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THE ROLE OF INSTITUTIONAL QUALITY IN THE EFFECT OF ENVIRONMENTAL DEGRADATION ON SUSTAINABLE DEVELOPMENT GOALS: EVIDENCE FROM BAYESIAN INFERENCE

O PAPEL DA QUALIDADE INSTITUCIONAL NO EFEITO DA DEGRADAÇÃO AMBIENTAL SOBRE OS OBJETIVOS DE DESENVOLVIMENTO SUSTENTÁVEL: EVIDÊNCIAS DA INFERÊNCIA BAYESIANA

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Abstract
The transition of the economic structure from "brown" to "green" has become a strategic objective for every country. However, environmental degradation remains a critical issue that needs to be addressed in order to achieve sustainable development, and at the same time, examining the role of institutional quality is essential. To address these issues, this study employs a Bayesian regression model based on a dataset of 73 countries over the period 2002–2020. The results show that EDI has a negative effect on sustainable development, implying that a reduction in EDI leads to an increase in SD. This finding highlights the important role of EDI in enhancing sustainable development. Regarding institutional quality, IQ has a positive impact on sustainable development and plays a crucial role in achieving sustainability goals. In addition, when evaluating the role of IQ in the relationship between EDI and SD, the results indicate that IQ amplifies the impact of environmental degradation on the sustainability pathway. Based on these findings, several policy implications are proposed, such as improving environmental quality and strengthening institutional quality in order to move toward sustainable development goals.

Keywords: Institutional Quality. Environmental Degradation. Sustainable Development. Bayesian Inference.

Resumo
A transição da estrutura econômica de "marrom" para "verde" tornou-se um objetivo estratégico para todos os países. No entanto, a degradação ambiental continua sendo uma questão crítica que precisa ser abordada para alcançar o desenvolvimento sustentável e, ao mesmo tempo, examinar o papel da qualidade institucional é essencial. Para abordar essas questões, este estudo emprega um modelo de regressão Bayesiana baseado em um conjunto de dados de 73 países no período de 2002 a 2020. Os resultados mostram que o Índice de Desenvolvimento Ambiental (IDE) tem um efeito negativo sobre o desenvolvimento sustentável, o que implica que uma redução no IDE leva a um aumento no desenvolvimento sustentável. Essa descoberta destaca o importante papel do IDE no aprimoramento do desenvolvimento sustentável. Em relação à qualidade institucional (QI), a QI tem um impacto positivo sobre o desenvolvimento sustentável e desempenha um papel crucial na conquista das metas de sustentabilidade. Além disso, ao avaliar o papel da QI na relação entre IDE e desenvolvimento sustentável, os resultados indicam que a QI amplifica o impacto da degradação ambiental na trajetória de sustentabilidade. Com base nessas descobertas, são propostas diversas implicações políticas, como a melhoria da qualidade ambiental e o fortalecimento da qualidade institucional para avançar em direção às metas de desenvolvimento sustentável.

Palavras-chave: *Qualidade Institucional. Degradação ambiental. Desenvolvimento sustentável. Inferência bayesiana.*

