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RESEARCH ARTICLE
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The Impact of Economic Growth on Sustainable Development: an Analysis of ESG Indicators

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ABSTRACT

This study aims to evaluate economic growth's impact on key sustainability components, including carbon productivity, ecological conditions, healthcare, social well-being, and education. This paper employs Principal Component Analysis (PCA) to group complex ESG indicators into five distinct categories, followed by quadratic regression modeling to capture nonlinear relationships between GDP growth and each ESG component. The study uses statistical data collected from national and international sources for the period 2012-2022. The analysis showed that the impact of economic growth on ESG indicators in Kazakhstan is expressed heterogeneously. Economic growth showed the greatest correlation with education indicators (R2 = 0.696, $p < 0.01$), indicating a significant improvement in the educational sector as GDP per capita increases. At the same time, the impact on environmental indicators turned out to be weaker (R2 = 0.352, p = 0.176), which indicates minor improvements in the environment that require additional environmental initiatives. Economic growth had the least impact on carbon productivity, with R2 = 0.13 (p = 0.58), which underlines the need for targeted measures to improve carbon efficiency. The results highlight that although economic growth contributes to social and educational development, specific ESG-oriented strategies are required to achieve sustainable development in Kazakhstan, especially in the field of carbon efficiency. Therefore, future research may be aimed at localizing ESG metrics, evaluating the effectiveness of programs in the socio-environmental field, and creating multifactorial models for ESG analysis.

KEYWORDS: Sustainable Development, Economics, Green Economy, Carbon Productivity, Environmental Efficiency, Social Indicators, Economic Growth, Kazakhstan

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1. INTRODUCTION

In recent years, significant attention has been devoted to sustainable development and integrating Environmental, Social, and Governance (ESG) principles into national economic strategies. Countries with substantial carbon potential play a crucial role in these processes by developing concepts and strategies to reduce emissions and improve resource efficiency. However, the theoretical foundations, criteria, and methodological approaches to structural and technological modernization of the economy with ESG considerations require further development and adaptation, especially for countries in the midst of an energy transition, such as Kazakhstan. Thus, ESG indicators serve as a framework for assessing how countries and businesses manage environmental impact, social responsibilities, and governance standards, thereby enabling sustainable growth that aligns economic advancement with long-term well-being for society and the planet.

The ESG framework focuses on three key aspects: environmental, social, and governance components that form the basis of sustainable management for enterprises and industries. Environmental criteria, such as carbon footprint management and renewable resource use, are pivotal for creating long-term sustainability strategies in countries with high industrial production levels. Thus, structural changes in the mining and energy sectors can be successful only when technologies that contribute to reducing greenhouse gas emissions are integrated. Kazakhstan, as a major exporter of mineral resources, faces the challenge of adapting these theoretical provisions to its specific context.

Kazakhstan's technological potential indicates that many fundamental economic sectors, such as mining and agriculture, require significant reforms to achieve sustainable growth. Despite increasing production capacity, planning and corporate governance systems still need to be developed concerning ESG indicators. Current enterprise management models often need to fully consider the long-term environmental and social consequences of their actions, which could lead to inefficient resource use in the future. Integrating ESG indicators into corporate planning and management could improve resilience and promote more efficient resource utilization - a crucial factor for Kazakhstan, where natural resources play a key role in the economy.

The study aims to evaluate the impact of economic growth on key components of sustainability, including carbon productivity, ecological conditions, healthcare, social well-being, and education. This analysis is vital for policymakers in Kazakhstan and other resource-dependent economies aiming to foster long-term growth while addressing environmental and social challenges. Hypotheses include:

H1: Economic growth has no significant impact on Carbon Productivity, indicating that increasing GDP per capita does not inherently lead to greater carbon efficiency.

H2: Economic growth exhibits a moderate impact on Ecology, initially leading to environmental degradation but potentially showing improvement at higher income levels, consistent with an inverted-U relationship.

H3: Economic growth positively influences Healthcare indicators, enhancing healthcare quality and accessibility as GDP per capita rises.

H4: Economic growth has a moderate effect on Social indicators, supporting social welfare improvements but insufficiently reducing inequality and social disparities without additional interventions.

H5: Economic growth has a strong positive relationship with Education, significantly improving educational quality and accessibility with rising GDP per capita.

2. LITERATURE REVIEW

Successful modernization of industries and agriculture, especially in countries with high carbon potential, is linked to developing and implementing new technologies that minimize emissions and reduce dependency on fossil fuels. In countries focusing on the mining industry, the widespread adoption of ESG indicators has been a critical factor in reforming corporate strategies. Adopting environmental standards, such as carbon taxes and emission quotas, has reduced carbon footprints and increased investments in renewable energy.

