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Interlinkages Between Environmental Quality, Economic Growth, and Human Capital in Indonesia: Implications for Sustainable Development Policies

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Abstract: This study investigates the complex interrelationships between environmental quality, economic growth, and human capital across 34 provinces in Indonesia from 2017 to 2023, employing a vector autoregression (VAR) approach. The analysis seeks to elucidate how these three critical dimensions influence one another and to provide insights for formulating sustainable development policies that balance economic progress with environmental preservation and human capital enhancement. The findings reveal a bidirectional causality between environmental quality and economic growth, indicating that improvements in one are likely to promote advances in the other. A similar bidirectional causality is observed between environmental quality and human capital, suggesting that better environmental conditions may enhance human capital development, which in turn can contribute to environmental sustainability. However, the relationship between economic growth and human capital is found to be unidirectional, with evidence showing that human capital positively influences economic growth, but not vice versa. This unidirectional causality highlights the importance of investing in human capital to sustain economic growth without compromising environmental integrity. The study underscores the necessity of integrated policy approaches that simultaneously address environmental quality, economic growth, and human capital development. Focusing narrowly on economic growth without considering its environmental and social dimensions may lead to adverse outcomes, undermining long-term sustainability objectives. Therefore, it is recommended that policymakers in Indonesia adopt a holistic perspective, integrating environmental, economic, and social policies to achieve sustainable development goals. The findings of this study provide a nuanced understanding of the interplay among these factors and offer valuable guidance for designing policies that ensure balanced and sustainable development in Indonesia.

Keywords: Causality analysis; Economic growth; Environmental quality; Human capital; Sustainable development; Vector Autoregression (VAR); Policy integration

1. Introduction

Global development policies and strategies are based on the international agenda known as sustainable development (SD). The primary goal is to achieve a balance between economic growth (EG), environmental sustainability, and social welfare (Fleming et al., 2017; Hák et al., 2016; Halisçelik & Soytas, 2019). This concept emphasizes the importance of preserving and protecting the environment so that current generations can meet their needs without compromising the ability of future generations to meet their own needs (Străchinaru & Străchinaru, 2014). In this context, environmental quality (EQ) is a crucial component of SD. A healthy and well-maintained environment supports ecosystem survival and enhances the quality of life for people (Vulevic et al., 2022).

In Indonesia, a country rich in natural resources (NR) and biodiversity, EQ significantly impacts various aspects of life. However, the country faces several serious environmental challenges. Issues such as air pollution, deforestation, and soil degradation are becoming increasingly urgent and require serious action (Austin et al., 2019; Prasetyanto & Sari, 2021). For example, air pollution can endanger public health by increasing the risk of respiratory and cardiovascular diseases, as well as generally lowering the quality of life (Andini et al., 2018;

Haryanto, 2018; Waluyo et al., 2019). Ongoing deforestation threatens forest ecosystems, reduces biodiversity, and affects water cycles and soil stability (Arifanti et al., 2021; Tacconi et al., 2019). Additionally, soil degradation can impact agricultural productivity and food security, as well as exacerbate poverty in rural areas (Nurrochmat et al., 2019; Pirmana et al., 2021; Salahuddin et al., 2018).

Detrimental environmental issues also have the potential to hinder SD. Then EG reflects a country's progress by indicating increases in productivity, income, and overall societal well-being (Aimon et al., 2022; Cassar, 2022; Nathaniel et al., 2021a). In Indonesia, although the country has shown significant economic progress in recent decades, EQ challenges remain a major issue. Industrial growth, rapid urbanization, and changing consumption patterns have placed significant pressure on EQ (Aimon et al., 2023; Vo et al., 2019). However, in many countries, including Indonesia, EG is often associated with increased NR consumption and pollutant emissions. As a result, there is a decline in EQ that impacts the competitiveness and productivity of EG (Ahmad et al., 2018; Bakirtas & Akpolat, 2018; Carfora et al., 2019). This phenomenon has substantial implications for EQ, potentially affecting public health, biodiversity, and ecosystem stability.

Moreover, a decline in EQ can also impact human capital (HC), which means that individual health and well-being deteriorate, reducing their ability to participate effectively in economic and social activities (Zajacova & Lawrence, 2018). For instance, health issues caused by pollution can lead to a range of health problems, which in turn disrupt the learning process (Bachama et al., 2021; Raghupathi & Raghupathi, 2020). On the other hand, HC, which encompasses education, skills, and health, is a key pillar of EG as it affects labor productivity, innovation capabilities, and the competitiveness of a country or region (Garza-Rodriguez et al., 2020; Sultana et al., 2022). High-quality HC, relevant skills, and good health can enhance an individual's ability to contribute maximally across various economic sectors, thereby supporting sustainable and inclusive EG (Khaleel et al., 2024).

