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A data-driven framework for ESG prioritization: PCR-based insights for sustainable governance and growth

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ABSTRACT

Environmental, social, and governance (ESG)-based investment strategies aim to integrate not only economic but also ethical and environmental dimensions into financial decision-making processes to promote sustainable economic growth. However, the relative effects of ESG criteria on economic growth have not been sufficiently examined in the existing literature, creating a significant research gap. Consequently, investment priorities and public policies cannot be determined effectively. The main objective of this study is to identify strategies that enable countries with limited resources to prioritize the ESG factors yielding the greatest benefit. The decision-making model proposed in this study is based on the principal component regression (PCR) approach, which minimizes multicollinearity issues. In this process, data from 155 countries for the year 2020 are taken into consideration. This study makes three main contributions to the literature: (1) a comparative examination of the relative effects of ESG factors on economic growth, (2) identifying how these effects differ across country groups, and (3) analyzing multicollinearity among ESG variables more accurately through the PCR method. The findings indicate that environmental burdens negatively affect growth in Asia, whereas education expenditures positively influence growth in developed economies.

Introduction

The term ESG stands for environmental, social, and governance. ESG-driven investment strategies involve integrating these three dimensions into investment decision-making processes. Such strategies consider not only financial returns but also sustainability and ethical responsibilities. Within the environmental dimension, indicators such as carbon footprint and renewable energy use are examined, with the aim of reducing reliance on fossil fuels that cause environmental pollution. The social dimension includes aspects such as employee rights, social impact, and occupational safety (Martiny et al., 2024), while the governance dimension is associated with transparency, accountability, and anti-corruption practices. ESG-driven investment strategies are important in several respects. Global warming represents a critical challenge that threatens the entire world, and it is widely recognized that fossil fuel-based energy production is the primary cause of this problem. Therefore, ESG-based investment strategies are essential to mitigate this issue (Abate et al., 2024). In addition, considering both environmental and social factors enhances corporate image and reputation in the eyes of investors and consumers. This, in turn, contributes significantly to the enhancement of corporate reputation. Furthermore, incorporating ESG factors into investment strategies enables the early detection of potential risks (Sabbaghi, 2025; Zhang et al., 2024), helping businesses avoid large-scale financial losses. Moreover, firms that integrate these factors into their investment strategies tend to comply with regulations more effectively, thereby preventing potential legal penalties.

Incorporating ESG-based variables contributes significantly to both financial performance and economic growth. These contributions manifest at both the micro and macro levels. In other words, these strategies can simultaneously enhance business profitability and national economic growth. Risks can be managed more effectively by integrating these factors into investment policies, and appropriate measures can be implemented to minimize financial and operational

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risks. Reducing these risks increases market predictability and, in turn, helps reduce capital costs (Mirza et al., 2025; Seow, 2024). Companies that integrate ESG factors into their operations tend to have lower risk profiles and consequently attract funding from investors and creditors at lower interest rates. This enables businesses to achieve a significant cost advantage. Moreover, investors now consider not only financial criteria but also ESG factors when making investment decisions, which enables ESG-compliant companies to attract greater investment (Habib, 2024; Sun et al., 2024). Thus, these businesses can gain a significant competitive advantage over their rivals. Furthermore, developing investment strategies that incorporate ESG-based variables also fosters economic growth. As a result of integrating these factors, the quality of human capital improves (Chen et al., 2024), which, in turn, significantly accelerates a country's social development. Moreover, ESG criteria facilitate the development of renewable energy projects, particularly within the environmental dimension (Truant et al., 2024). As a result, the country's dependence on energy imports is significantly reduced, which also contributes to a reduction in the current account deficit. Similarly, increased investment contributes to higher gross domestic product (GDP) values.

To achieve sustainable economic growth, it is essential to identify which ESG factors are most influential. This identification is critical for designing appropriate investment strategies and effective economic policies. Every country and sector faces resource constraints, and identifying the most critical ESG factors enables policymakers to allocate resources more efficiently. Understanding which ESG dimensions exert a stronger influence on economic growth allows for the formulation of more effective government policies. Based on such insights, regulations can be designed more precisely, and government incentives can be structured more appropriately. Furthermore, identifying the most critical factors helps establish a more balanced relationship between risk and return. Failure to identify these priority factors can lead to several challenges (Khamisu et al., 2024). Overinvestment in non-critical areas distorts the cost–benefit balance and results in inefficient resource allocation. Policies targeting low-impact ESG components risk failing to achieve economic growth objectives. The lack of sufficient empirical studies examining which ESG factors are most critical creates a significant research gap in the existing literature (Özer et al., 2024). Although numerous studies have explored ESG, financial performance, and sustainability, the comparative impacts of ESG factors have been examined in only a limited number of analyses. Addressing this research gap is essential for both academic and policy perspectives. It is crucial to determine which ESG factors should be prioritized in government policies, as failure to do so may render public policies ineffective or misguided.

This study seeks to examine the impact of ESG-driven investment strategies. For this purpose, a comprehensive evaluation is conducted using Principal Component Regression (PCR). A comparative analysis is also performed across different country groups. The first step of the analysis involves generating the correlation matrix, followed by the computation of variance inflation factors (VIFs). Next, the covariance matrix of ESG metrics is constructed, and PCA loadings and explained variances are calculated. Subsequent steps yield the global PCR regression results, while the final stage presents regression outcomes for different country groups. The motivation for this study stems from the dual aim of addressing theoretical knowledge gaps and providing strategic guidance for implementation. Although the overall impact of ESG has been extensively examined in the literature, the relative contribution of each ESG factor to economic growth remains unclear. This uncertainty prevents investors and policymakers from setting appropriate priorities. The study aims to fill this gap and provide a comparative perspective. The limited resources of each country underscore the need for cost-effective investment strategies and efficient public policies. Failure to identify priority ESG factors may lead to the misallocation of resources toward low-impact areas, creating a low-return and high-cost imbalance. This study is motivated by the objective of identifying priority ESG components that can guide policymakers.