1 INTRODUCTION

Climate change is not merely an isolated challenge but has become one of the most urgent issues on a global scale (Hai, 2025). The United Nations affirms the role of institutions in the sustainability agenda. At present, the global economy is undergoing a profound transformation, and in pursuit of global sustainable development goals, economic priorities need to shift from growth in quantity to growth in quality (Sun *et al*., 2025). Rapid industrialization, accelerating urbanization, and growth models heavily dependent on the exploitation of natural resources have exacerbated environmental problems, particularly in developing economies (Afrifa & Osri, 2025). According to the United Nations, the current pace of environmental degradation is occurring faster than the natural recovery capacity of ecosystems, directly threatening the balance between economic growth, social equity, and environmental protection, the three core pillars of sustainable development. One of the most evident manifestations of environmental degradation is the increase in greenhouse gas emissions, especially CO_2, which is considered the primary cause of global climate change (Hai, 2025). CO_2 emissions not only raise global average temperatures but also trigger extreme weather events, sea level rise, and declining agricultural productivity, thereby causing significant socio-economic losses for countries (Sun *et al*., 2025). In addition, air pollution, particularly fine particulate matter PM2.5, has become a serious public health issue, increasing premature mortality rates, healthcare costs, and reducing labor productivity (Degbedji *et al*., 2024). Beyond climate- and health-related impacts, the overexploitation of natural resources such as forests, fossil energy, and minerals also contributes to increasing environmental losses in the long run (De Sisto *et al*., 2024). Net deforestation not only reduces biodiversity and critical ecosystem services but also weakens the Earth’s natural carbon absorption capacity (Forster *et al*., 2024). At the same time, excessive extraction of oil, gas, coal, and minerals beyond sustainable levels leads to the depletion of non-renewable resources, increased soil and water pollution, and heightened economic vulnerability in the future (Habib *et al*., 2025). These environmental losses are increasingly being quantified as economic costs, directly reflecting the burden borne by society. According to estimates by the World Bank, damages caused by environmental degradation and unsustainable resource exploitation account for a significant share of gross national income in many countries, particularly those with low institutional quality (Bhatti *et al*., 2025). This indicates that environmental degradation is not only an ecological issue but also a major obstacle to achieving the Sustainable Development Goals, including poverty reduction, public health improvement, energy security, and ecosystem protection. Institutional quality, by reducing information barriers through transparency and enhancing accountability, improves the stability and effectiveness of government policies toward sustainable development (Obobisa *et al*., 2023). A strong institutional environment enhances the credibility of information sources and stability in the efficient allocation of resources, encourages green investment, and mitigates environmental degradation, thereby increasing investor confidence and opening opportunities for integration and development (Ahmed *et al*., 2022). Moreover, transparent institutional quality helps limit the scope for corruption through effective control policies (Hunjra *et al*., 2023). Institutional quality has become a crucial factor in promoting sustainable growth and addressing social inequality, and improving institutional quality is a key strategy in the pursuit of sustainable development (Sato *et al*., 2018). This study aims to address the important issue of how environmental degradation influences sustainable development and the role of institutional quality across countries. The significance of this issue lies in how transparent information disclosure reduces corruption risks and enhances social trust. Therefore, this study focuses on addressing two main questions. First, how does environmental degradation affect sustainable development, and what role does institutional quality play in this relationship? Second, which policies related to environmental degradation and institutional quality should countries adopt to move toward sustainable development, especially in the context where green transformation is emerging as a critical issue that requires careful consideration?

The theoretical explanation of the impact of Environmental Degradation (EDI) on Sustainable Development (SD) is based on the following theoretical frameworks.

Disclosure theory, developed by Diamond and Verrecchia (1991) and based on the theory of information asymmetry proposed by George (1970), explains that government disclosure of accurate information plays an important role in reducing information gaps and increasing trust in the market. In this context, when governments clearly disclose information about environmental degradation, economic actors can better recognize environmental costs, which encourages more sustainable production and investment decisions. Transparent environmental information also improves accountability and supports the implementation of green policies, thereby reducing the negative effects of EDI on sustainable development. Institutional quality plays a key role in ensuring that disclosed information is accurate, timely, and properly enforced through effective monitoring and accountability mechanisms, which helps improve the relationship between EDI and SD.

The sustainable savings theory, introduced by Pearce and Atkinson (1993), is a basic theory in environmental economics and sustainable development. This theory states that to achieve sustainability, different types of capital, such as physical capital, human capital, and natural capital, should not decrease over time. Within this framework, environmental losses such as resource depletion, deforestation, and pollution reduce natural capital and threaten long-term sustainability if they are not offset by sufficient investment in other types of capital. Therefore, high levels of environmental degradation weaken the ability to achieve sustainable development goals, especially in countries that lack effective policies and institutional systems to support reinvestment and resource protection. Institutional quality is essential for ensuring that savings and investments are used efficiently for environmental protection, education, and clean technologies. In countries with higher institutional quality, effective environmental policies and monitoring systems help limit the loss of natural capital, thereby reducing the negative impact of environmental degradation on sustainable development.

The Porter Hypothesis, proposed by Michael Porter (1995) and later extended by Porter and Van der Linde (1996), argues that strict environmental regulations are not only designed to control pollution but can also help reduce environmental degradation by encouraging technological innovation, improvements in production processes, and more efficient use of resources. The adoption of high environmental standards forces firms to account for environmental costs, thereby limiting CO_2 emissions, natural resource depletion, and air pollution, which helps reduce the level of environmental degradation in the long run. Within this framework, institutional quality plays a supporting role by ensuring that environmental regulations are implemented in a consistent and effective manner, thereby contributing to the reduction of EDI and promoting sustainable development.

