the SDI throughout the analysis period. The largest negative effect was observed in the initial periods, such as periods 3 (–0.001568) and 4 (–0.001424), then gradually stabilized in the range of –0.0007 to –0.00085 in subsequent periods. Overall, the results indicate that SDI was highly responsive to external shocks in the early period but gradually followed a stable adjustment path toward long-run equilibrium. This positive convergence reflects the economic system’s capacity to sustain stable and sustainable development amid global environmental changes. The findings highlight the crucial role of strengthening renewable energy (NRE) and institutional stability (IDS), while the impacts of geopolitical risk (GPR) and trade uncertainty (TR) remain temporary and manageable through appropriate mitigation and adaptive governance.

Table 11. **Response of SDI**

Period	S.E	D(SDI)	D(GPR)	D(NRE)	D(TR)	D(IDS)
1	0.005	100.000	0.000	0.000	0.000	0.000
2	0.006	94.627	0.194	2.229	0.009	2.941
3	0.006	77.196	1.507	11.883	0.436	8.978
4	0.006	69.929	2.763	13.544	0.714	13.049
5	0.007	67.459	3.140	14.022	3.006	12.373
6	0.007	58.852	2.927	17.512	9.920	10.789
7	0.008	57.168	2.926	18.177	10.527	11.203
8	0.008	55.753	3.262	18.101	10.188	12.696
9	0.008	54.168	3.161	19.048	11.075	12.548
10	0.008	53.243	3.103	20.539	10.932	12.184

Source: Author’s Calculation, 2025

Table 11 extensively explains the findings of our study related to variance decomposition. Based on the findings, in the initial period, the fluctuation of SDI was largely influenced by itself, namely 100% in the first period and gradually decreased to 53.24% in the 10th period. This indicates that the internal influence of SDI is decreasing in the long run. Meanwhile, the consumption of non-renewable energy (NRE) showed a significant increase in influence from 0% at the beginning of the period to 20.54% in the 10th period, making it the most dominant external factor affecting sustainability dynamics. Geopolitical risk (GPR) experienced an increase in contribution from 0% to 3.10%, indicating a relatively small but steadily increasing influence on SDI. On the other hand, the trade (TR) and industrial development (IDS) variables also made increasing contributions, reaching approximately 10.93% and 12.18%, respectively, in the 10th period. Overall, these results confirm that in the long run, non-renewable energy, trade, and industrialization factors play a major role in determining the direction of sustainable development, while geopolitical risks have a more limited influence.

Conclusion

Based on the results of a long-term analysis using the Vector Error Correction Model (VECM) method, this study found that non-renewable energy (NRE) consumption and industrialization (IDS) have a negative and significant relationship with environmental sustainability (SDI) in Indonesia. This means that the increasing use of fossil energy and the expansion of industrial sectors that are not environmentally friendly contribute to a decline in the quality of environmental sustainability. In addition, trade liberalization (TR) also shows a positive effect on SDI, indicating that increased trade openness in Indonesia has not been balanced by the implementation of adequate environmental standards. Conversely, geopolitical risk (GPR) is not proven to have a significant long-term effect on SDI, indicating that global geopolitical dynamics have not directly affected the condition of national environmental sustainability.

The Granger causality test results indicate a bidirectional relationship between NRE and SDI, meaning that non-renewable energy consumption not only affects environmental sustainability but also, conversely, changes in environmental conditions can influence energy consumption patterns in Indonesia. This finding indicates a feedback effect between energy and the environment, where environmental degradation can encourage transition policies towards cleaner energy while dependence on fossil fuels worsens environmental conditions in the long term. Impulse Response Function (IRF) analysis shows that when shocks occur to key variables, Indonesia's economic and environmental systems tend to stabilize around the 30th period, indicating a capacity for adaptation and structural adjustment in the medium term. Meanwhile, the Variance Decomposition (VD) results show that the variation in SDI is mostly explained by itself at 53 percent, followed by NRE at 20 percent, IDS at 12 percent, TR at 11 percent, and GPR at only 3 percent. This indicates that environmental sustainability in Indonesia is more influenced by domestic factors, especially energy and industrialization policies, rather than external factors such as global geopolitics.

Overall, the negative relationship between NRE and SDI reflects the fact that fossil fuel consumption remains a major contributor to carbon emissions in Indonesia. Dependence on non-renewable energy sources creates significant ecological pressure, particularly as the national energy mix remains dominated by coal and petroleum. Meanwhile, the negative relationship between industrialization and SDI can be explained through the concept of the

Environmental Kuznets Curve (EKC), where, in the early stages of industrialization, economic growth tends to be accompanied by increased pollution and exploitation of natural resources before reaching a turning point towards sustainable development. In the Indonesian context, most industrial sectors are still extractive and energy-intensive, so their contribution to environmental sustainability remains negative. The positive impact of trade liberalization on SDI shows that environmental aspirations will be realized if accompanied by strong environmental governance, green technology innovation, and effective green economic policies, so that in an open economy like Indonesia, it can import environmentally friendly technology from developed countries and export more energy-efficient products, thereby reducing emission intensity and improving environmental quality. Meanwhile, the insignificant effect of geopolitical risk on SDI suggests that environmental conditions in Indonesia are more influenced by domestic policies than by global geopolitical fluctuations, given Indonesia's relatively inward-looking economic structure.

Based on these findings, several policy implications can be formulated. First, the government needs to accelerate the clean energy transition by increasing investment in renewable energy sources such as solar, wind, and biomass to reduce carbon emissions and improve the environmental sustainability index. Second, it is necessary to encourage the implementation of green industrial policy, namely a policy that directs the industrial sector towards environmentally friendly practices through fiscal incentives, the implementation of clean technology, and sustainable waste management. Third, in the context of trade, a sustainable trade policy is needed that integrates environmental standards into every international trade agreement so that economic liberalization does not worsen ecological conditions. Finally, although the effect of GPR is not significant, Indonesia still needs to increase its resilience to geopolitical risks by strengthening domestic energy reserves and diversifying trading partners to maintain economic stability and environmental sustainability in the future.

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