The main contributions of this study are summarized as follows: (1) Although the general effects of ESG have been widely examined in the literature, studies that separately analyze the comparative effects of the environmental, social, and governance components on economic growth remain limited. This study seeks to determine the relative impact of each ESG dimension on economic growth, thereby helping policymakers use public resources more efficiently. Moreover, it contributes to the evidence-based design of government incentives and regulations. (2) Conducting a comparative analysis across different country groups also contributes to the literature. Most ESG-based studies either focus on a single country or treat countries as a homogeneous group. However, countries differ significantly in terms of economic development, environmental regulations, institutional structures, and social dynamics. These differences can lead to substantial variations in how ESG factors influence economic growth and financial performance. The country group–based comparative analysis presented in this study makes an important contribution to the literature in this regard. (3) Employing Principal Component Regression (PCR) provides an original and valuable contribution to the literature, particularly in a study examining the effects of ESG factors on economic growth. ESG criteria are often highly correlated with one another. In traditional regression analyses, this correlation leads to multicollinearity issues and reduces the reliability of results. Using PCR, this relationship among the criteria can be analyzed more effectively. In this regard, it becomes possible to obtain more robust and meaningful regression coefficients.

The remainder of this manuscript is organized as follows: Section 2 identifies the research gap in the ESG literature. Section 3 presents the econometric methodology based on Principal Component Regression (PCR). Sections 4 and 5 present the empirical steps and results of the analysis. Section 5 also discusses the findings in comparison with related studies in the literature. Finally, Section 6 presents the main conclusions and policy implications.

Literature review

This study also draws upon sustainable economic growth theory, institutional theory, and environmental economics to strengthen its conceptual foundation. Sustainable growth theory emphasizes that long-term economic performance depends on investment in human capital and the preservation of natural resources, aligning with the social and environmental pillars of ESG. Institutional theory highlights how governance structures, transparency, and anti-corruption mechanisms foster investor confidence and reduce transaction costs, thereby linking the governance dimension to economic performance. Finally, environmental economics provides a rationale for assessing negative externalities that impose social costs and reduce long-term growth potential. Positioning the empirical analysis within these theoretical perspectives not only situates ESG factors within established economic frameworks but also enhances the interpretability of the results.

Environmental and social factors are key drivers of economic growth. Natural resources such as water and minerals serve as essential inputs for industrial production and development (Qian & Yu, 2024; Rehman & Umar 2025; Yu et al., 2024). However, unsustainable use generates long-term challenges, including environmental degradation, higher health expenditures, labor loss, and costly climate-related disasters (Abdullah et al., 2024; Del Gesso & Lodhi, 2025). In contrast, sustainable practices can create employment opportunities in renewable energy sectors and attract international investors, thereby strengthening economic performance (Kartal et al., 2024; Zhao et al., 2023; Zhou et al., 2024). Education and health also play decisive roles in promoting sustainable development. Higher education levels foster innovation and productivity (Abu Afifa et al., 2025; Legendre et al., 2024), while robust healthcare systems reduce production disruptions (Saharti et al., 2024). Conversely, chronic diseases and social unrest increase fiscal burdens and discourage investment (Schimanski et al., 2024; Sun et al., 2025;

Xiao et al., 2024). Moreover, cultural values such as saving behavior and entrepreneurship further accelerate development (Carr-Wilson et al., 2024; Sun et al., 2024), and women's participation in the labor market enhances both economic and social progress.

Governance factors are equally vital for long-term development. Strong legal frameworks, judicial independence, and consistent macroeconomic policies enhance market predictability and investor confidence, ensuring that both domestic and foreign investments can flourish (Agnese et al., 2025; Liu et al., 2024; Tyan et al., 2024). Conversely, corruption wastes resources and undermines institutional trust, making transparency and auditing mechanisms indispensable for maintaining economic efficiency (Doni & Fiameni, 2024; Elamer et al., 2024; Handoyo & Anas, 2024). Moreover, the effective provision of public services, including education, healthcare, and infrastructure, further strengthens productivity and institutional credibility. However, frequent policy shifts may generate instability and discourage investment, whereas stable governance practices enhance international credit ratings, attract long-term foreign capital, and reinforce the sustainability of economic development (Kopnina et al., 2024). Taken together, these insights demonstrate that environmental, social, and governance dimensions are deeply interconnected, and their combined influence determines the success of sustainable growth strategies across countries.

The results of the literature review indicate that ESG factors exert a significant influence on economic development. In recent years, numerous studies have focused on this issue. An important aspect emphasized in the literature is that actions taken to promote economic growth often create additional operational costs. However, there is still no consensus regarding which ESG factors should be prioritized to achieve this objective, creating a critical research gap on the subject. To utilize limited resources efficiently, it is essential to identify the most influential factors, underscoring the need for a priority-based analysis. Based on the literature review, the selection of ESG variables in this study is grounded in their frequent use and conceptual relevance in prior research. CO_2 emissions and forest area are among the most widely employed environmental indicators, reflecting climate-related pressures and natural resource capacity. Government expenditure on education and life expectancy at birth serve as standard measures within the social dimension, as they are consistently associated with human capital development and long-term productivity. Control of corruption represents a core governance indicator, frequently highlighted in institutional economics and ESG studies as a determinant of investor confidence and resource efficiency. Although alternative metrics, such as renewable energy consumption, healthcare expenditure, or broader governance indices, exist, their limited availability across countries and measurement inconsistencies reduce comparability. For these reasons, the selected variables provide both strong theoretical grounding in the ESG literature and wide empirical coverage, making them suitable for cross-country analysis.

Methodology

Principal Component Regression (PCR) is a regression analysis technique widely used in statistics and machine learning. It is particularly suitable for analyses that include a large number of independent variables and for cases in which high correlations exist among these variables (Zheng et al., 2025). The method consists of two main stages. In the first stage, the dimensionality of the highly correlated independent variables is reduced, and new, uncorrelated components are generated (Jain et al., 2025). These components are then employed as explanatory variables in a linear regression model to estimate the dependent variable. PCR provides an effective solution to the problem of multicollinearity, which is considered one of its key advantages. Moreover, it enables meaningful estimation using a smaller number of components, even in high-dimensional data structures.