Many theories discuss the relationship between EQ, EG, and HC. However, understanding the causality among these three variables remains limited, particularly in the case of Indonesia, and previous research often contradicts one another. According to earlier studies (Khan et al., 2021b), EG might initially harm EQ, but EQ can improve with rising income. This finding contrasts with the more pessimistic view of Usman et al. (2022), which argues that the relationship between EG and EQ may not be universal or consistent. Additionally, Haseeb et al. (2019) contends that EG does not always positively impact EQ and that the effects of EG can vary depending on the situation and country. This is supported by Khan et al. (2021a), which states that depending on the policies implemented, applying Kuznets' theory to environmental policy can yield varying results, indicating contradictions in the application of this theory. On the other hand, Liang & Yang (2019) finds that empirical results are highly variable, reflecting uncertainty about the relationship between EG and EQ.

Additionally, other research on the relationship between EQ and HC has shown that HC can influence EQ in various ways. This contradicts theories suggesting that EG always has a positive impact on the environment after reaching a certain point (Khan et al., 2021c). Specifically, Zhang et al. (2021) conducted a study in China on the relationship between EQ and HC and found that the results could differ depending on the stage of development and the policies implemented. According to Nathaniel et al. (2021b), the relationship between EQ and HC in China does not always align with the theory that HC can reduce pollution. Moreover, Hao et al. (2021) found that the connection between EQ and HC can vary and is highly dependent on the context. Furthermore, Ahmed et al. (2021) suggests that HC is generally believed to improve EQ, although the impact of HC may differ in developing countries.

Equally important, studies on the relationship between EG and HC indicate that the quality of education, as part of HC, plays a crucial role in EG (Fukao et al., 2021). However, there is also evidence that increased HC does not always translate into higher EG in some countries (Ali et al., 2018). This finding is reinforced by Bucci et al. (2019), which found that, although there is generally a positive relationship, results vary significantly between countries and over time, suggesting that HC does not always have a direct correlation with EG. Further research by Wegari et al. (2023), which developed an EG model incorporating HC, shows that while the relationship is generally positive and consistent, improved HC is associated with EG in major cities, but this finding does not always hold outside of cities or in countries with different levels of development. This challenges the notion that HC always has the same positive effect (Prasetyo & Kistanti, 2020).

According to various previous studies, which highlight the complexity and uncertainty in the relationship between EQ, EG, and HC, it is evident that differences in methodology, country context, policies, and time often lead to differing findings. Against this background, the novelty of this research lies in integrating a causality analysis that simultaneously connects the three key dimensions—EQ, EG, and HC. Many previous studies have tended to focus on these dimensions separately; however, this research provides a more comprehensive understanding of how they interact and form a complex cycle. This study also focuses on the context of Indonesia, although similar research could be conducted in other developing countries or advanced economies. It offers relevant and specific insights into policy in Indonesia due to factors such as environmental diversity, rapid economic dynamics, and challenges in HC development. This is crucial for developing strategies that are suited to the local situation. The study is innovative in that it not only focuses on theory but also on practical applications for designing effective SD policies in Indonesia. Its main objective is to highlight the policy implications of the identified relationships, particularly in the context of SD, and to provide more integrated and holistic policy recommendations.

Based on the explanation above, this study aims to identify and analyse the causal relationships between EQ, EG, and HC in Indonesia. By employing causality analysis methods, the goal of this research is to provide a better understanding of how these three dimensions interact with each other and how this interaction impacts SD policies. This study is expected to offer valuable recommendations for policymakers. By integrating these three dimensions, the research not only enhances theoretical understanding of the relationships among EQ, EG, and HC but also provides practical guidance for policymakers in designing more effective SD strategies in Indonesia. Effective policies will also assist Indonesia in achieving its SD goals and addressing challenges arising from globalization and climate change.