Improving energy efficiency, particularly in rapidly urbanizing regions, was shown to reduce emissions while simultaneously supporting social and economic benefits significantly. Li and Colombier (2009) highlighted that building energy efficiency was crucial for climate change mitigation and also supported social development by reducing energy costs and improving living conditions, especially in developing countries. Huisingh et al. (2015) noted that a transition to low-carbon systems required substantial shifts in product design, production, and consumption patterns - adjustments that impacted not only environmental goals but also contributed to social well-being and the sustainability of urban growth.

The concepts of a circular economy and industrial ecology have been widely explored across various systems to enhance resource efficiency and reduce environmental impact. Prieto-Sandoval et al. (2019) examined the role of a circular economy, particularly within construction and production sectors, integrating resource-sharing models to achieve environmental benefits Sinha and Chaturvedi (2019) investigated energy-efficient processes as essential for reducing carbon emissions in industrial production, while Daniek (2020) developed a composite model to assess national progress toward environmentally sustainable economies, focusing on critical indicators like energy consumption, carbon emissions, and resource use intensity. Differences in methodologies for environmental, social, and governance ratings further hinder the adoption of effective global sustainability strategies (Rossi et al., 2024).

Approaches to sustainability are closely interconnected with economic growth, as ESG factors are shaped by economic conditions and influence long-term economic outcomes. Thus, economic growth can drive improvements in sustainability, while sustainable practices can support continued economic development. Ness and Xing (2017) explored how circular economy principles could enhance resource efficiency, while Ingarao (2017) considered energy-efficient processes essential for reducing carbon footprints in industrial production. Mohsin et al. (2019) introduced a composite model for evaluating national sustainability progress, outlining energy consumption and carbon emissions indicators. While ESG performance is often linked to financial outcomes, Daugaard and Ding (2022) observed that this relationship is complex and not always straightforward; higher ESG scores may support corporate growth by reducing risks. This complexity highlights the need for new models, such as those proposed by Tan et al. (2024), that incorporate multi-criteria decision-making to address gaps in current frameworks by better-capturing factors like political stability and governance.

Recently, multifactor models and composite indicators have been extensively applied to analyze the relationship between economic growth and ESG components. El Gibari et al. (2019) focused on the significance of multicriteria decision-making in constructing composite indicators, including economic, social, and environmental factors, into a sustainability index. Deng et al. (2019) found that sustainability declines in the early stages of growth, but after reaching a certain level of economic development, the trend reverses, and sustainability begins to increase. Rusu (2023) applied Principal Component Analysis (PCA) to analyze the interrelations among economic, social, and environmental indicators. Vargas-Santander et al. (2023) used PCA to create a country-level sustainability indicator, uncovering connections between sustainability and economic factors. Finally, Hussain et al. (2023) applied the Kuznets curve to analyze the relationship between financial inclusion and carbon emissions. This reveals a nonlinear dynamic where inclusion initially increases emissions at specific growth stages but subsequently contributes to their reduction. Different countries accumulated varied experiences implementing ESG principles shaped by economic and technological disparities. Khoruzhy et al. (2022) indicated that developing countries faced limitations related to technology access, which influenced their ESG approaches. Meanwhile, Wang et al. (2023) demonstrated how levels of industrialization and technology access created distinct sustainable development trajectories, necessitating tailored strategies for each country.

Given the crucial role of economic growth in shaping the impact of a sustainable economy, a comprehensive analysis of the relationship of economic development with ESG components is essential. A review of existing studies showed that practices of successful modernization in high-carbon-potential industries, such as mining and agriculture, define the importance of associating economic growth with sustainable practices. Nevertheless, studies showed that the relationship between economic growth and ESG performance is complex, often requiring more specific frameworks to capture factors like social development and environmental impact. Conducting a detailed analysis will contribute to revealing the pathways through which economic expansion can drive sustainable growth.

3. RESEARCH METHODS

By grouping indicators into key sustainability categories such as carbon productivity, ecology, healthcare, social, and education - and applying PCA, the methodology effectively reduces data dimensionality while enhancing interpretability. Using PCA to form aggregated indicators allows for a structured and comprehensive analysis of how economic growth interacts with diverse socio-economic and environmental aspects.