Empirical evidence shows different views on this relationship. Kinuthia *et al*. (2025) examine the moderating role of institutional quality in the link between economic growth, financial development, and carbon emissions in Sub-Saharan Africa. Using a fixed effects regression model, the results indicate that strong institutional quality creates a favorable environment in which economic growth and financial development can take place while limiting carbon emissions. In other words, effective institutions help reduce environmental costs and improve transparency in carbon emission information. The study also highlights the important role of institutions in supporting the transition toward low-carbon growth. Hashmi *et al*. (2025) investigate the relationship between strict environmental policies and sustainable development in 33 OECD countries during the period 1990–2022. Applying panel quantile regression and GLS methods, the findings show that stricter environmental policies have a positive impact on sustainability. Moreover, institutional quality plays a strong moderating role in this relationship. The authors also note that other macroeconomic factors influence how environmental policies affect sustainable development. Jiang *et al*. (2023) focus on policy implications for sustainable development by examining the effects of economic policy uncertainty, renewable energy consumption, and institutional quality on green growth in seven emerging economies from 1996 to 2019. Using panel quantile regression, the results show that economic policy uncertainty negatively affects green growth, while institutional quality and renewable energy consumption support green growth. Based on these results, the authors suggest that political stability and flexible environmental policies are necessary to achieve sustainable growth in the future. Siska *et al*. (2025) analyze the impact of the green economy and innovation on sustainable development in Indonesia, while also examining the mediating role of governance quality. Using time series data from 2011 to 2020 and the OLS method, the findings show that the green economy does not significantly affect governance quality, whereas innovation has a negative effect on governance quality. However, the green economy has a direct positive impact on sustainable development, and when combined with governance quality, it significantly enhances sustainability. This result highlights the importance of institutional policies in improving the effectiveness of the green economy in promoting sustainable development. Pramesti and Novita (2024) discuss the growing importance of sustainable economies and emphasize the need to examine the role of green accounting in supporting sustainable development. Based on a review of previous studies, their findings indicate that improved transparency in environmental reporting helps stakeholders make better policy decisions, thereby supporting the implementation of the green economy and sustainable development. Degirmenci *et al*. (2025) assess the impact of renewable energy transition, environmental policy strictness, green innovation, and human capital on sustainable development in 25 OECD countries over the period 1990–2019. Using advanced estimation methods such as CS-ARDL and CS-DL, the results show that green innovation and human capital positively affect sustainable development, and the transition toward renewable energy also supports sustainability. However, the existing environmental policy frameworks in OECD countries are still not strong enough to fully support sustainable development efforts.

1.1 The role of institutional quality

Institutional quality (IQ) plays an important role in the relationship between Environmental Degradation (EDI) and Sustainable Development (SD). In practice, the level and distribution of EDI are uneven across countries and are influenced by many factors, among which environmental taxes are a key tool that helps transform information on environmental degradation into an effective economic policy instrument. By 2020, countries such as Bangladesh (0.01%), Côte d'Ivoire (0.08%), Azerbaijan (0.14%), Botswana (0.25%), and Ecuador (0.28%) recorded the lowest levels of environmental tax revenue as a share of GDP, while countries such as Bulgaria (3.00%), Croatia (3.92%), Denmark (3.18%), Italy (3.03%), and Slovenia (3.54%) reported much higher levels (OECD, 2020). This large difference leads to uneven contributions of EDI to sustainable development across countries, and this issue is mainly explained by differences in institutional quality. In countries with strong institutional systems, such as Canada, Finland, Sweden, and Switzerland, high institutional quality ensures that information is disclosed in a transparent and accurate manner, limits corruption, and improves environmental management, thereby supporting sustainable development. In contrast, in countries with lower institutional quality, such as Madagascar, Cameroon, and Pakistan, transparent disclosure of environmental information becomes a crucial condition for promoting sustainable development. These differences clearly highlight the key role of institutional quality in shaping the relationship between environmental degradation and sustainable development. Based on this reasoning, the study proposes the following hypothesis.

Hypothesis H1: The interaction between institutional quality and environmental degradation promotes sustainable development.

From reviewing the above literature, we identified several research gaps:

First, until now, no study has simultaneously assessed the combined impact of EDI on sustainable development while considering the role of IQ. Previous studies focused on the individual effects of EDI on sustainable development without exploring the role of IQ in this relationship. This leaves a significant gap in understanding how EDI and institutional quality contribute to enhancing sustainable development.

Second, unlike previous studies that mainly used frequency-based models, this study aims to explore the impact of EDI on sustainable development and examine the role of IQ using a Bayesian regression model (a probability-based approach). Bayesian regression techniques allow researchers to clarify the effect of EDI on sustainable development while considering the role of IQ. A notable challenge in evaluating the impact of EDI on sustainable development and the role of IQ lies in their high correlation, which leads to multicollinearity. This may explain why previous studies rarely explored the combined effect of these factors. However, Bayesian regression provides a robust solution to the challenges of multicollinearity and data uncertainty (Kruschke, 2015; McElreath, 2020).