Based on the explanations above, the question this research will address is how the causality between EQ, EG, and HC in Indonesia supports the implications for sustainable development policies in Indonesia, with the following hypotheses (H):

H1: There is causality between EQ and EG
H2: There is causality between EQ and HC
H3: There is causality between EG and HC

2. Methodology

2.1 Data and Variables

Data and variables are two fundamental concepts in research that are closely related. Data refers to a collection of numerical information, while a variable is an attribute measured in a study. Therefore, data represents or results from the measurement of variables as elements to be analysed. This study uses panel data, which includes longitudinal or time-series cross-sectional data because it combines elements from multiple units over various points in time. The data is sourced from Statistics Indonesia (Badan Pusat Statistik). Data relevant to the research topic is often available only in limited quantities or for specific periods. If official or relevant data is only available from 2017 to 2023, this period will be used to ensure the accuracy and completeness of the data. Then, the cross-section comprises 34 provinces in Indonesia, resulting in a total of 238 observations. Moreover, all variables in this study are endogenous because their values are influenced by other variables in the model or system being analysed. In an economic context, endogenous variables are often the focus of analysis because they are affected by other variables in the model. Based on this explanation, the focus of this study is on EQ, EG, and HC. Figure 1 provides a simplified depiction of the previous explanation to offer a clearer understanding of the relationships among the variables in this study.

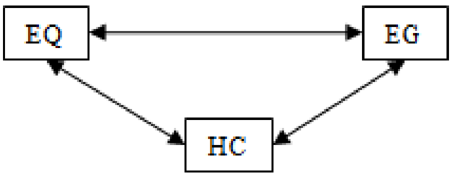

Figure 1. Relationships among variables

Table 1 outlines the operational definitions of each research variable based on the relationships among the variables shown in Figure 1. This is done to provide a clearer understanding of how these variables will be measured and observed in this study.

Table 1. Operational definitions of variables

Variable	Description
EQ	Strategies for reducing disaster risk selected and implemented by local governments, measured as a percentage
EG	Regional Gross Domestic Product per capita at constant 2010 prices, measured in thousands of rupiah
HC	Average years of schooling for the population aged 15 years and over, measured in years

2.2 Analysis Model

The analysis model in this study is derived from the relationships among the variables shown in Figure 1, which includes three equations, namely:

$$EQ_{it} = \alpha_{01i} + \sum_{j=1}^{p} \beta_{01i} EQ_{i,t-j} + \sum_{j=1}^{p} \gamma_{01i} EG_{i,t-j} + \sum_{j=1}^{p} \sigma_{01i} HC_{i,t-j} + \varepsilon_{01t} \quad (1)$$

$$EG_{it} = \alpha_{02i} + \sum_{j=1}^{p} \beta_{02i} EQ_{i,t-j} + \sum_{j=1}^{p} \gamma_{02i} EG_{i,t-j} + \sum_{j=1}^{p} \sigma_{02i} HC_{i,t-j} + \varepsilon_{02t} \quad (2)$$

$$HC_{it} = \alpha_{03i} + \sum_{j=1}^{p} \beta_{03i} EQ_{i,t-j} + \sum_{j=1}^{p} \gamma_{03i} EG_{i,t-j} + \sum_{j=1}^{p} \sigma_{03i} HC_{i,t-j} + \varepsilon_{03t} \quad (3)$$

where:
t: period;
i: cross-section;
i, t-j: lagged values of the variable;
α: constant;
β, γ, σ: coefficients;
p: number of lags;
ε: residual.

2.3 Data Analysis Techniques

The data analysis techniques in this study are derived from Figure 1 and Eqs. (1) to (3) previously explained. The application of the VAR approach is most suitable for achieving the objectives set in this study. VAR is a data analysis method used to model and analyse the dynamic relationships among various variables. This method is particularly useful because it can capture interactions between different variables and identify patterns and effects among them. The following are the steps to be followed when using the VAR method:

2.3.1 Stationarity test

The stationarity test helps determine whether the data remains stable over time. For accurate analysis, the data must be stationary, meaning its statistical properties remain consistent over time. In this study, stationarity is tested using the Phillips-Perron (PP) test. If the data is found to be non-stationary, transformations or differencing will be applied to achieve stationarity before proceeding to the next testing stages. Results are interpreted based on the probability (P) value, where if the $P < 0.05$, the data is considered stationary.

2.3.2 Optimal lag

Optimal lag helps balance the complexity of the model with its ability to predict accurately, allowing the model to capture significant patterns and structures in the data and improve prediction accuracy. Several criteria are used to select the best lag in this study, including the Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), and Hannan-Quinn Information Criterion (HQ).

2.3.3 Stability test

To produce reliable and consistent results, the VAR model must be stable. Assessing the stability of the VAR model is a crucial part of model validation. The stability condition of the VAR model is examined through the characteristic roots, where if the modulus of all roots is less than 1, the VAR system is considered stable.