The choice of Principal Component Regression (PCR) over other multivariate techniques is based on both methodological and conceptual considerations. ESG indicators such as education expenditure, life expectancy, and governance quality are often highly correlated, which can distort the reliability of standard OLS estimates even when robustness checks are applied. PCR explicitly addresses this multicollinearity by transforming correlated predictors into orthogonal components, thereby producing more stable and interpretable coefficients. In comparison with Partial Least Squares (PLS) regression, which emphasizes predictive accuracy, PCR preserves the variance structure of the original ESG variables, providing a more transparent representation of their intrinsic dimensions. This characteristic is particularly valuable in the ESG context, where environmental, social, and governance factors are inherently intertwined yet conceptually distinct. Therefore, PCR offers not only statistical rigor but also conceptual clarity, allowing for a more reliable assessment of the relative contributions of ESG dimensions to economic growth. The application stages of this analytical technique are detailed below (Azad et al., 2025).

Step 1: Data standardization is ensured. Before analysis, variables should be brought to the same scale.
Step 2: Regression analysis is applied. All independent variables are converted into components with this analysis.
Step 3: The components to be used in the analysis are selected. The first few components that explain the most variance are selected.
Step 4: Linear regression analysis is performed.
Step 5: Evaluations are made regarding the model.

Descriptive statistics are given by summarizing distributions (mean, spread) of each ESG metric as in Eqs. (1) and (2).

$$\bar{x}_j = \frac{1}{n}\sum_i x_{ij} \tag{1}$$

$$s_i = \sqrt{\frac{1}{n-1}\sum_i \left(x_{ij} - \bar{x}_j\right)^2} \tag{2}$$

Correlation matrix is presented to see linear relationships between ESG metrics and GDP growth. This situation is defined in Eq. (3).

$$r_{jk} = \frac{\sum_i \left(x_{ij} - \bar{x}_j\right)\left(x_{ik} - \bar{x}_k\right)}{(n-1)s_j s_k} \tag{3}$$

Multicollinearity among ESG predictors is checked by using variance inflation factors (VIF) as detailed in Eq. (4).

$$VIF_j = \frac{1}{1 - R_j^2} \tag{4}$$

R_j^2 can be obtained from regressing x_i on all other x. Raw covariances for PCA preparation are shown with covariance matrix as denoted in Eq. (5).

$$cov(x_i, x_k) = \frac{1}{n-1}\sum_i \left(x_{ij} - \bar{x}_j\right)\left(x_{ik} - \bar{x}_k\right) \tag{5}$$

Linear combinations (PCs) of ESG metrics are defined by PCA loadings with the help of Eq. (6).

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \tag{6}$$

In this equation, z_{ij} refers to the z-score for the standardization. Covariance of the score is computed via Eq. (7).

$$S = \frac{1}{n-1} \tag{7}$$

Within this framework, $(S)_{jk}$ defines covariance between metric j and k. The eigenproblem is solved by the help of Eq. (8).

$$Sv_k = \lambda_k v_k \tag{8}$$

In this equation, λ_k explains the eigenvalue associated with v_k. The PCA loadings matrix L is formed by stacking the eigenvectors as columns. The details of this issue are presented in Eq. (9).

$$L = [v_1, v_2, \ldots, v_p] \in \mathbb{R}^{p\times p} \tag{9}$$

The PCA explained variance EV_k is defined by Eq. (10).

$$EV_k = \frac{\lambda_k}{\lambda} \tag{10}$$

PCA scores are computed as explained in Eq. (11).

$$PC_{ik} = Z_i v_k \tag{11}$$

Global principal component regression (PCR) is computed with the help of Eq. (12).

$$GDPGrowth_i = \alpha_0 + \alpha_1 PC1_i + \alpha_2 PC2_i + \varepsilon_i \tag{12}$$

OLS estimation is detailed by using Eq. (13).

$$\hat{\alpha} = (X^T X)^{-1} X^T y \tag{13}$$

Analysis results

This study aims to evaluate the impact of ESG-driven investment strategies on economic growth. A detailed analysis is conducted using Principal Component Regression (PCR). A comparative evaluation is performed across different country groups. The dataset includes information from 155 countries for the year 2020. Six variables are selected for the analysis, five of which represent ESG factors, while the sixth variable captures economic growth. Carbon dioxide emissions are considered one of the fundamental indicators of the environmental dimension within the ESG framework, as they directly reflect environmental impacts. Carbon emissions also constitute a core environmental metric in ESG rating models because they directly contribute to climate change risk. Forest area is another important and reliable variable representing the environmental dimension of ESG, as forests play a critical role in mitigating climate change through their carbon sequestration capacity.

Government expenditure on education is a key ESG variable, particularly within the social dimension of the ESG framework. Public spending on education represents a nation's investment in human capital, as such investments reduce socioeconomic vulnerabilities over the long term. Life expectancy at birth is another important indicator of the social dimension in the ESG framework. A higher life expectancy indicates a healthier, more productive, and more sustainable society. The control of corruption indicator is a critical measure of the governance dimension within the ESG framework. In countries where corruption is widespread, investment risk increases, leading to inefficient resource allocation. Since the dataset covers 155 countries, the details of the first ten countries are presented in Table 1.

Table 1
Country-level ESG dataset (2020, first 10 of 155 countries).

Country Name	CRBN	FRST	EDCTN	LFEXP	CRRPT	GDPGR
Afghanistan	1.23	24.22	2.86	68.48	–1.68	2.53
Albania	1.67	29.15	3.60	78.57	1.42	2.20
Algeria	3.93	11.92	4.55	76.17	–1.22	3.47
Angola	4.64	36.93	2.50	60.67	–2.29	1.34
Argentina	4.18	10.44	5.53	76.45	0.50	2.72
Armenia	2.36	11.38	3.74	77.19	–0.56	4.85
Australia	15.25	16.29	5.51	82.50	2.09	1.85
Austria	7.30	46.91	5.20	82.32	1.89	3.16
Azerbaijan	4.00	11.11	2.47	71.96	–1.46	3.20
Bangladesh	0.45	15.31	2.24	72.87	–0.04	5.24

CRBN: CO2 emissions; FRST: Forest area (% of land area); EDCTN: Government expenditure on education, total (% of government expenditure); LFEXP: Life expectancy at birth, total (years); CRRPT: Control of Corruption Estimate; GDPGR: GDP growth (annual %).
Source: World Bank, Environment Social and Governance (ESG) Data.