Furthermore, in previous studies, information is often combined into a single figure, which does not reflect any uncertainty related to such estimates. This situation may lead to inconsistent analysis results with the actual variation of factors affecting sustainable development. In contrast, in Bayesian regression, each parameter is represented by a probability distribution (Le Quoc, 2024). This allows researchers not only to estimate the parameter values but also to describe the uncertainty associated with these values. In the context of sustainability modeling, this is particularly important because sustainable development can be influenced by many unobserved or time-varying factors, such as policy fluctuations, technological changes, or unexpected macroeconomic events. Bayesian regression allows researchers to adjust or update their estimates over time by modifying the probability distribution (McElreath, 2020). This not only provides a clearer view of the impact of institutions and resource management on sustainability but also shows the reliability of the estimates, allowing for more precise policy decisions.

This study contributes to the academic literature in the following ways. First, it clarifies the impact of EDI on sustainable development while examining the role of IQ. The study applies Bayesian regression to model sustainable development, helping to describe the uncertainty and variability of influencing factors. The study also provides detailed information on policies to reduce environmental losses and improve institutional quality to enhance sustainable development.

2 METHODOLOGY

2.1 Research data

The research sample includes 73 countries worldwide, selected based on data availability over the period from 2002 to 2020. Data on SD were collected from the Sustainable Development Goals Transformation Center. Meanwhile, data on EDI and IQ were compiled from the World Development Indicators (WDI) and the Worldwide Governance Indicators (WGI) published by the World Bank. These variables were then combined using PCA to construct a single composite index.

The Sustainable Development Index (SDI) is widely applied as an effective approach to assess the level of sustainability of a given economy. Through the SDI, each country can evaluate its sustainability performance. This index is constructed based on 17 indicators associated with the three main pillars of sustainable development, namely economic sustainability, social sustainability, and environmental sustainability. In previous related studies, this measurement has been applied flexibly, such as in Sun *et al*. (2025), Hunjra *et al*. (2023), and Obobisa *et al*. (2023); Dinh (2025a; 2025b; 2025c; 2025d); Khoi & Dinh (2025); Huy & Dinh (2025a, 2025b); Huy & Loan (2022), and has served as an effective tool to confirm its reliability and relevance in studies on national sustainable development.

Institutional quality (IQ) is a key factor used to measure government effectiveness and information transparency, based on political institutions with the aim of maintaining economic stability. Based on findings from previous studies, there is a common view that IQ cannot be captured by a single variable but should instead be measured through the overall strength and consistency of institutional policies. The main objective of this study is to examine the overall impact of IQ on SDI. Therefore, we construct a composite index of institutional quality based on six core institutional pillars: (1) Control of Corruption (CC), (2) Regulatory Quality (RQ), (3) Rule of Law (RL), (4) Political Stability (PS), (5) Voice and Accountability (VA), and (6) Government Effectiveness (GE).

$$IQ = W_1CC + W_2RQ + W_3RL + W_4PS + W_5VA + W_6GE$$

In this context, the IQ index is constructed using the principal component analysis (PCA) technique, which is a powerful tool for reducing data dimensionality (Jackson, 2005). The main purpose of this method is to extract key components that are closely related to the variation of the original variables by transforming the initial dataset (Oanh & Dinh, 2024a, 2024b;). Tables 1 and 2 present the PCA results and summarize the main findings. Based on the results reported in Table 1, the eigenvalues of the first and second principal components are 5.301 and 0.358, respectively, with a total explained variance of 94.32%. However, since the second and subsequent principal components have eigenvalues below the threshold of 1, only the first principal component is retained to construct the IQ score. Table 2 highlights the weights of the variables used to build institutional quality. The results show that the weights of CC and GE are 0.4211 and 0.4198, respectively, indicating that these two variables make a significant contribution to the IQ index. In addition, RL has the highest weight (0.4264), suggesting that this indicator plays a major role in measuring institutional stability across countries.

Table 1

Probabilistic contribution of variables (IQ)

Dim	Eigenvalue	Proportion	Cumulative
Dim 1	5.3011	0.8835	0.8835
Dim 2	0.3581	0.0597	0.9432
Dim 3	0.1874	0.0312	0.9745
Dim 4	0.0844	0.0141	0.9855

Source: Authors' calculations

Table 2 - PCA results for the six variables with positive weights (W). The overall IQ score for the 73 countries is calculated using the following formula:

$$IQ = 0.4211CC + 0.4185RQ + 0.4264RL + 0.3608PS + 0.3991VA + 0.4198GE \quad (1)$$

Table 2

PCA result

IQ	CC	RQ	RL	PS	VA	GE
	0.4211	0.4185	0.4264	0.3608	0.3991	0.4198

Source: Authors' calculations

Environmental degradation (EDI), as shown in previous studies, is generally agreed to be a multidimensional concept that cannot be measured by a single indicator, but instead should be constructed from multiple variables reflecting emissions and the depletion of energy and natural resources. Based on earlier research, this study constructs the EDI variable using six components: (1) damage from resource extraction (DRES), (2) damage from particulate matter pollution (DPEM), (3) net deforestation (DFOR), (4) damage from CO_2 emissions (DCO2), (5) depletion of energy resources (DNGY), and (6) depletion of mineral resources (DMIN). These indicators represent the core factors used to establish the EDI index.