2.3.4 Granger causality test

In the VAR model, the Granger causality test helps understand the causal relationships between variables in the system. It provides insight into how one variable affects another and aids in developing better models, evaluating policies, and conducting more in-depth system dynamics analysis. The main point of the Granger causality test is to determine whether endogeneity occurs when there is a feedback relationship between variables in the model. Results are interpreted based on the P value, where if the value of $P < 0.05$, the variable is considered significant.

2.3.5 Cointegration test

In the context of VAR, the cointegration test is used to determine whether there is a long-term relationship among several time series variables that are integrated at the same level. When variables are individually integrated but can form a stationary linear combination, this is known as cointegration. Results are interpreted based on the P value, where if $P < 0.05$, the data is considered cointegrated, and a restricted VAR model is used. Conversely, if the data is not cointegrated, a standard VAR model will be applied.

2.3.6 Impulse Response Function (IRF)

The IRF is a method used to examine how a shock to one variable in the VAR system affects other variables in the system over time. Additionally, the IRF shows the dynamics and dispersion of the impact of shocks within the system.

2.3.7 Variance Decomposition (VD)

VD is a VAR analysis technique that determines the extent to which shocks to each variable contribute to the variability or uncertainty in the forecast of other variables within the VAR system. This technique helps understand how shocks to one variable impact other variables in the long term.

3. Results

3.1 Descriptive Statistical Analysis

This section begins with an explanation of the descriptive statistics to provide an overview of the data for each variable analysed in this study. However, the descriptive statistics are primarily focused on aggregates at the provincial or national level. The goal is to help identify patterns and general trends in the data. By analyzing the data on a national level, it becomes possible to see how the data behaves overall, such as trends of increase or decrease and seasonal patterns as shown in Table 2.

Table 2. Descriptive statistics of research variables

Data Description	Variable		
	EQ	EG	HC
Mean	24.41	58392.86	8.74
Std. Dev	22.61	45193.75	0.30
Skewness	1.97	2.63	-0.04

The descriptive data information in Table 2 will be explained for each variable. First, the EQ in the dataset is relatively low, with an average of only 24.42% and substantial variation in the data, as indicated by a standard deviation of 22.61. This suggests that EQ can vary significantly from one observation to another. Additionally, a skewness value of 1.97 indicates that the data distribution is positively skewed, with a tendency towards a longer right tail. Second, the average EG for the analysed data is approximately 58,392.86 thousand rupiah, with a standard deviation of 45,193.75 thousand rupiah and a skewness of 2.63. This indicates that the distribution of EG is asymmetric, with a long right tail. Most of the data cluster around lower values, while higher values are more dispersed. Third, the HC analysed has an average of 8.74 years, with an annual standard deviation of 0.30, indicating relatively small variation in HC. Most HC data are close to the average, and a skewness of -0.04 suggests that the data distribution is nearly symmetric, with no clear tendency to deviate to the right or left. Fourth, with a standard deviation of 0.88 points, the variation in INS is relatively small, and the average is 8.83 points per year, reflecting the overall level of INS. Most of the data are centred around the average of 8.83 points, with minor variation. There is no clear tendency for the distribution to skew right or left, with a skewness of -0.01.

3.2 Stationarity Test Results

The stationarity test is conducted to ensure that the results obtained from the model are valid and accurate. Stationary data typically exhibit stable characteristics over time, making it easier to predict relationships among variables. Table 3 presents the results of the stationarity test for this study.

Table 3. Stationarity test results

Variable	Level		1st Difference	
	PP	P	PP	P
EQ	33.1030	0.9937	105.437	0.0000
EG	160.273	0.0000	-	-
HC	41.7268	0.9950	157.182	0.0000

Table 3 summarizes the results of the stationarity test. EQ and HC were found to be non-stationary at level, requiring further testing at the 1st difference. After this adjustment, stationarity was achieved for both variables. Meanwhile, EQ was stationary at level, so it did not require differencing. Based on this, all analyzed variables are stationary at the 1st difference category, meeting the stationarity prerequisites needed to proceed with the VAR analysis and the optimal lag test.

3.3 Results of the Optimal Lag Test

To enhance the model's reliability and predictive effectiveness, determining the optimal lag is crucial for accurately capturing the dynamics among variables. Table 4 presents the results of the optimal lag analysis for this study.