Furthermore, using a quadratic regression model, incorporating a quadratic GDP term enables a more precise exploration of potential nonlinear, inverted U-shaped relationships within each sustainability component. This adaptation captures the concept of the Kuznets curve. At the same time, the inclusion of PCA and multi-component analysis expands the methodology's capacity to address complex interactions between economic growth and sustainability, providing deeper insights into the pathways through which economic development influences sustainable outcomes.

Based on a comprehensive literature review, we formulated a methodology to examine the relationship between economic growth and sustainability indicators. The Kuznets methodology was selected as the framework for analyzing these relationships due to its effectiveness in exploring the impact of economic growth on various socio-economic and environmental factors.

Given the many indicators, they were grouped into categories to improve interpretability and reduce dimensionality. Using Principal Component Analysis (PCA), aggregated indicators for critical components of sustainability were created: carbon productivity, ecology, healthcare, social, and education. In PCA, each component CiC_iCi is defined as a linear combination of the original indicators (1):

$$C_i = a_1X_1 + a_2X_2 + \cdots a_nX_n \qquad (1)$$

where:

a_n - the component loadings;

X_n - the standardized original indicators for each category.

Next, there was applied a quadratic regression model to these aggregated indicators to assess the relationship between economic growth (GDP per capita) and each sustainability component (2):

$$Y = \beta_0 + \beta_1 GDP_{PC} + \beta_2 {GDP_{PC}}^2 + \in \qquad (2)$$

where:

Y - aggregated component (e.g., carbon productivity, ecology);

β_0- intercept;

β_1 and β_2 - coefficients representing the linear and quadratic effects of GDP per capita;

$\in$ - error term.

The quadratic term ${GDP_{PC}}^2$ captures any nonlinear, inverted-U-shaped relationships, according to the Kuznets theory.

The methodology was based on the versatility and established effectiveness of the Kuznets theorem in analyzing the relationship between economic growth and socio-economic and environmental indicators. The Kuznets theorem is traditionally used to explain inverted U-shaped relationships between income levels and factors such as inequality or ecological costs, proposing that as the economy and per capita income increase, these factors may worsen and improve.

This study modified and adapted the traditional Kuznets approach by incorporating Principal Component Analysis (PCA) to create aggregated indicators. Integrating the Kuznets curve with Principal Component Analysis (PCA) will create aggregated indicators for analyzing the relationship between economic growth and sustainability indicators. While the Kuznets theorem is traditionally used to identify U-shaped relationships between economic growth and individual factors, such as inequality or pollution, this approach extends its application to multidimensional analysis of ESG components.

4. FINDINGS AND DISCUSSION

The analysis consists of several stages. The first stage involved factor loadings to identify the main components influencing each sustainability category. Next, a component characteristics analysis was performed to determine the variance explained by each component, followed by a parallel study to validate the identified factors. A quadratic regression analysis was then applied to assess the relationship between economic growth and each aggregated ESG component. Finally, residuals were examined for each component to evaluate model fit and identify areas for potential improvement.

The results of the factor loadings analysis are presented in Table 1, indicating the primary components that influence each category.

TABLE 1. Factor loadings

Indicator	RC1	Uniqueness
Healthcare component		
Doctors	0.945	0.107
Healthcare staff	0.931	0.134
Hospitals	-0.886	0.214
Hospital beds	0.401	0.840
Ecology component		
GDP Energy Productivity	0.984	0.031
Per Capita Energy Use	-0.954	0.089
Water Stress Level	0.900	0.190
Hazardous Waste per Capita	-0.821	0.326
CO_2 Emissions per Capita (Energy)	-0.669	0.552
Stationary Source Emissions	0.580	0.663
RenewableEnergy Share	0.536	0.713
Social component		
Poverty_Depth	0.988	0.023
Poverty_Rate	0.965	0.069

Income-Subsistence_Ratio	-0.950	0.098
Employed	0.903	0.184
Gini_Index	0.874	0.235
Unemployement %	-0.645	0.584
Real_Income_Index	0.430	0.815
Education component		
Unemployment	-0.843	0.290
University graduates	0.843	0.290

Note: compiled based on calculations

In the healthcare component, the most significant indicators are 'Doctors' (0.945) and 'Healthcare staff' (0,931), emphasizing their essential roles within this category. In contrast, the 'Hospital beds' indicator shows minimal influence with a high uniqueness value (0,843), indicating its limited impact on the overall structure.

In the Ecological component, 'GDP Energy Productivity' (0,984) and 'Per Capita Energy Use' (-0,954) exhibit the highest loadings, underscoring their leading role in shaping the ecological component; additionally, 'Water Stress Level' (0,900) contributes strongly as a significant factor.