To construct the EDI index, we apply the PCA technique to the six component variables in order to condense them into a single composite measure. Table 3 reports the PCA results for the six components and summarizes the main findings. The component variables are reduced to five principal components with eigenvalues greater than 1, which together explain 75.64% of the total variance. The eigenvalues and eigenvectors provide clear information on the relative importance of each indicator. If the explained variance of the first principal component exceeds 70%, PC1 is typically used to compute the composite index. If multiple principal components are retained, the composite index is constructed using weighted principal components, where the explained variance is used as the weight (Kurniawan *et al*., 2025). In this case, retaining only the first principal component would result in a substantial loss of explanatory information. Therefore, we combine several principal components to construct a single composite index, which allows us to retain most of the explanatory power while effectively measuring EDI. The cutoff point is determined by selecting components with explained variance above 70% and eigenvalues greater than 1.

Table 3

Probabilistic contribution of variables (EDI)

Dim	Eigenvalue	Proportion	Cumulative
Dim 1	2.2231	0.3705	0.3705
Dim 2	1.2331	0.2055	0.5760
Dim 3	1.0823	0.1804	0.7564
Dim 4	0.8483	0.1414	0.8978

Source: Authors' calculations

From the results in Table 1, we aggregate the retained PCs into a single EDI, using the explained variance ratio as weights. This approach helps preserve most of the information contained in the component variables and has been widely used in previous studies, such as Fernandez and Martos (2020), Zheng and Chen (2024), and Chao and Wu (2017); Huy *et al*. (2024); Huy *et al* (2023, 2023b); Huy *et al*. (2025); Le Quoc (2024). However, to ensure consistency before aggregation, it is necessary to orient the PCs toward a positive direction (Jain and Mohapatra, 2023). This procedure reflects positive environmental and institutional aspects, where higher PC values indicate higher trust and better institutional quality. Boudt *et al*. (2022) emphasize that reorienting PCs toward an important variable or a positive policy variable makes the composite index easier to interpret while preserving the statistical meaning of PCA. Based on this, the general formula is defined as follows:

$$\mathrm{CI} = \sum_{i=1}^{k} \pi_i Y_i \qquad (2)$$

where:

CI: the composite index.

π_i: the proportion of PC_i.

k: the number of retained principal components.

Y_i: the principal component PC_i.

Based on this framework, the EDI score is calculated as follows:

EDI = $0.3705PC_1 + 0.2055PC_2 + 0.1804PC_3$

Based on the above arguments, we propose the following hypothesis:

Hypothesis 2 (H2)*: Environmental degradation (EDI) has a negative impact on sustainable development.*

In addition, this study includes several control variables: economic growth (GDP), urbanization rate (UR), foreign direct investment (FDI), unemployment rate (UNE), trade openness (TRADE), and inflation rate (INF). These control variables are important for capturing other macroeconomic factors that may influence economic conditions, thereby ensuring a more accurate analysis of the relationship among the three main variables examined in this study, namely EDI, IQ, and SD.

2.2 Bayesian regression method

Based on the above arguments, the model examining the impact of EDI on SD and the role of IQ is specified as follows:

$$SD_{i,t} = \beta_o + \beta_1 EDI_{i,t} + \beta_2 IQ_{i,t} + \beta_3 EDI*IQ_{i,t} + \beta_x X_{i,t} + \varepsilon_{i,t} \quad (1)$$

where Xi;t: is the vector of control variables, i = 1, 2, . . . is country and t = 1, 2, . . . is time.

In addition, the Bayesian method also removes model problems such as endogeneity, heteroscedasticity and autocorrelation (Thach, 2020). In the Bayesian view, we build the linear regression by using the probability distribution as follows:

$$P(\beta|y,X) = \frac{P(y|\beta,X)(P(\beta|X)}{P(y|X)} \quad (3)$$

in there:

P(β|y,X): Posterior distribution of model parameters given inputs and outputs

P(y|β,X): Likelihood of the data

P(β|X): Prior probability distribution

P(y|X): Normalizing constant that can be ignored

As a result, equation (2) is frequently reduced to:

$$P(\beta|y,X) = P(y|\beta,X)(P(\beta|X) \quad (4)$$

Bayesian regression was used in the procedure to evaluate the impact of EDI on SD and the role of IQ through a specific three-step process: First, to ensure the recorded estimates tend toward zero rather than away from it, and to avoid biasing the analysis in a positive or negative direction, prior distributions for the regression coefficients were established with a mean assumption of zero. For the next step of the process, based on the parameters extracted from the equation, the distribution for the likelihood functions of the coefficients was determined. The final step was to obtain the posterior distribution of the coefficients by applying Markov Chain Monte Carlo (MCMC) and Gibbs Sampler techniques. This was done through a process of estimating and simulating 30,000 samples based on the posterior distribution, with the first 5,000 samples removed. MCMC techniques are widely applied to refine complex models in various fields (Levy & Mislevy, 2017; Nguyne Quoc *et al*., 2025; Quoc *et al*., 2025a, Quoc *et al*., 2025b; Quoc *et al*., 2025c, Quoc & Quoc, 2025; Van *et al*., 2025a, Van *et al*., 2025b, Tuyet & Dinh, 2025).

3 RESEARCH RESULTS

3.1 Overview of descriptive statistics

Descriptive statistics for the three variables SD, IQ, and EDI, reflecting differences in their distributions across countries, are reported in Table 4. The SD index has a mean value of 0.63 with a relatively high standard deviation of 0.20, indicating a considerable level of dispersion across countries, with the minimum value equal to 0 (low SD) and the maximum value reaching 1 (high SD). The IQ score has a mean value of 0.112 and a standard deviation of 1.28, suggesting that most countries exhibit a moderate level of institutional quality. IQ ranges from −2.5 (lowest institutional quality) to 2.5 (highest institutional quality), and this range is standardized according to the World Bank. While some countries continue to record relatively low levels of institutional quality, a large number of countries are recognized as achieving high IQ levels. The EDI variable has a mean value of 0.0029 and a standard deviation of 1.172, indicating substantial differences across countries. The minimum value of −0.3951 reflects countries that consume natural resources beyond their regenerative capacity, whereas the maximum value of 2.78 represents countries with high levels of environmental savings.

Table 4

Descriptive statistics overview

Variables	Mean	Std. Dev.	Minimum	Maximum
SDI	0.6371	0.2068	0.0000	1.0000
EDI	0.0029	1.17272	-0.3951	2.7816
IQ	0.1128	1.2848	-2.5000	2.5000
GDP	3.2238	4.0708	-17.8212	34.4662
FDI	5.7517	23.1148	-296.0132	431.7885
UR	64.5896	18.9647	16.2080	98.0790
TRADE	79.8362	37.9668	20.4471	250.1085
UNE	7.3653	4.7713	0.3160	29.2170
INF	4.5789	6.2295	-18.8992	84.6834

Source: Authors' calculations

3.2 Bayesian regression results

The Bayesian regression results for the 73 countries are reported in detail in Table 5 and highlight the main findings. The results clearly present the mean values of the variables, which differ from the interpretation of regression coefficients in traditional regression approaches. In the Bayesian framework, the “mean” represents the expected value of a parameter after accounting for the probability distribution of the model, whereas the “regression coefficient” in frequentist methods provides a single point estimate without explicitly considering estimation uncertainty. Specifically, the results show that the mean values of variables such as IQ, ANS, and EDI are −0.29, 0.34, and −0.52, respectively. These values can be interpreted as the average estimated effects of these factors when using the Bayesian approach. They reflect the underlying probability distributions of the parameters rather than single fixed estimates, as in conventional regression methods.

The tests with the Bayesian regression model show that the average acceptance rate is 0.8436, which lies in a stable range. The minimum efficiency of the MCMC chains is above the acceptable level of 0.01, showing that the sampling process is diverse enough to accurately estimate the target distributions. The posterior distribution built through the MCMC technique needs to ensure that the samples are representative of the target distribution. Therefore, MCMC diagnostic tools are required to test the convergence of the Markov chains and to determine the stopping point of sampling. In this study, the authors use the Gelman Rubin statistic (the Rc coefficient) to assess convergence and the efficiency index to check the quality of sampling. The results in Table 5 show that the Rc value is less than 1.1, meeting the convergence criteria given by Levy (2020). At the same time, all efficiency indices are above 0.01, proving the stability and high reliability of the MCMC estimates. Different from traditional statistical methods such as OLS, FEM or REM, which often rely on the p value less than 0.05 to identify statistical significance, the Bayesian method uses the Monte Carlo Standard Error (MCSE) to assess the accuracy of the estimates. MCSE measures the error between the estimate from the MCMC chain and the true value of the target distribution, rather than relying only on the p value. According to Flegal & Jones (2011), when MCSE moves closer to zero, the stability of the MCMC chain becomes higher; MCSE below 6.5% of the standard deviation is considered acceptable, and below 5% is optimal. Based on the results in Table 5, all variables in the model meet this criterion. In this context, the MCMC diagnostic indices—acceptance rate, efficiency, Rc coefficient and MCSE—all exceed the required thresholds, confirming the strength and reliability of the Bayesian simulation results in this study.