Table 4. Optimal lag test results

Lag	LogR	LR	FPE	AIC	SC	HQ
0	-140.0935	NA	0.001081	1.683452	1.738790	1.705908
1	788.5851	1813.655	2.16e-08	-9.136295	-8.914945*	-9.046474
2	805.9724	33.34272*	1.96e-08*	-9.234969*	-8.847606	-9.077782*

For the variables in this study, the results of the optimal lag test are shown in Table 4. The LR, FPE, AIC, and HQ criteria indicate that the optimal lag is 2, while the SC criterion suggests a lag of 1. The analysis results show that the criteria for determining the optimal lag are more dominant at lag 2.

3.4 Results of the Stability Test

The stability test for the validity and accuracy of long-term predictions, as shown in Table 5 and Figure 2.

Table 5. Stability test results

Root	Modulus
0.983648 – 0.002844i	0.983652
0.983648 + 0.002844i	0.983652
0.696448	0.696448
0.173653	0.173653
-0.013604 – 0.144902i	0.145539
-0.013604 + 0.144902i	0.145539

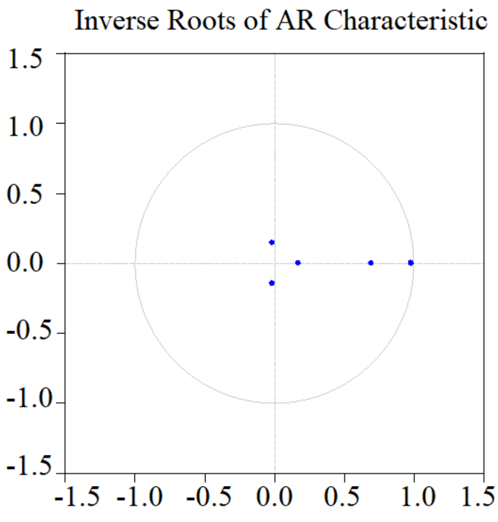

Figure 2. Stability graph

Table 5 summarizes the results of the stability test, showing that no characteristic roots or moduli exceed 1. Additionally, Figure 2 illustrates that the roots of the AR polynomial are within the unit circle. Based on this overall explanation, it is confirmed that the analytical model built is stable.

3.5 Results of the Causality Test

Table 6 presents the results of the causality test for this study, illustrating how variables interact with one another and aiding in making more informed and evidence-based decisions.

Table 6. Granger causality test results

Null Hypothesis	Observation	F-Statistic	P
EG does not Granger Cause EQ	170	9.53583	0.0002
EQ does not Granger Cause EG		3.41287	0.0370
HC does not Granger Cause EQ	170	5.35269	0.0062
EQ does not Granger Cause HC		4.60521	0.0123
HC does not Granger Cause EG	170	8.29563	0.0004
EG does not Granger Cause HC		1.39429	0.2509

First, there is a causal relationship between EQ and EG, indicating that they influence each other. The complex interaction between these two variables results in mutual interdependence. Environmental externalities related to EG can impact EQ, while improvements in EQ can support EG. Specifically, EG is driven by the accumulation of capital, including NR from the environment. Environmental externalities of EG can degrade EQ, which in turn can affect human health and productivity. This is because EG often requires intensive use of NR, such as fossil fuels, water, and land. Excessive exploitation can lead to risks like air and water pollution, deforestation, and ecosystem damage. These conditions subsequently lead to a decline in EQ. Air and water pollution can cause diseases, increasing healthcare costs and reducing work productivity, potentially impacting EG. Conversely, EG driven by environmentally friendly technologies or investments in renewable energy can enhance EQ, making the integration of environmental policies and SD strategies crucial for creating a mutually supportive relationship between the two. These findings are consistent with previous research, such as Wen et al. (2021), which indicates that rapid EG can lead to land use changes, such as deforestation for agricultural or residential purposes, affecting biodiversity loss and EQ. Additionally, Kurniadi et al. (2021) highlights that good EQ is essential for sustaining NR, which supports EG through productive economic activities.

Second, there is a causal relationship between EQ and HC, indicating that they influence each other in various ways. Good EQ, such as clean air, clean water, and a healthy environment, supports public health. Good health, in turn, enhances productivity and HC capacity. Conversely, a polluted or poor environment can lead to health problems, reducing productivity and quality of life. Moreover, maintaining EQ can create better conditions for teaching and learning processes. People growing up in a healthy environment are more likely to reach their full educational potential, thereby improving HC. On the other hand, high-quality HC contributes to the development and implementation of environmentally friendly technologies. Additionally, the causality can also be observed in the economic and welfare sectors, where EQ can affect EG and job opportunities. A good environment can attract investment and support sustainable industries. This contributes to improved HC quality as people have more opportunities for good jobs and better access to services. This, in turn, encourages individuals to develop their skills more effectively. Improved HC can then be used to sustain and enhance EQ. These findings align with previous research, such as Ahmed & Wang (2019), which suggests that good EQ supports effective HC development, while high-quality HC can contribute to the preservation and improvement of EQ. Additionally, Kuziboev et al. (2023) found that a healthy ecosystem can provide the resources needed for quality HC, aiding in the management and preservation of EQ.