Within the Social component, the indicators 'Poverty Depth' (0,988) and 'Poverty Rate' (0.965) demonstrate the highest loadings, highlighting their influence on the social dimension. 'Income-Subsistence Ratio' (-0,950) and 'Employed' (0,903) indicators also play substantial roles, reflecting socioeconomic factors. In the Education component, 'Unemployment' (-0,843) and 'University Graduates' (0,843) show equal loadings, indicating opposing trends related to education and employment dynamics within this factor.

The Social component stands out with the highest eigenvalue, 4.991, explaining 71.3% of the variance independently and cumulatively. The Education component, with an eigenvalue of 1.421, captures 71.0% of the variance.

Table 2 presents the component characteristics, showing unrotated and rotated solutions for each extracted component.

TABLE 2. Component characteristics

Component	**Unrotated solution**			**Rotated solution**		
	Eigenvalue	**Proportion var.**	**Cumulative**	**SumSq. Loadings**	**Proportion var.**	**Cumulative**
Healthcare	2.705	0.676	0.676	2.705	0.676	0.676
Ecology	4.436	0.634	0.634	4.436	0.634	0.634
Social	4.991	0.713	0.713	4.991	0.713	0.713
Education	1.421	0.710	0.710	1.421	0.710	0.710

Note: complied based on calculations

For complete analysis the results were also interpreted through residual plots. Each plot shows eigenvalues from the data (black circles) and simulated eigenvalues from parallel analysis (black triangles) for the component groups: Healthcare (PC_Healthcare), Ecology (PC_Ecological), Social (PC_Social), and Education (PC_Education).

Figure 1 presents the results of a parallel analysis to confirm the components identified in the factor loadings and Component Characteristics.

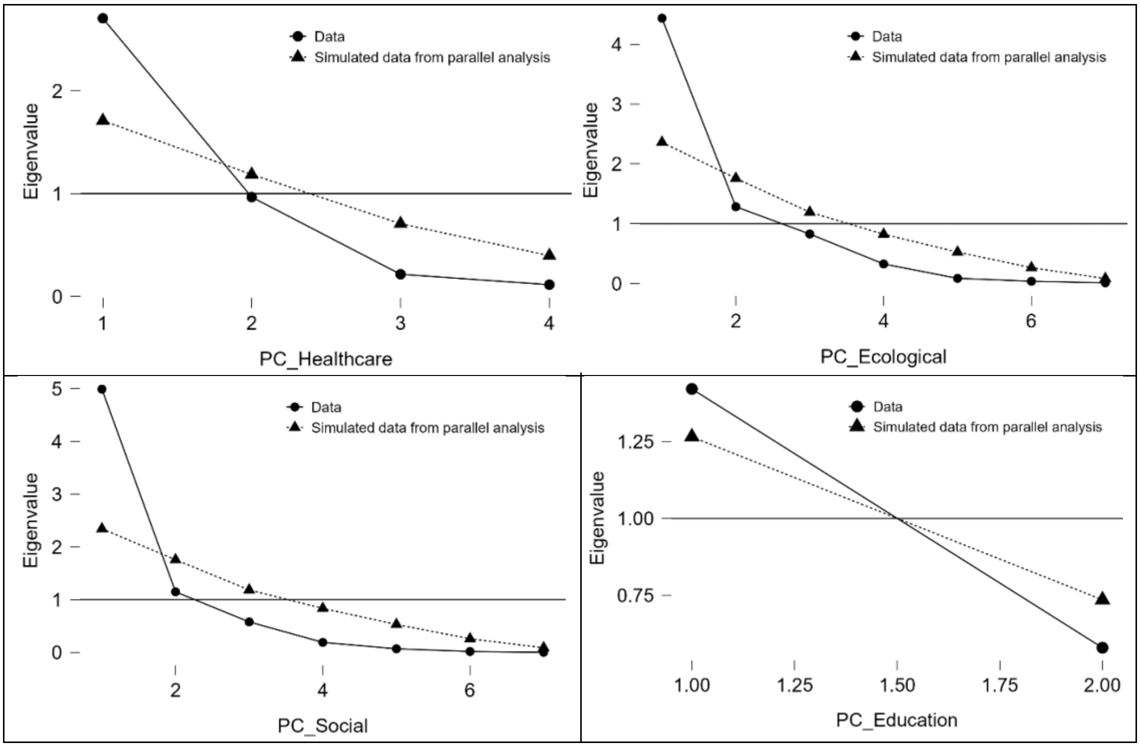

FIGURE 1. Residual plots

Note: compiled based on calculations

For Healthcare (PC_Healthcare), only the first component, with an eigenvalue of 2.705, exceeds the simulated threshold, confirming a single significant factor in this category. In Ecology (PC_Ecological), the first two components have eigenvalues of 4.436 and 2.634, respectively, supporting the need for two factors to capture the complexity in this group. The Social (PC_Social) group also shows two significant components with eigenvalues of 4.991 and 2.713, indicating two primary factors for this domain. In Education (PC_Education), only the first component, with an eigenvalue of 1.421, is above the threshold, confirming it as the sole necessary factor for this category.