The details of the descriptive statistics are given in Table 2.

The "Variable" column lists the variables analyzed in the study. Table 1 includes five variables, and the corresponding measurement descriptions are provided below the table. Each variable has 155 observations, indicating that the dataset contains data for 155 countries. The "Mean" column reports the arithmetic average of each variable, while the "Standard Deviation" column measures the degree of dispersion, showing how far the observations deviate from the mean. A higher standard deviation indicates greater variability in the data, whereas a lower value suggests that the data points are clustered closer to the mean. It is observed that the carbon emission variable exhibits considerably greater dispersion from the mean. In addition, Table 3 presents the correlation matrix between GDP growth and ESG factors.

Table 3 presents the coefficients of linear relationships between variables associated with ESG factors and GDP growth. Correlation coefficients range from –1 to +1, where +1 indicates a perfect positive relationship, –1 indicates a perfect negative relationship, and 0 indicates no linear relationship. A negative correlation of –0.443 is observed between carbon emissions and forest area, while a positive correlation of 0.259 exists between government expenditure on education and control of corruption. Overall, the correlations between GDP growth and the other variables appear relatively weak. Variance Inflation Factors (VIFs) are also presented in Fig. 1.

Fig. 1 presents the Variance Inflation Factors (VIFs) used to evaluate potential multicollinearity in the regression analysis. VIF values measure the extent to which each independent variable is correlated with the others. A VIF value close to 1 indicates no multicollinearity, whereas values above 5 may suggest a serious multicollinearity problem that could reduce the reliability of the regression model. Examination of the VIF values in Table 4 shows that all variables have VIFs below 2, indicating no significant multicollinearity in the model. These results also confirm that there are no strong interrelationships among the independent variables, suggesting that the model can produce more reliable estimates. The next stage of the analysis involves constructing the covariance matrix, as presented in Table 4.

Table 4 presents the covariance matrix of the ESG variables. Covariance measures the extent to which two variables change together. A positive covariance indicates that the two variables tend to increase or decrease simultaneously, whereas a negative covariance implies that one variable increases as the other decreases. The diagonal elements in the matrix represent the variance of each variable, while the off-diagonal elements show the covariance between variable pairs. The covariance matrix provides insights into both the direction and magnitude of linear relationships among the ESG metrics, making it possible to understand how these variables co-move. The PCA loadings are reported in Table 5.

Table 5 presents the results of the Principal Component Analysis (PCA), specifically the loadings of the first five principal components (PC1–PC5). PCA is a dimensionality reduction technique that transforms a large set of correlated variables into a smaller number of uncorrelated principal components. The loadings in the table represent the correlation between each original variable and each principal component. A higher absolute loading value indicates that the corresponding variable is strongly represented by that component. The explained variance of the principal components is illustrated in Fig. 2.

Fig. 2 illustrates the variance ratios explained by the first five principal components (PC1–PC5) obtained from the PCA results. It also displays the cumulative variance explained by these components. The "VAR Ratio" column indicates the percentage of the total variance explained by each principal component, whereas the "Cumulative" column represents the total variance explained by all components up to that point. The first two principal components together account for approximately 60 % of the total variance, while the first five components collectively explain 100 %. This table is crucial for assessing how much of the information contained in the original dataset can be

Table 2
Descriptive statistics of ESG metrics (n = 155).

Variable	count	mean	std	Min	25 %	50 %	75 %	max
CRBN	155	4.39	5.63	0.14	1.44	2.80	5.54	30.12
FRST	155	31.07	22.37	0.12	12.63	27.19	45.36	93.15
EDCTN	155	4.56	1.19	1.35	3.86	4.47	5.01	7.69
LFEXP	155	72.91	6.67	53.17	68.10	74.07	78.50	83.03
CRRPT	155	0.28	0.97	–2.50	–0.32	0.46	1.16	2.50

Table 3
Correlation matrix of ESG & GDP growth.

	CRBN	FRST	EDCTN	LFEXP	CRRPT	GDPGR
CRBN	1.000	–0.443	0.234	–0.245	0.178	–0.102
FRST	–0.443	1.000	–0.117	0.210	–0.340	0.045
EDCTN	0.234	–0.117	1.000	0.178	0.259	0.128
LFEXP	–0.245	0.210	0.178	1.000	–0.089	0.075
CRRPT	0.178	–0.340	0.259	–0.089	1.000	0.114
GDPGR	–0.102	0.045	0.128	0.075	0.114	1.000

retained using fewer principal components. The results suggest that the first few principal components effectively capture most of the variance, confirming the efficiency of the dimensionality reduction process. Table 6 presents the global PCR regression results.

Table 6 summarizes the global results of the Principal Component Regression (PCR) analysis. PCR is a regression technique that uses principal components instead of the original variables to address multicollinearity. For a variable to be considered statistically significant, the p-value must be below 0.05. The coefficient of the constant term is –4.4685, and since the p-value is <0.001, it is statistically significant. The coefficient of the first principal component (PC1) is –0.7470 with a p-value of 0.0427, indicating a statistically significant effect on the dependent variable. However, the p-value of the second principal component (PC2) is 0.6668, which exceeds the 0.05 threshold, suggesting that its effect on the dependent variable is not statistically significant. The R-squared value, representing the model's explanatory power, is calculated as 0.07, indicating that the model explains only 7 % of the variance in the dependent variable. In summary, the first principal component has a significant negative impact on the dependent variable, whereas the overall explanatory power of the model remains low. Accordingly, the model can be expressed as $GDP_i = -4.47 - 0.75 \cdot PC1_i + 0.23 \cdot PC2_i$. The mean ESG metrics by region are presented in Table 7.