Third, there is no causal relationship between EG and HC, as EG does not significantly affect HC. This condition occurs because EG is not always evenly distributed across different segments of society. If EG benefits only certain groups, such as large companies or wealthy individuals, while other groups do not experience these benefits, investments in education—an element of HC—may not increase significantly for less fortunate groups. Even if EG increases, issues such as unemployment or underemployment can persist if HC does not align with labor market demands. Irrelevant skills or lack of access to training can hinder individuals' ability to take advantage of available opportunities, thereby limiting the impact of EG on the enhancement of HC. Additionally, EG can be driven by substantial investments in infrastructure, industries, or specific sectors, which may not always be directly related to the improvement of HC quality. If economic policies focus more on developing certain sectors without prioritizing HC development, EG may occur without significant changes in the quality of HC. On the other hand, HC significantly affects EG because high-quality HC, such as skills and knowledge, enables workers to perform their jobs more efficiently and effectively. This increases labour productivity, which is a key factor in EG. Furthermore, good education and skills foster innovation and creativity. Individuals with knowledge and skills are more likely to develop new technologies, production methods, and business processes that enhance efficiency and create added value, driving EG. Skilled and educated workers are better equipped to handle complex and technical tasks, which is crucial for rapidly growing economic sectors such as technology and advanced manufacturing. Additionally, investments in education and training improve HC quality, which in turn creates a more competent workforce. A skilled workforce can attract foreign investment and facilitate EG through job creation and increased competitiveness. Conversely, good HC also contributes to economic efficiency. With the right skills and knowledge, individuals can work in a more organized and planned manner, reducing resource wastage and improving economic outcomes. These findings align with previous research, such as Ibrahim (2018), which indicates that high-quality HC enhances efficiency, innovation, and adaptability in the economy—factors crucial for sustainable EG and improved living standards. Moreover, Lima et al. (2021) found that strong HC contributes to the growth of specific sectors in the economy, such as information and communication technology, which drives faster innovation and economic expansion.

3.6 Results of Cointegration Test

In a VAR system, the cointegration test helps determine whether there is a long-term stable relationship among the variables. This is important because, although the variables individually may not be stationary, they might exhibit a stable long-term relationship. The results of the cointegration test for this study are presented in Table 7.

Table 7. Results of Cointegration Test

Hypothesized No. of CE(s)	Eigenvalue	TS	0.05 CV	P
None *	0.275581	54.42429	29.79707	0.0000
At most 1	0.072864	10.57993	15.49471	0.2387
At most 2	0.002136	0.290839	3.841466	0.5897

Based on the information in Table 7, the p-values are greater than 0.05 for "at most 1" and "at most 2," which are 0.2387 and 0.5897, respectively. Therefore, it is concluded that there is no cointegration, and the model for this study uses the standard VAR model.

3.7 Results of IRF Test

The purpose of the IRF analysis is to provide a better understanding of the dynamics and interactions among variables in the VAR model. This helps in gaining insights for better planning and assists in evaluating and designing effective policies. Figure 3 shows the results of the IRF test for this study.