Table 3 presents the results of the model summary for quadratic regression analysis.

TABLE 3. Model summary

No.	Model	R	R^2	Adjusted R^2	RMSE
1	M_0 Carbon Productivity	0.000	0.000	0.000	0.178
	M_1 Carbon Productivity	0.358	0.128	-0.090	0.186
2	M_0 PC_Ecological	0.000	0.000	0.000	1.000
	M_1 PC_Ecological	0.593	0.352	0.190	0.900
3	M_0 PC_Healthcare	0.000	0.000	0.000	1.000
	M_1 PC_Healthcare	0.648	0.419	0.274	0.852
4	M_0 PC_Social	0.000	0.000	0.000	1.000
	M_1 PC_Social	0.589	0.348	0.184	0.903
5	M_0 PC_Education	0.000	0.000		1.000
	M_1 PC_Education	0.834	0.696		0.616

Note: compiled based on calculations

Carbon Productivity has a low R^2 of 12.8% in the enhanced model (M_1), indicating a weak relationship with economic growth. This low explanatory power shows that GDP growth alone does not inherently lead to improvements in carbon productivity. Economic growth may contribute only marginally without specific measures directed toward emissions reduction and resource efficiency.

The Ecological component has a moderate association with economic growth, with M_1 explaining 35.2% of the variance. Some relationship exists between economic growth and ecological outcomes, yet it remains limited. Factors such as resource use inefficiencies or environmental degradation accompanying industrial expansion may influence this result. Economic growth may moderately impact ecological sustainability but does not guarantee substantial ecological benefits.

Healthcare shows a more substantial relationship with economic growth, with the model explaining 41.9% of the variance. Economic growth impacts healthcare accessibility and quality, often leading to increased investment in healthcare infrastructure, workforce, and technology. This model outcome emphasizes the positive impact of economic expansion on healthcare systems, which contributes to labor productivity and population well-being. However, more than GDP growth is needed to fully address healthcare needs in areas with underfunded healthcare systems.

The Social component has moderate explanatory power, with M_1 accounting for 34.8% of the variance. Economic growth can positively influence social well-being by reducing poverty or improving income distribution; however, GDP growth alone may not sufficiently address social inequalities or poverty depth. Therefore, economic growth alone does not guarantee comprehensive social progress.

The Education component exhibits the most vital relationship with economic growth, with M_1 explaining 69.6% of the variance. Economic growth impacts educational quality and accessibility, as higher GDP per capita generally correlates with greater investments in education. Improved educational outcomes contribute to a skilled labor force, fostering innovation and productivity, thus reinforcing a cycle of economic growth. Education funding directly correlates with long-term economic benefits by equipping the workforce with skills necessary for adapting to technological advancements and shifts in labor market demands.

Individual indicators within these aggregated components carry greater weight in shaping each ESG component. In the Healthcare component, indicators like “Doctors” and “Healthcare staff” show higher factor loadings, meaning that increases in these indicators drive much of the component's response to economic growth. In the Ecological component, “GDP Energy Productivity” and “Per Capita Energy Use” play the most influential roles, meaning that efforts to boost energy productivity or manage energy use per capita can be critical for advancing ecological sustainability.

Table 4 presents the results of the ANOVA analysis for each component model.

TABLE 4. ANOVA

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
M_1 Carbon Productivity	Regression	0.041	2	0.020	0.588	0.578
	Residual	0.276	8	0.035		
	Total	0.317	10			
M_1 PC_Ecological	Regression	3.520	2	1.760	2.173	0.176
	Residual	6.480	8	0.810		
	Total	10.000	10			
M_1 PC_Healthcare	Regression	4.194	2	2.097	2.890	0.114
	Residual	5.806	8	0.726		

	Total	10.000	10			
M_1 PC_Social	Regression	3.475	2	1.738	2.130	0.181
	Residual	6.525	8	0.816		
	Total	10.000	10			
M_1 PC_Education	Regression	6.961	2	3.480	9.160	0.009
	Residual	3.039	8	0.380		
	Total	10.000	10			

Note: complied based on calculations

For Carbon Productivity (M_1), the regression sum of squares is 0.041 with an F-value of 0.588 and a non-significant p-value of 0.578, indicating a weak model fit. In the Ecological component (M_1), the regression sum of squares is 3.520 with an F-value of 2.173 and a p-value of 0.176, suggesting a moderate fit but not statistically significant. The Healthcare component (M_1) shows a regression sum of squares of 4.194 with an F-value of 2.890 and a p-value of 0.114, indicating some predictive power but not reaching significance.