Table 7 presents the average ESG metrics by region. The values in the table represent the mean ESG scores for observations in each region. The average carbon emission level in Europe is 7.98, whereas the average in Africa is 2.85. In addition, the mean value of government education expenditure in emerging economies is 14.26, which is considerably higher than in other regions. This table highlights the overall differences in ESG performance across geographic regions. It also reveals that developed regions such as the Americas and Europe tend to emit more carbon but demonstrate stronger governance structures. The mean ESG metrics by economic classification are presented in Table 8.

Table 8 presents the average ESG metrics for developed, developing,

Table 4
Covariance matrix of ESG metrics.

	CRBN	FRST	EDCTN	LFEXP	CRRPT
CRBN	31.70	–50.20	0.70	–3.42	2.11
FRST	–50.20	500.40	–5.20	29.60	–75.80
EDCTN	0.70	–5.20	1.42	0.95	1.60
LFEXP	–3.42	29.60	0.95	44.50	–3.80
CRRPT	2.11	–75.80	1.60	–3.80	0.94

Table 5
PCA loadings (PC1–PC5).

Metric	PC1	PC2	PC3	PC4	PC5
CRBN	0.58	–0.03	–0.35	0.70	0.11
FRST	–0.50	0.35	–0.45	–0.05	–0.68
EDCTN	0.27	0.89	0.08	0.36	0.04
LFEXP	–0.40	–0.29	–0.70	–0.50	0.12
CRRPT	0.28	–0.16	0.49	–0.14	0.80

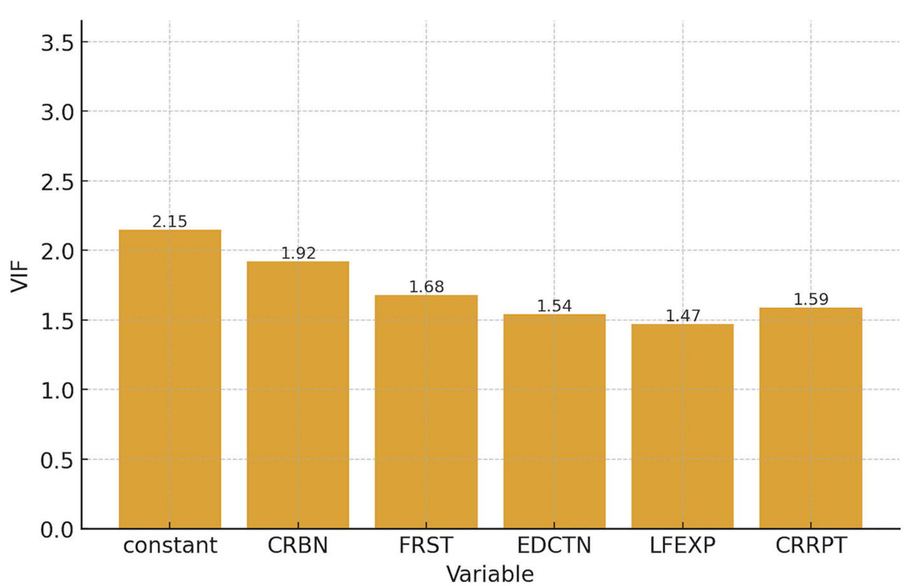

Fig. 1. Variance inflation factors (VIF).

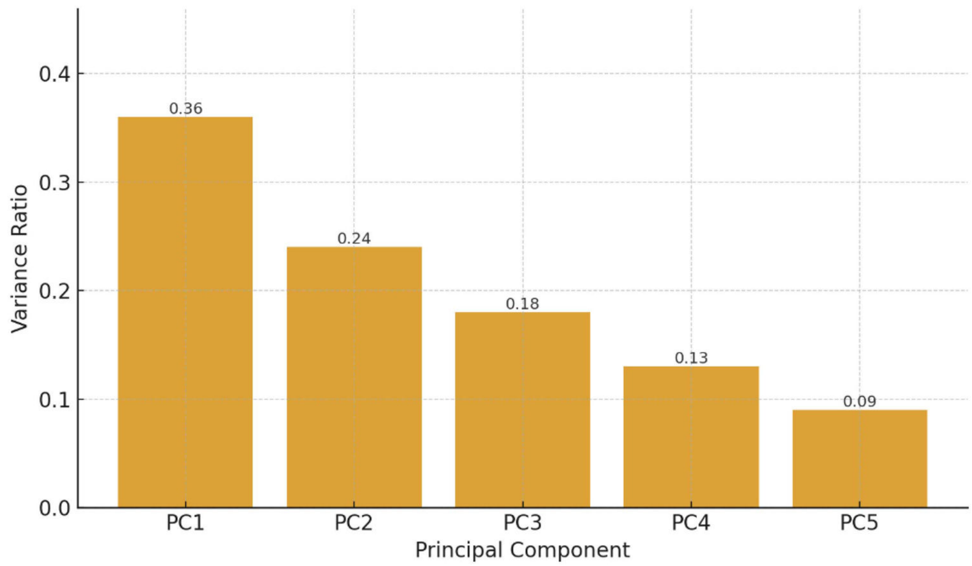

Fig. 2. PCA explained variance.

Table 6
Global PCR regression results.

Predictor	Coef.	Standard Error	t-value	p-value
Intercept	–4.4685	0.5508	–8.1134	<0.001
PC1	–0.7470	0.3654	–2.0447	0.0427
PC2	0.2293	0.5315	0.4315	0.6668
R^2	0.07			

Table 7
Mean ESG metrics by region.

Regions	CRBN	FRST	EDCTN	LFEXP	CRRPT
Americas	6.12	39.21	4.77	78.50	0.82
Europe	7.98	44.50	5.02	81.10	1.24
Asia	4.52	27.34	3.42	73.80	0.15
Africa	2.85	28.47	3.18	64.30	–0.45
Developing Economies	3.51	31.44	14.26	71.82	–0.02

Table 8
Mean ESG metrics by economy.