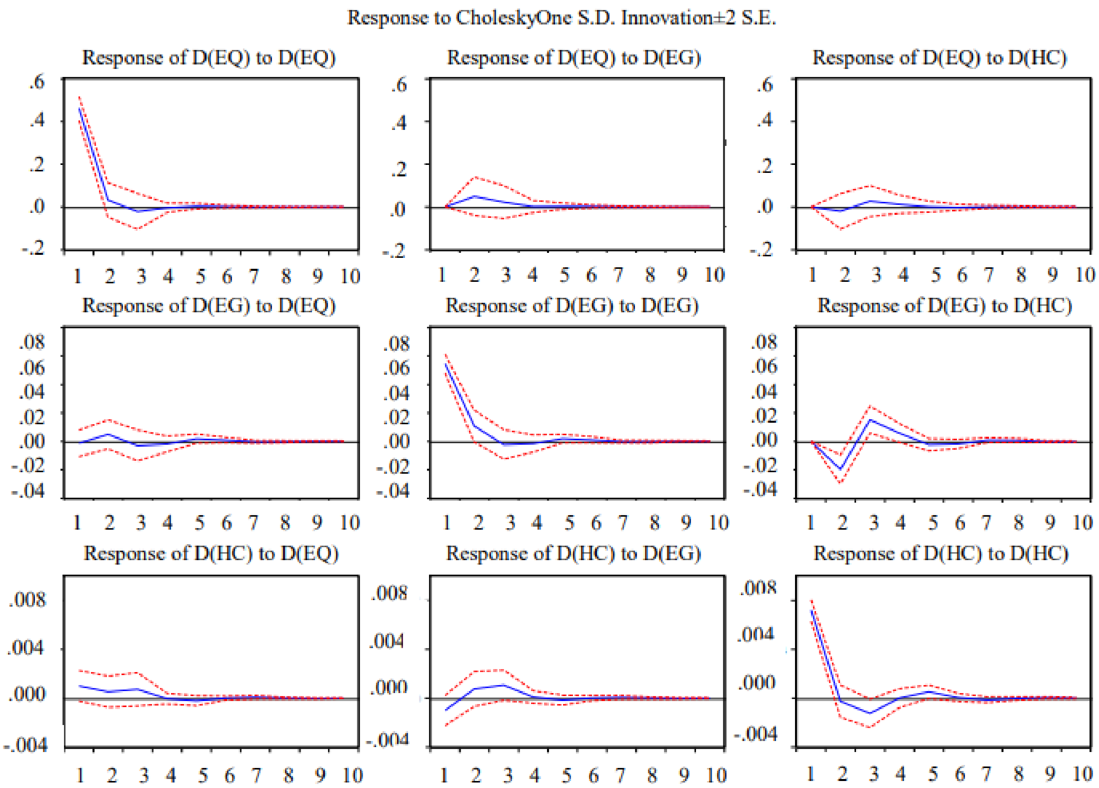

Figure 3. IRF graph

Several important points are found, as shown in Figure 3, including the EQ response to EQ shocks in the D(EQ) to D(EG) response panel for ten months, the tendency of EG to respond to EQ shocks and reach equilibrium with positive responses from the fourth month to the end of the period. This differs from HC when responding to EQ shocks in the D(EQ) to D(HC) response panel for ten months. HC tends to respond positively to EQ shocks in the second month but begins to respond positively in the third and fourth months and reaches equilibrium with positive responses until the end of the period. In addition, except for the first, third, and fourth months, EQ tends to respond positively to EG shocks in the D(EG) to D(EQ) response panel for ten months. However, in the fifth month, things start to return to normal with positive responses until the end of the period. For ten months, HC responds to EG shocks in the D(EG) to D(HC) response panel. In the third to fourth months, HC tends to respond negatively to EG shocks, and in the sixth month, HC gets closer to equilibrium with positive responses until the end of the period. In addition, for ten months, EQ received positive shocks when responding to HC shocks on the D(HC) to D(EQ) response panel. Except for the fourth to fifth and sixth periods, EQ has reached equilibrium with positive responses until the end of the period. Finally, for ten months, EG responded to HC shocks on the D(HC) to D(EG) response panel. Except for the first period, EG tended to respond positively to HC shocks; however, in the fourth period, EG is getting closer to the equilibrium point with positive responses until the end of the period.

3.8 Results of VD Test

The goal of the VD analysis is to determine the relative contribution of each variable in explaining the variability or uncertainty of the target variable's predictions. The results of the VD analysis for this study are shown in Table 8.

Table 8. Results of VD test

		VD of D(EQ)		
Period	**S.E.**	**D(EQ)**	**D(EG)**	**D(HC)**
1	0.462319	100.0000	0.000000	0.000000
2	0.466518	98.68569	1.119575	0.194734
3	0.468346	98.13512	1.338368	0.526508
4	0.468522	98.06804	1.338345	0.593620
5	0.468544	98.06411	1.341768	0.594123
6	0.468559	98.05931	1.343996	0.596692
7	0.468559	98.05915	1.344080	0.596768
8	0.468560	98.05871	1.344092	0.597199
9	0.468560	98.05870	1.344094	0.597204
10	0.468560	98.05867	1.344102	0.597229
		VD of D(EG)		
Period	**S.E.**	**D(EQ)**	**D(EG)**	**D(HC)**
1	0.054512	0.067504	99.93250	0.000000
2	0.059161	0.729442	81.41300	11.12696
3	0.061200	0.924526	81.41397	16.56698
4	0.061524	1.011517	81.41479	17.28033
5	0.061628	1.095568	81.42494	17.37431
6	0.061671	1.112611	81.44253	17.44486
7	0.061678	1.117006	81.53012	17.45805
8	0.061683	1.118680	81.70815	17.46653
9	0.061683	1.119042	82.50849	17.46698
10	0.061683	1.119245	88.14360	17.46776
		VD of D(HC)		
Period	**S.E.**	**D(EQ)**	**D(EG)**	**D(HC)**
1	0.007335	1.910182	1.887624	96.20219
2	0.007396	2.371074	2.914961	94.71396
3	0.007612	3.153428	4.713371	92.13320
4	0.007613	3.155679	4.726756	92.11756
5	0.007635	3.210800	4.743158	92.04604
6	0.007635	3.210844	4.743368	92.04579
7	0.007637	3.218188	4.749041	92.03277
8	0.007637	3.218204	4.749226	92.03257
9	0.007637	3.218756	4.749478	92.03177
10	0.007637	3.218762	4.749488	92.03175