For the Social component (M_1), the regression sum of squares is 3.475 with an F-value of 2.130 and a p-value of 0.181, also showing a moderate fit without statistical significance. The Education component (M_1) has the strongest model fit, with a regression sum of squares of 6.961, an F-value of 9.160, and a significant p-value of 0.009, indicating a strong and statistically significant association with economic growth.

Table 5 shows the coefficients for each model, providing details on the intercepts, coefficients for GDP and its square (GDP_PCS2), and their significance levels.

TABLE 5. Coefficients

Model		**Unstandardized**	**Standard Error**	**Standardized**	**t**	**p**
M_0 Carbon Productivity	(Intercept)	1.620	0.054		30.177	< .001
M_1 (Carbon Productivity)	(Intercept)	-0.360	2.024		-0.178	0.863
	GDP_PCS2	-1.796×10^{-8}	1.721×10^{-8}	-4.029	-1.044	0.327
	GDP_PC	3.823×10^{-4}	3.768×10^{-4}	3.917	1.015	0.340
M_0 PC_Ecological	(Intercept)	-1.272×10^{-15}	0.302		-4.219×10^{-15}	1.000
M_1 PC_Ecological	(Intercept)	-13.676	9.800		-1.396	0.200
	GDP_PCS2	-1.365×10^{-7}	8.333×10^{-8}	-5.452	-1.638	0.140
	GDP_PC	0.003	0.002	5.065	1.522	0.166
M_0 PC_Healthcare	(Intercept)	-2.678×10^{-16}	0.302		-8.882×10^{-16}	1.000
M_1 *PC_Healthcare*	(Intercept)	-10.525	9.276		-1.135	0.289
	GDP_PCS2	-1.166×10^{-7}	7.887×10^{-8}	-4.656	-1.478	0.178
	GDP_PC	0.002	0.002	4.128	1.311	0.226
M_0 *PC_Social*	(Intercept)	5.189×10^{-16}	0.302		1.721×10^{-15}	1.000
M_1 *PC_Social*	(Intercept)	-17.073	9.834		-1.736	0.121
	GDP_PCS2	-1.589×10^{-7}	8.362×10^{-8}	-6.347	-1.901	0.094
	GDP_PC	0.003	0.002	6.094	1.825	0.105
M_0 *PC_Education*	(Intercept)	0.000	0.302		0.000	1.000
M_1 *PC_Education*	(Intercept)	2.969	6.712		0.442	0.670
	GDP_PCS2	6.610×10^{-8}	5.707×10^{-8}	2.640	1.158	0.280
	GDP_PC	-0.001	0.001	-1.827	-0.802	0.446

Note: compiled based on calculations

Carbon Productivity, the intercept in the baseline model (M_0) is highly significant (t=30.177t = 30.177t=30.177, p<.001p < .001p<.001), while the enhanced model (M_1) shows non-significant coefficients for both GDP_PCS2 (p=0.327p = 0.327p=0.327) and GDP_PC (p=0.340p = 0.340p=0.340), indicating limited impact from economic growth variables.

Ecological component (PC_Ecological), the intercept for M_0 is not significant, and in M_1, while GDP_PCS2 and GDP_PC have t-values of -1.638 and 1.522 respectively, they do not reach statistical significance (p=0.140p = 0.140p=0.140 and p=0.166p = 0.166p=0.166), indicating a moderate but non-significant effect.

Healthcare component (PC_Healthcare), neither GDP_PCS2 (p=0.178p = 0.178p=0.178) nor GDP_PC (p=0.226p = 0.226p=0.226) are statistically significant in the enhanced model (M_1), suggesting limited explanatory power of GDP growth for this component.

Social component (PC_Social), both GDP_PCS2 and GDP_PC coefficients approach significance, with t-values of -1.901 and 1.825 and p-values of 0.094 and 0.105, respectively. This indicates a potential relationship, although it remains marginally non-significant.