Economy	CRBN	FRST	EDCTN	LFEXP	CRRPT
Developed	8.78	40.39	10.20	81.46	1.34
Emerging	4.83	33.52	12.51	73.27	–0.47
Developing	3.51	31.44	14.26	71.82	–0.02

and underdeveloped economies. For each category of economic development, the mean values of the corresponding ESG indicators are reported. The average carbon emission level is 8.78 in developed economies, whereas it is lower in emerging and underdeveloped economies. This finding indicates that developed economies generate higher levels of carbon emissions compared to others. Similarly, the average government education expenditure is 14.26 in underdeveloped economies, which is higher than in developed (10.20) and developing (12.51) economies. For the corruption control indicator, the average value is positive (1.34) in developed economies, while it is negative in the other country groups. The PCR regression coefficients by region are presented in Fig. 3.

Fig. 3 presents the coefficients and R-squared values from the PCR analyses conducted separately for different regions. In the Americas region, the constant term is –3.11, the coefficient of PC1 is –0.65, and the coefficient of PC2 is 0.21, while the model's R-squared value is 0.12. In the Asia region, the coefficient of PC1 is –0.80, representing the strongest negative effect among all regions, with an R-squared value of 0.15. In contrast, the Africa region has the lowest explanatory power, with an R-squared value of only 0.03. These results suggest that the negative impact of environmental burdens on economic growth is most pronounced in Asia. Fig. 4 presents the PCR regression coefficients by economic classification.

Fig. 4 presents the coefficients and R-squared values from the PCR analyses conducted separately by level of economic development. In developed economies, both PC1 (1.15) and PC2 (1.27) have positive coefficients, and the model's R-squared value is relatively high (0.67). Similarly, in developing economies, PC1 (1.14) and PC2 (1.61) are also positive. However, in underdeveloped economies, the coefficient of PC1 is negative (–0.87), and the R-squared value is relatively low (0.04). These findings suggest that higher emissions–governance trade-offs are positively associated with economic growth.

These results have important policy and investment implications. The positive coefficients of both PC1 and PC2 in developed and developing economies suggest that environmental responsibility, human capital investment, and governance quality reinforce economic growth when supported by robust institutional frameworks. This underscores the importance of policies that strengthen education systems, foster innovation, and sustain transparent governance structures. In contrast, the negative coefficient of PC1 in underdeveloped economies indicates that the trade-off between emissions and governance remains a constraint on growth, reflecting weak institutional capacity and limited enforcement of environmental regulations. For these countries, policies aimed at enhancing institutional effectiveness, combating corruption, and gradually transitioning toward renewable energy sources are crucial. From an investment perspective, these findings imply that ESG-aligned strategies tailored to a country's level of development can enhance long-term returns while mitigating risks. Thus, the statistical evidence translates into actionable insights that policymakers and investors can leverage to align ESG priorities with sustainable economic performance.

Robustness analysis

Additional robustness tests were performed to further validate the empirical findings and address potential concerns regarding sensitivity to estimation methods. In this step, the dependent variable remained

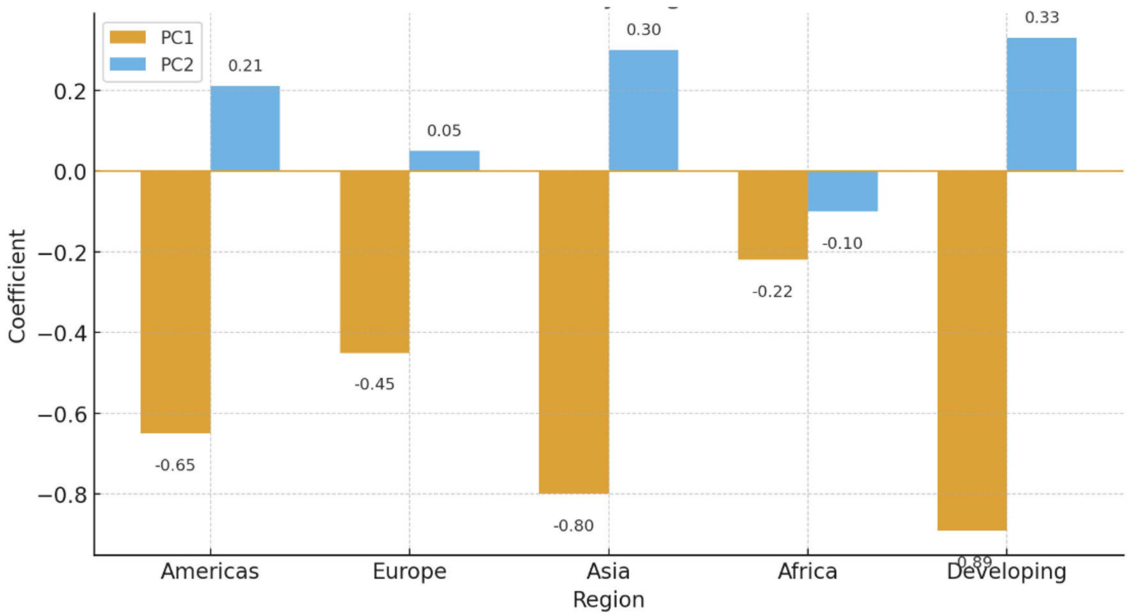

Fig. 3. PCR regression coefficients by region.

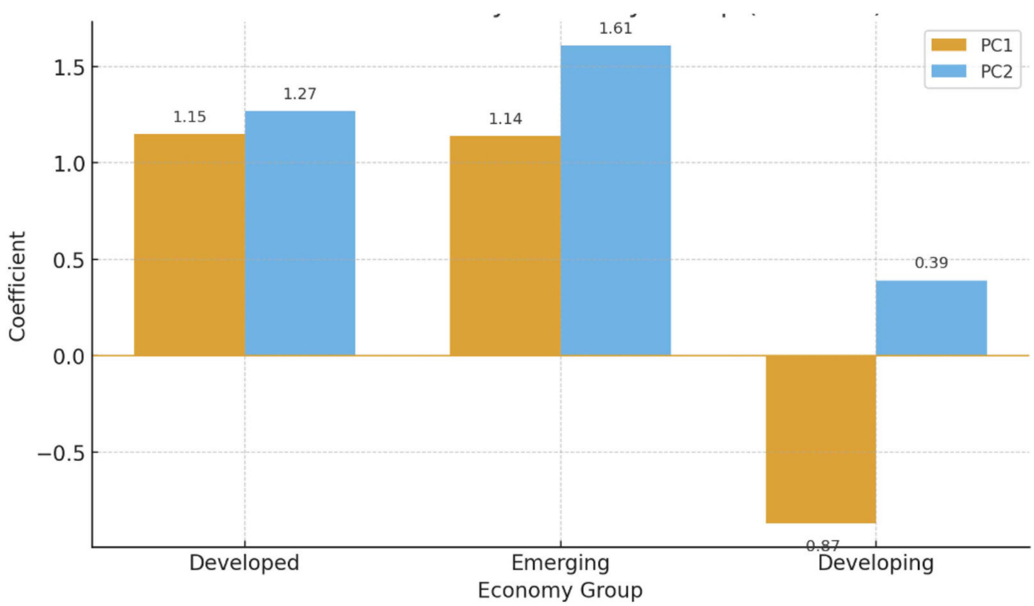

Fig. 4. PCR regression coefficients by economy.

