"Relationships between human development, economic growth, and environmental condition: The case of South Korea"

AUTHORS	Zeynab Giyasova (iD)
	Ⓡ
	Shafa Guliyeva (iD)
	Reyhan Azizova (iD)
	Liliana Smiech (iD)
	Irada Nabiyeva

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
36	2	8

© Zeynab Giyasova, Shafa Guliyeva,
Reyhan Azizova, Liliana Smiech, Irada
Nabiyeva, 2025

Zeynab Giyasova, Ph.D., Department
of Economy, Azerbaijan State
University of Economics (UNEC),
Azerbaijan; Department of Economics
and Statistics, Azerbaijan Technical
University, Azerbaijan. (Corresponding
author)

Shafa Guliyeva, Ph.D., Full Professor,
Department of Business and Logistics,
Azerbaijan State University of
Economics (UNEC), Azerbaijan.

Reyhan Azizova, Ph.D., Department
of Digital Technologies and Applied
Informatics, Azerbaijan State University
of Economics (UNEC), Azerbaijan.

Liliana Smiech, Ph.D., Department of
Public Economics, Krakow University
of Economics, Poland.

Irada Nabiyeva, Ph.D.(c), Department
of Business and Logistics, Azerbaijan
State University of Economics (UNEC),
Azerbaijan; Department of Economics
and Statistics, Azerbaijan Technical
University, Azerbaijan.

Zeynab Giyasova (Azerbaijan), **Shafa Guliyeva** (Azerbaijan), **Reyhan Azizova** (Azerbaijan), **Liliana Smiech** (Poland), **Irada Nabiyeva** (Azerbaijan)

RELATIONSHIPS BETWEEN HUMAN DEVELOPMENT, ECONOMIC GROWTH, AND ENVIRONMENTAL CONDITION: THE CASE OF SOUTH KOREA

Abstract

The study examines the long-term relationships between human development, economic growth, and environmental conditions in South Korea from 1996 to 2021. Understanding these interactions is crucial for shaping policies that balance economic progress, social well-being, and environmental sustainability. The analysis employs cointegration techniques, including the Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegration Regression (CCR) methods, to estimate long-run relationships among GDP per capita, the Human Development Index (HDI), and carbon dioxide emissions per capita. Empirical findings confirm a stable long-term equilibrium between GDP and HDI, as demonstrated by significant Engle-Granger and Phillips-Ouliaris test statistics (p-values ≤ 0.0245). The results suggest that economic growth consistently enhances human development, while improvements in HDI contribute to sustained economic progress. The relationship between HDI and carbon emissions per capita, however, yields mixed evidence. The Engle-Granger test supports a long-term association (p-values ≤ 0.015), but the Phillips-Ouliaris test does not confirm cointegration (p-values ≥ 0.112). The covariance matrix test indicates that the negative relationship between HDI and carbon emissions per capita is stronger and more variable compared to the more stable inverse association between HDI and GDP per capita. Additionally, Granger causality analysis reveals a significant causal relationship between HDI and GDP per capita, supported by a Chi-square value of 20.627 and a p-value below 0.001. These findings highlight the complexity of integrating environmental considerations into development policies. South Korea's experience underscores the necessity of a balanced policy framework that ensures sustainable economic growth while advancing human development and mitigating environmental impacts.

Keywords	human development index, economic growth, human capital, environment, CO_2 emissions, econometrics, time-series, South Korea
JEL Classification	Q56, O44, C32, I31, F43

INTRODUCTION

The dynamic interplay between human development, economic growth, and environmental sustainability has emerged as a key focus in academic and policy discourse, particularly within the framework of sustainable development. While economic growth contributes to improving living standards, it often exacerbates environmental degradation, notably through increased greenhouse gas emissions. The central challenge is to reconcile these objectives to achieve long-term sustainability, as outlined in the United Nations Sustainable Development Goals. Human capital theory underscores the importance of education in shaping human capital, which plays a vital role in fostering economic growth (Acevedo, 2008). This interconnectedness between human development and economic progress makes understanding their

dynamics a priority for policymakers striving to achieve sustainable development. Today's global trend emphasizes the need for sustainable management and the innovative redesign of the future, particularly in cases related to human capital development (Hitka et al., 2019; Hasanov & Safarli, 2023).

South Korea, a highly industrialized country, offers an exemplary case study for exploring the intersection of economic growth and human development. The nation's economic transformation is frequently attributed to its strategic emphasis on human development, particularly through its robust education system (Lee, 2005, 2007; U. Kim & J. Kim, 2022; Park, 2024). Over several decades, South Korea has undergone significant political and economic changes, evolving from an agrarian economy to one of the world's leading economies. A cornerstone of this development has been its focus on expanding educational opportunities, thereby equipping its workforce with the skills necessary to drive economic growth in an increasingly knowledge-based global economy (Isozaki, 2019). The country's experience has shaped global discussions on development, influencing organizations such as the United Nations Development Programme (UNDP) and other UN bodies (McNeill & Ottersen, 2015).