Education component (PC_Education), neither GDP_PCS2 (p=0.280p = 0.280p=0.280) nor GDP_PC (p=0.446p = 0.446p=0.446) in M_1 is significant, suggesting that GDP growth does not strongly influence this component based on the tested model. Overall, the results reveal limited significance across most components, with slight tendencies towards relevance in the social component.

The residual plots for each component, Residuals vs. Dependent Variable, illustrate the model's fit and highlight areas needing refinement in the Education, Healthcare, Ecology, Carbon Productivity, and social components (Figure 2).

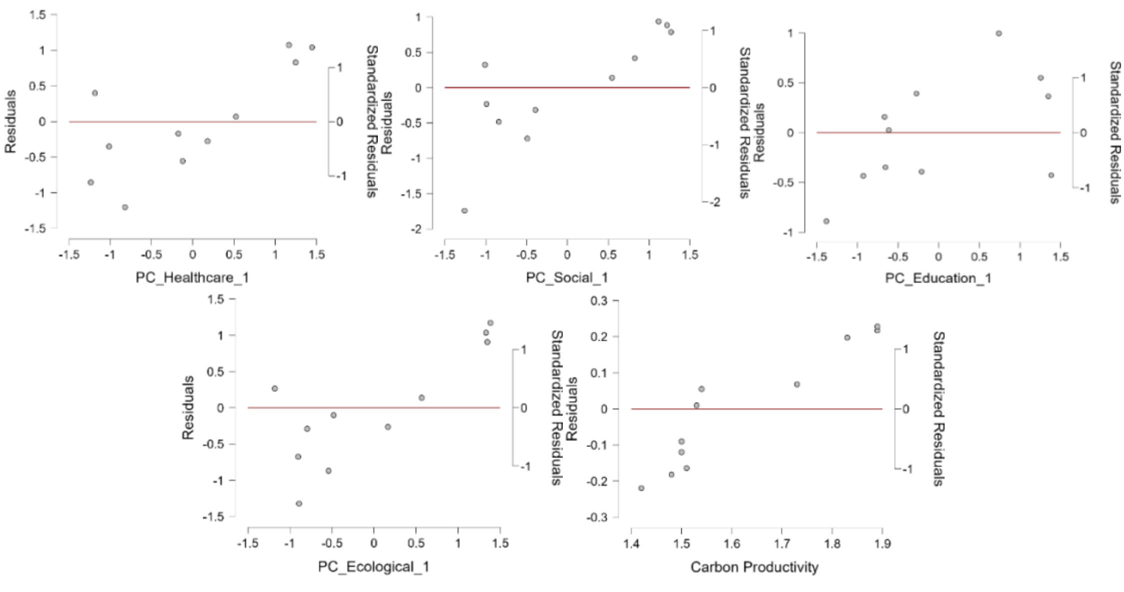

FIGURE 2. Residual plots

Note: complied based on calculations

In the Education component, residuals are evenly distributed around zero, with values ranging from approximately -1.0 to 1.0, demonstrating an excellent fit and minimal bias in the model's predictions. For the Healthcare component, residuals cluster at higher values, particularly between 0.5 and 1.5, which shows reduced model accuracy for dependent variable values in this range, possibly due to slight heteroscedasticity.

The Ecology component displays a few positive outliers, with residuals reaching up to 1.5, indicating underpredictions at higher dependent variable values, where the model does not capture these extremes accurately. In Carbon Productivity, residuals are small, generally between -0.3 and 0.3, and centered around zero. However, there is a minor upward trend as values increase, pointing to slight underfitting at higher productivity levels.

In the Social component, residuals range from -2.0 to 1.0, with positive residuals clustering at the higher end, which reveals limited model accuracy for certain outcomes in this category. Overall, while the model fits well for Education and Carbon Productivity, adjustments in the Healthcare and Ecology components could improve predictive accuracy across the full range of dependent variable values.

The absence of a significant relationship with GDP growth for carbon productivity shows that increases in GDP do not inherently lead to higher carbon efficiency. Direct environmental and technological interventions are necessary to enhance carbon productivity alongside economic growth, particularly in light of the growing emphasis on ESG (environmental, social, and governance) standards. Low carbon productivity with economic expansion increases the risk of ecological costs and challenges to long-term sustainability.

The Ecological Component, the moderate association with GDP growth, reveals that environmental conditions may improve with economic growth but only to a limited degree. The underprediction of higher ecological values indicates that GDP growth alone is insufficient to drive substantial ecological benefits, emphasizing the need for more stringent environmental policies and incentives that ensure economic growth aligns with ecological sustainability.