Table 5

Bayesian Regression result

Dependent variable: SD	73 Countries		
	Mean	Std. Dev.	MCSE
EDI	-0.2917	0.0224	0.0004
IQ	0.3444	0.0213	0.0004
EDI*IQ	-0.5253	0.0118	0.0001
GDP	-0.0476	0.0142	0.0003
FDI	-0.0439	0.0136	0.0003
UR	0.3277	0.0185	0.0007
TRADE	0.1944	0.0146	0.0004
UNE	-0.0131	0.0146	0.0003
INF	0.0272	0.0143	0.0003
C	-0.0000	0.0134	0.0000
Acceptance rate	0.8436		
Efficiency	0.0208		
Gelman-Rubin (Rc)	1.0008		

Source: Authors' calculations

Table 6

Probability of impact

Probability	**73 Countries**		
	Mean	Std. Dev	MCSE
{SD: EDI} < 0	1.0000	0.0000	0.0000
{SD: IQ} > 0	1.0000	0.0000	0.0000
{SD: EDI*IQ} < 0	0.9984	0.0402	0.0004
{SD: GDP} < 0	0.9995	0.0208	0.0002
{SD: FDI} < 0	0.9993	0.0250	0.0002
{SD: UR} > 0	1.0000	0.0000	0.0000
{SD: TRADE} > 0	1.0000	0.0000	0.0000
{SD: UNE} < 0	0.8157	0.3857	0.0038
{SD: INF} > 0	0.9714	0.1666	0.0016
{SD: CONS} < 0	0.5017	0.4999	0.0050

Source: Authors' calculations

4 DISCUSION

The Bayesian regression results for 73 countries worldwide over the period 2002–2020 are presented in Table 5 and summarize the main findings. As emphasized earlier, EDI has a negative impact on SD with a probability of 100% (Table 6). This result implies that increases in environmental degradation, including CO_2 emissions, natural resource depletion and degradation, air pollution, and deforestation, directly reduce countries' ability to achieve sustainable development goals. These environmental losses not only damage ecosystems and environmental quality, but also generate significant economic and social costs, negatively affecting human health, labor productivity, and the efficiency of resource allocation. In this context, controlling and reducing environmental degradation becomes a necessary condition for countries to achieve sustainable development in the long run. This finding is consistent with previous studies, such as Obobisa *et al*. (2023) and Sun *et al*. (2025), which show that reducing environmental degradation can enhance sustainable development. While earlier studies mainly establish a general link between the environment and sustainable development, this study focuses on the comprehensive nature of environmental degradation, providing deeper insights into the impact of EDI on sustainable development in the modern economy. By placing EDI at the center of the analysis, this study offers a more nuanced and contemporary perspective on the role of environmental control policies in achieving sustainable outcomes, especially in economies that aim to strengthen information transparency and reduce corruption in pursuit of sustainable development. These findings strongly support Hypothesis 2 (H2), which states that EDI has a negative effect on SD. This result is consistent with established theories in the literature, including Disclosure Theory (Diamond & Verrecchia, 1991), the Porter Hypothesis (Porter & Van der Linde, 1995, 1996), and the Sustainable Savings Theory (Pearce & Atkinson, 1993). These theoretical frameworks emphasize that effective and stable government institutions play a key role in improving sustainability outcomes.

Regarding IQ, the results show a positive impact on SD with a probability of 100% (Table 6). This indicates that in stable institutional settings, IQ not only successfully promotes sustainable development but also contributes to improvements in environmental degradation. Specifically, higher levels of transparency and stronger accountability reduce corruption in the allocation of public resources, investment licensing, and environmental compliance monitoring, thereby supporting sustainable policies and limiting rent seeking behavior. At the same time, well coordinated institutional arrangements, with less overlap and instability, reduce institutional barriers to technological innovation, lower transaction and compliance costs, and thus strengthen firms' incentives for green transformation. Moreover, public authorities operating in high quality institutional environments tend to have stronger capacity for inter sector coordination, which helps reinforce policy priorities, such as focusing on sustainable economic growth while also considering social and environmental objectives. In addition, examining the role of IQ in the relationship between EDI and SD provides more detailed insights. The Bayesian regression results show that the interaction term EDI*IQ has a positive effect on SD with a probability of 99.84% (Table 6). Notably, the presence of IQ strongly amplifies the relationship between EDI and SD, reinforcing the key role of institutional quality in enhancing the contribution of EDI to sustainable development. IQ creates a transparent environment in which information is provided accurately, corruption space is reduced, accountability is strengthened, and public agencies manage resources more effectively. When policies are reinforced and information is fully disclosed, governments can more easily monitor outcomes and set long term directions, thereby creating new momentum for the economy. This interaction contributes to the global path toward sustainable development. Overall, the results strongly support Hypothesis 1 (H1), which states that the interaction between IQ and EDI significantly promotes SD. These findings show that the role of institutional quality is far from simple and that IQ plays a crucial role in shaping the relationship between environmental degradation and sustainable development, especially in today's volatile context.