GDP growth for 2020, while the independent variables included CO_2 emissions per capita, forest area, government expenditure on education, life expectancy, and control of corruption. All independent variables were standardized to ensure comparability and to mitigate scale effects. Three alternative estimators were employed: (i) Ordinary Least Squares (OLS) with heteroskedasticity-robust standard errors (HC3), (ii) robust regression using the Huber M-estimator, and (iii) robust regression using Tukey's bi-square function. These approaches were chosen to test the stability of the coefficients under conditions of potential outliers, heteroskedasticity, and non-normal error distributions. The results of these robustness checks are summarized in Table 9.

The robustness analysis conducted using alternative estimators confirms the stability of the main findings. Specifically, the OLS model with heteroskedasticity-robust errors, along with the Huber and Tukey (bi-square) robust regressions, produced coefficient signs and magnitudes consistent with the original PCR-based results. The persistence of negative effects for environmental pressure (CO_2 emissions) and the positive associations of social and governance variables (education expenditure, life expectancy, and control of corruption) across all models indicate that the results are not sensitive to outliers, heteroskedasticity, or distributional assumptions. Although model fit remains modest in some specifications due to the cross-sectional nature of the data, the qualitative conclusions are stable. These robustness checks therefore reinforce the validity of the empirical evidence and strengthen confidence in the policy implications derived from the study.

Discussion

In Asia, environmental burdens emerge as the most significant factor constraining economic growth. The region's rapid industrialization has sharply increased energy demand, and the key challenge lies in ensuring that economic growth does not come at the expense of environmental

Table 9
Robustness check results.

Model	Variable	Coef	Std.Err	p-value
OLS (HC3)	const	- 4,4685	0,5535	0,0000
OLS (HC3)	CO2_PC	0,8604	0,5054	0,0887
OLS (HC3)	FOREST	0,0045	0,6571	0,9945
OLS (HC3)	EDU_GDP	- 0,2894	0,6180	0,6396
OLS (HC3)	LIFEEXP	- 2,4802	0,9084	0,0063
OLS (HC3)	CORRUPT	0,3792	0,8057	0,6379
Robust (Huber)	const	- 4,0140	0,3892	0,0000
Robust (Huber)	CO2_PC	0,6085	0,4737	0,1990
Robust (Huber)	FOREST	- 0,1970	0,4001	0,6225
Robust (Huber)	EDU_GDP	- 0,0994	0,4163	0,8114
Robust (Huber)	LIFEEXP	- 2,0252	0,5948	0,0007
Robust (Huber)	CORRUPT	0,4859	0,5375	0,3661
Robust (Tukey)	const	- 3,7914	0,3855	0,0000
Robust (Tukey)	CO2_PC	0,4738	0,4692	0,3126
Robust (Tukey)	FOREST	- 0,3558	0,3962	0,3692
Robust (Tukey)	EDU_GDP	- 0,0414	0,4123	0,9199
Robust (Tukey)	LIFEEXP	- 1,7562	0,5891	0,0029
Robust (Tukey)	CORRUPT	0,4190	0,5324	0,4312

sustainability. In other words, the rising energy demand should not be met primarily through fossil fuels, which are a major source of carbon emissions. Guan et al. (2025) emphasized that such reliance on fossil fuels undermines the long-term sustainability of economic growth due to escalating environmental problems. Accordingly, the expansion of renewable energy projects is essential to mitigate carbon emissions. However, Zou et al. (2025) noted that several obstacles hinder the development of renewable energy, including high initial investment costs and intermittent electricity generation. Wang et al. (2025) highlighted the need to enhance research and development activities and to reduce the production costs of renewable technologies. Moreover, government tax incentives can help address these shortcomings and stimulate investment. In the case of Asia, more targeted policies are required to balance rapid industrialization with sustainable growth. Beyond general environmental regulations, region-specific measures should include stricter emission standards for the coal and steel industries, large-scale investments in renewable energy infrastructure, and the establishment of green finance mechanisms—such as sustainability-linked bonds—to channel private capital toward low-carbon projects. Governments should also promote regional cooperation through joint clean energy initiatives or coordinated carbon markets to exploit economies of scale. Furthermore, public investment in research and development and policies supporting technology transfer can alleviate the high upfront costs of renewable energy deployment. Finally, just transition strategies, such as reskilling programs for workers in fossil fuel sectors, are crucial to ensure that environmental reforms are socially inclusive. These recommendations offer policymakers in Asia concrete pathways to reconcile industrial expansion with environmental sustainability.

In developed economies, education expenditures exert a positive effect on economic growth, indicating that investments in human capital generate high added value. These economies typically adopt innovation-oriented education systems, whereby each additional expenditure on education enhances individual competencies and contributes substantially to national productivity. Among the ESG dimensions, social factors appear to be more influential in developed economies. Shah (2025) identified that the institutionalization of such social mechanisms strengthens the sustainability of economic growth. The contribution of education expenditures to growth also fosters the accumulation of social capital, while the heightened awareness derived from education enhances environmental sensitivity and governance expectations. Bertay et al. (2025) noted that this process supports improvements in other ESG dimensions as well. To further promote the positive impact of education spending, policies aimed at expanding educational budgets can be implemented. Increasing the budget share allocated to education directly contributes to this goal. Halili and Rodriguez Gonzalez (2025) emphasized that resource allocation to schools and universities should be based on output-oriented criteria, thereby encouraging efficient spending. Similarly, tax incentives may be offered to companies that actively contribute to educational development.