The Healthcare Component shows that GDP growth positively influences healthcare systems, though it does not fully determine healthcare quality and accessibility. Since population health directly affects labor productivity, a healthy workforce is crucial for sustained economic growth. Investments in healthcare, in addition to GDP growth, are essential to improving life quality and maximizing economic returns from a healthier, more productive population.

The Social Component's moderate link with GDP growth confirms that economic growth supports poverty reduction and social well-being. Still, it alone cannot ensure improved living conditions for all. Additional social programs are required to address inequality effectively, as GDP growth does not always benefit the most vulnerable groups. Supporting social programs would enable a more equitable distribution of economic gains, thus enhancing overall economic development.

The Education Component demonstrates the strongest relationship with GDP growth, indicating that economic expansion directly improves educational quality and accessibility. This connection is critical, as investment in education develops human capital, which sustains long-term economic growth and fosters innovation. Higher educational attainment strengthens the economy by equipping a skilled workforce and boosting productivity and technological advancement.

The analysis confirms the Kuznets hypothesis with specific distinctions. According to Kuznets' theory, economic growth initially worsens specific sustainability indicators, improving as development progresses. Quadratic regression, applied to each sustainability component (e.g., Carbon Productivity, Ecology), captures the inverted U-shaped relationships characteristic of the Kuznets model.

The results indicated that the relationship between economic growth and each component (e.g., Carbon Productivity and Ecology) could be more consistently strong and significant. GDP growth alone does not guarantee improvements in sustainability, particularly without targeted measures and environmental policies. Stronger correlations appear in components like Healthcare and Education, where GDP growth positively impacts these areas, underscoring the importance of social investments for sustainable development.

Therefore, the Kuznets method is partially validated: the link between growth and improvements in sustainability indicators varies across different areas, highlighting the necessity of a comprehensive approach that addresses the unique factors influencing each category.

5. CONCLUSIONS

The primary objective of this study is to evaluate the impact of economic growth on key components of sustainability, including carbon productivity, ecological conditions, healthcare, social well-being, and education. Results showed no significant relationship between GDP growth and Carbon Productivity, indicating that economic growth does not inherently improve carbon efficiency. For the Ecology and Healthcare components, moderate relationships were observed, suggesting that while economic growth contributes to some improvements, it does not fully meet ecological or healthcare needs. In the Social component, economic growth supported social outcomes moderately but without significantly reducing inequality or social disparities. Education showed the strongest relationship, with GDP growth substantially enhancing access and quality, underscoring the importance of prioritizing education funding and aligning it with labor market needs to leverage economic growth's impact on human capital fully. Building on these conclusions, the implications for Kazakhstan indicate that sustainable development cannot rely solely on economic growth. The study’s findings support the Kuznets hypothesis in certain domains: while economic growth initially increases pressure on environmental resources, positive effects on social indicators, such as healthcare and education, become more apparent as income levels rise. The lack of a strong relationship between GDP growth and Carbon Productivity underscores that environmental sustainability demands direct policy interventions beyond economic expansion. For Kazakhstan, this analysis highlights that Sustainable Development Goals (SDGs) focused on environmental sustainability and carbon efficiency are not substantially advanced through economic growth alone. While the Kazakhstani economy continues to expand, this growth does not inherently address environmental challenges such as pollution or resource use efficiency. GDP growth in Kazakhstan has not translated into significant improvements in carbon efficiency or reduced ecological impact, underscoring the necessity of stricter environmental policies and the adoption of technologies designed to enhance resource management and lower emissions. Conversely, SDG areas related to social development show more positive outcomes associated with economic expansion. For instance, Kazakhstan has been able to improve access to healthcare and education, as well as elevate general living standards. As the economy grows, increased resources are available for investments in public health, education, and social welfare programs, helping to address issues of poverty and inequality. Social domains thus become more resilient and contribute to an enhanced quality of life for the Kazakhstani population.

To achieve Sustainable Development Goals in the areas of ecology and carbon efficiency, Kazakhstan must go beyond economic policies alone. Additional targeted efforts are essential, including stricter environmental regulations and advanced technologies aimed at improving carbon efficiency. While economic growth in Kazakhstan supports the social sphere, ensuring sustainable development in environmental areas requires a comprehensive approach. There must be considered economic growth strategies with specific environmental policies focused on resource management, emissions reduction, and energy efficiency. Through prioritizing investments in education, social well-being, and environmental programs, Kazakhstan can foster sustainable economic growth, reduce its environmental impact, and create a foundation for long-term prosperity.

AUTHOR CONTRIBUTION

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