The results of the VD are in Table 8. First, based on VD D(EQ), it is observed that EQ is the variable expected to contribute the most to EQ over the next ten months, with an average monthly contribution of 98.77 percent. This is followed by contributions from HC at 0.81 percent and EG at 0.43 percent. This indicates that EQ makes the largest monthly contribution, although its contribution gradually decreases. Second, according to VD D(EG), the variable predicted to provide the greatest contribution to EG over the next ten months is EG itself, with an average monthly contribution of 96.81 percent. Contributions from HC at 3.35 percent and EG at 0.57 percent follow. However, the monthly contribution of EG is declining, which is the opposite of the previous year's contribution. Third, based on VD D(HC), HC provides the largest average monthly contribution at 95.95 percent, followed by contributions from EG at 3.03 percent and EQ at 1.02 percent. This condition indicates that HC provides the largest average monthly contribution, but its contribution decreases each month, in contrast to EG and EQ.

4. Conclusion

The conclusions of this study are based on three key points derived from the analysis conducted. First, there is a causal relationship between EQ and EG, meaning that a better environment can support EG and economic activities, whereas poor management of the environment can lead to a decrease in EQ. Second, there is a causal relationship between EQ and HC, meaning that good EQ contributes to enhancing individual learning capabilities, while low HC results in a lack of awareness, inefficient management practices, minimal innovation, and less effective decision-making regarding EQ. Third, only HC affects EQ, which is suspected to be because EQ might not be sufficiently poor to significantly impact HC; if the environment is relatively clean and there are no severe environmental health issues, its impact on education or skills may not be apparent.

To improve EQ, this study recommends implementing sustainable NR management practices. This includes focusing on the rehabilitation and conservation of critical ecosystems such as forests, peatlands, and coral reefs through reforestation programs, forest protection, and effective national park management. These measures should be supported by strict environmental regulations, including penalties for violators and incentives for those who adopt environmentally friendly practices. To enhance EG, it is advised that community-based development projects consider sustainability as well as local needs and potential. Engaging local communities in resource management and environmental protection will support long-term sustainability. These policies should also be accompanied by strengthening the capacity of government institutions and environmental agencies to implement policies and programs more effectively. Finally, for HC, it is recommended that sustainability and ecological education be incorporated into school and university curricula to equip the younger generation with the knowledge and skills to contribute to sustainability solutions. Additionally, collaboration between educational institutions and industries in research and development can accelerate the adoption of innovations supporting sustainability and provide practical experience for students and professionals. Based on these policy recommendations, it is crucial to design policies that holistically consider EQ, EG, and HC. By doing so, Indonesia can create a conducive environment for sustainable EG, improve the quality of life for its citizens, and fully leverage HC potential. Integrated and forward-thinking policies will help Indonesia achieve its SD.

This study faces several limitations that should be considered for future research. One limitation is the VAR model's reliance on the assumption that relationships between variables remain stable over time. If there are structural changes or major policy shifts during the study period, the model may not accurately capture the effects of such changes. Additionally, the findings of this study may not be generally applicable to other countries with different conditions or to different periods without considering specific local contexts. Furthermore, while the VAR model is useful for analysing dynamic relationships between variables, it may not always capture all the complex aspects of EQ, EG, and HC. For example, the model may be less effective at addressing non-linear relationships or unobserved variables.

Author Contributions

Suhatman, correspondent and first author, has contributed in preparing the research conceptual framework, results and discussion. S. Amar, the second author, has contributed in preparing all tables, figures, introduction, materials and methods. H. Aimon, the third author, has contributed to preparing the conclusions and references.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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