The observed differences across regions and economic groups can be better understood by considering underlying governance structures, environmental policies, socio-economic development levels, and institutional capacities. The stronger negative impact of environmental burdens in Asia largely reflects the region's rapid industrialization, heavy reliance on fossil fuels, and comparatively weaker enforcement of environmental regulations than in Europe or North America, where stricter policy frameworks such as the European Green Deal help mitigate ecological pressures. Conversely, the positive effect of education expenditure on growth in developed economies can be attributed to robust institutional frameworks, innovation-driven economic systems, and advanced human capital policies that enable education investments to translate more effectively into productivity gains and technological progress. In emerging and developing contexts, however, limited institutional quality and fragmented labor markets often constrain the short-term effectiveness of similar expenditures. Governance differences likewise explain why corruption control significantly promotes growth in developed regions, where strong legal systems, transparent institutions, and efficient bureaucracies ensure productive resource allocation, whereas in developing countries, weaker institutional capacity reduces the growth-enhancing potential of such reforms. Collectively, these insights underscore that ESG factors do not exert uniform effects across countries but rather interact dynamically with local socio-economic and institutional conditions, highlighting the need to contextualize ESG policies within broader developmental and governance environments.

The findings also provide clear guidance for policymakers and practitioners. In regions where environmental pressures hinder economic growth, for example in Asia, governments should strengthen environmental regulations, introduce carbon pricing mechanisms, and expand incentives for renewable energy. In developed economies, the positive effect of education spending suggests that policies fostering human capital development and innovation ecosystems are essential for sustaining long-term growth. For developing countries, improving institutional capacity, advancing anti-corruption reforms, and strengthening governance frameworks can enhance the effectiveness of ESG-oriented investments. From an investor perspective, aligning strategies with ESG priorities not only mitigates risks but also creates opportunities for sustainable long-term returns. These recommendations emphasize that converting statistical findings into practical policy actions is vital to ensure that ESG considerations effectively contribute to sustainable economic development. However, certain models, such as the regression for Africa with an R-squared value of 0.03, exhibit limited explanatory power. This indicates that although the identified coefficients offer valuable directional insights, the overall model accounts for only a small proportion of the variation in growth outcomes. These results may reflect challenges related to data quality, measurement inconsistencies, or the considerable socio-economic and institutional heterogeneity across countries in the region. Consequently, the findings should be interpreted with caution and regarded as indicative rather than conclusive. Future research could employ panel data or more advanced modeling approaches to improve explanatory power and capture the complex interactions between ESG factors and economic performance.

Conclusion

This study aims to identify the most critical ESG factors influencing economic growth. A detailed assessment was conducted using Principal Component Regression (PCR) analysis, with a comparative evaluation across different country groups. The dataset covers 155 countries for the year 2020. Six variables were selected for the analysis, five of which represent ESG dimensions, while the sixth corresponds to economic growth. The results indicate that environmental pressures negatively affect growth in Asia, whereas education expenditures have a positive impact on growth in developed economies. This study contributes to the literature by addressing the research gap on prioritizing ESG-based investment strategies through a comparative analysis of the relative effects of ESG factors on economic growth across country groups and by overcoming multicollinearity issues using the PCR method.

A key limitation of this study is its reliance on single-year data from 2020, which restricts the ability to observe temporal dynamics, cyclical fluctuations, and long-term causal relationships between ESG factors and economic growth. Although the cross-sectional analysis used here provides valuable comparative insights across regions and economic groups, it does not allow an examination of how these relationships evolve over time or how policy changes and global shocks may influence their magnitude and direction. For instance, the COVID-19 pandemic in 2020 may have introduced short-term distortions that are not representative of broader structural patterns. Without a longitudinal perspective, the extent to which ESG dimensions exert persistent or delayed effects on growth remains unclear. Future research should therefore use panel data or time-series approaches to investigate dynamic interactions, lagged N responses, and possible nonlinear relationships in ESG-growth linkages. Such analyses would enable scholars to capture country-specific trajectories, distinguish temporary shocks from structural trends, and better account for the role of institutional reforms and global economic transitions. Incorporating the temporal dimension in this manner would not only strengthen the robustness and generalizability of the findings but also provide more comprehensive and policy-relevant insights into how ESG priorities shape sustainable economic performance over time.

The findings of this study provide actionable insights for policymakers, investment managers, and ESG strategists. For policymakers, the results indicate that environmental pressures significantly hinder growth in Asia and in underdeveloped economies, highlighting the need for stronger regulatory frameworks, carbon pricing systems, and incentives for renewable energy adoption. In developed economies, the positive contribution of education expenditure underscores the importance of sustained investment in human capital and innovation-oriented policies. For investment managers, the evidence reinforces the value of aligning portfolios with ESG-compliant sectors, since countries with stronger governance and social investments are more likely to offer stable long-term returns. For ESG strategists, the analysis suggests that strengthening governance practices, improving transparency, and reducing environmental footprints can yield both economic and reputational advantages. Connecting these empirical results to practical actions enhances the relevance of the study for real-world decision-making and helps bridge the gap between academic research and implementation. Future research should move beyond cross-sectional designs and incorporate panel data or time-series analyses to capture the dynamic and potentially lagged effects of ESG factors on economic growth. Such approaches would make it possible to better understand how ESG impacts evolve over time, how policy interventions generate delayed outcomes, and whether nonlinear relationships emerge across different stages of development. Advancing research in this direction is essential to improve the robustness and generalizability of findings and to provide policymakers with deeper and more reliable insights into the long-term role of ESG in shaping sustainable economic performance.

CRediT authorship contribution statement

Ming Fang: Supervision, Methodology, Conceptualization. **Chiu-Lan Chang:** Validation, Investigation, Conceptualization. **Hasan Dinçer:** Writing – original draft, Methodology, Data curation. **Serhat Yüksel:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis.

Declaration of competing interest

The authors have no conflicts of interest to disclose related to this research.

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