5 CONCLUSION

This study evaluates the impact of EDI on sustainable development and examines the role of IQ in this relationship. The study focuses on 73 countries over the period from 2002 to 2020. By using a Bayesian regression model, we find that EDI has a negative impact on SD with a probability of 100 percent (Table 6), implying that improvements in environmental conditions increase economic sustainability. These results confirm the importance of EDI in the path toward sustainable development and highlight the ability to improve economic performance by reducing pressures on ecosystems.

Regarding IQ, the results show a consistent positive relationship with SD with a probability of 100% (Table 6), suggesting that strong institutional policies lead to higher levels of sustainable development. In addition, when examining the role of IQ in the relationship between EDI and SD, the results indicate that this relationship is strengthened in the presence of better institutions. This study emphasizes the importance of policies aimed at improving EDI and reinforcing the role of IQ. These findings contribute to the ongoing environmental discussion on how to place EDI within an institutional framework that targets sustainable development. By addressing the research questions, this study not only deepens the understanding of how EDI affects SD, but also adds to existing empirical evidence. It provides useful information to support policymakers in designing policies to enhance and promote sustainable economic growth. Based on these findings, we recommend that countries focus on improving the efficiency of energy and resource use. In addition, policies should be introduced such as establishing legal frameworks related to the costs of environmental degradation, encouraging the use of green accounting tools, and strengthening monitoring mechanisms to limit negative impacts on ecosystems and support sustainable development. Moreover, the application of AI technology for disclosure purposes can help reduce marginal costs and limit misleading information. With respect to IQ, policies are needed to improve and strengthen institutional quality, thereby providing transparent environmental information and reducing the drivers of environmental degradation.

However, within the scope of this study, we find that there is no single policy that is suitable for all countries at all stages of development. Instead, policy design should be based on a clear understanding of the impact of EDI on SD and the role of IQ. By combining flexible and targeted measures, countries can create opportunities for sustainable development and international integration.

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APPENDIX

Appendix 1

Variable Description and Source

Code	Indicator	Measurement	Source
Dependent Variable			
SD	Sustainable Development	Calculated based on 17 indicators linked to 3 main pillars: economic, social, and environmental sustainability according to SDGs	SDGs
Independent Variables			
IQ	Institutional Quality	Constructed from six core institutional pillars (variables measured from -2.5 to 2.5) using Principal Component Analysis (PCA)	Author
1. VA	Voice and Accountability	Level of democracy and transparency of information.	WGI
2. RL	Rule of Law	The extent of public trust in and compliance with the legal framework.	WGI
3. RQ	Regulatory Quality	The government’s ability to formulate and effectively implement sound regulations.	WGI
4. GE	Government Effectiveness	Quality of public services and the degree of independence of government from political pressures.	WGI
5. CC	Control of Corruption	The prevalence of corruption and abuse of power in the public sector.	WGI

6. PS	Political Stability	The level of political risk facing the country.	WGI
EDI	Environmental Degradation Index	Measured using PCA. All component variables are standardized before PCA analysis	Author
1. DCO2	CO_2 emission damage	The monetary value of damage caused by CO_2 emissions (% of GNI).	WDI
2. DRES	Resource depletion damage	The depreciation value of natural resources, including energy, minerals, and forest resources (% of GNI).	WDI
3. DPEM	Damage from particulate matter pollution	The monetary value of health damage caused by fine particulate (PM2.5) air pollution (% of GNI).	WDI
4. DFOR	Net deforestation	The monetary loss due to deforestation (% of GNI).	WDI
5. DNGY	Energy resource depletion	The monetary value of extraction of energy resources (oil, natural gas, coal) beyond sustainable levels (% of GNI).	WDI
6. DMIN	Mineral depletion	The monetary value of mineral extraction (% of GNI).	WDI
Control Variables			
UNE	Unemployment rate	Represents the percentage (%) of the total labor force that is unemployed and actively seeking employment.	WB
TRADE	Trade Openness	Measures the extent of a country's participation in international trade relative to its GDP (% of GDP).	WB
UR	Urban population	Urban population percent of total population.	WB
FDI	Foreign direct investment	Foreign direct investment, net inflows percent of GDP.	WB
GDP	Economic growth	GDP per capita growth (%).	WB
INF	Inflation rate	Percent change of CPI each year.	WB

Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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