Despite numerous challenges, including global trade tensions and regional geopolitical issues, South Korea's economy has remained resilient. From 2013 to 2022, the country's GDP growth was largely driven by strong export performance and technological advancements, with a post-pandemic recovery further bolstering economic resilience. During this period, South Korea achieved an average growth rate of 2.7%, slightly below the regional average of 4.4%. In 2022, the real GDP growth rate was recorded at 2.6% (FE, n.d.). However, alongside this economic success, South Korea has also grappled with the environmental consequences of rapid industrialization. In 2022, South Korea accounted for 1.6% of global CO_2 emissions from fuel combustion, with total emissions reaching 549.311 million metric tons (Mt CO_2), a 32% increase from 2000 to 2022 (IEA, n.d.). These figures highlight the pressing need to examine the relationship between economic growth and environmental impact, especially in the context of global efforts to mitigate climate change.

Sustainable development entails the integration of economic growth, social well-being, and environmental protection, a complex task particularly relevant to South Korea's rapid industrialization. Although the country has achieved substantial progress in economic and human development, the accompanying rise in carbon emissions raises concerns about the long-term sustainability of its growth model. Therefore, it is interesting to investigate the core scientific issue of aligning development objectives with environmental constraints by analyzing the long-term interrelationship between human development, economic growth, and per capita carbon emissions in South Korea.

1. LITERATURE REVIEW

The Human Development Index is a widely used composite measure for assessing human development, combining indicators of health, education, and income. Numerous studies have explored the impacts of HDI on various socio-economic and environmental factors, revealing both direct and indirect relationships with economic growth, environmental sustainability, and social well-being.

Costantini and Monni (2008) examined the relationship between economic growth, human development, and sustainability by integrating the Resource Curse Hypothesis (RCH) with the Environmental Kuznets Curve (EKC), incorporating a human development perspective. They argued that HDI-related factors, such as education and healthcare, play a significant role in fostering sustainability and mitigating the negative effects of resource dependence on economic growth. The study highlighted the importance of human development as a foundation for long-term sustainability. Maksymenko and Rabbani (2008) employed a multivariate time series model to analyze the impact of economic reforms and human capital on post-reform growth in India and South Korea. Their findings revealed that human capital, a key component of HDI, positively affected economic growth in both coun-

tries. However, the effectiveness of economic reforms in driving growth varied across the two countries, suggesting that human development, reflected in HDI, enhances the efficiency of economic reforms and contributes to sustainable growth. Gürlük (2009) focused on the role of human development in the economic development trajectories of Mediterranean countries. Using the EKC framework, the study analyzed the relationship between economic growth and industrial pollution, highlighting the role of human development in mitigating environmental degradation. The research emphasized the necessity of prioritizing human development in Southern Mediterranean countries for sustainable economic progress, with HDI serving as a vital indicator of overall well-being and development potential.

Jeremic et al. (2011) proposed the ecological footprint as a complementary welfare indicator to HDI, addressing the latter's limitations in incorporating sustainability. Their analysis of European Union countries underscored the importance of incorporating environmental factors alongside HDI to achieve a more comprehensive understanding of welfare. By integrating environmental sustainability into HDI, they emphasized the need to move beyond traditional economic indicators and focus on sustainable development outcomes. The impact of human development, particularly through human capital, is also evident in studies examining environmental decoupling. Han et al. (2018) explored the decoupling of fossil fuel-induced CO_2 emissions from economic growth in China. They found that stronger human capital, reflected through better education and health, was crucial in enabling the country to achieve relative decoupling. This suggests that HDI's focus on human development enhances the ability of countries to decouple growth from environmental degradation. Reyes and Useche (2019) analyzed the relationship between competitiveness, GDP growth, and human development in Latin American and Caribbean countries. Their study highlighted that while human development improved in the region, no significant correlation was found between economic growth and HDI. This finding suggests that HDI improvements may not always translate directly into economic

growth, indicating that other factors, such as governance and institutional quality, may mediate this relationship. Ahmed et al. (2020) investigated the relationship between natural resource abundance, human capital, and urbanization in China, highlighting the mitigating effect of human capital on environmental degradation. The study found that HDI-related factors, particularly human capital, helped reduce the ecological footprint by promoting sustainable practices, underscoring the role of HDI in fostering environmental quality. Zhou et al. (2022) examined the relationship between economic growth and environmental quality in Huzhou, China. Their study found that the inflection point for environmental quality, based on HDI components such as income and education, was higher than for CO_2 emissions, suggesting that improvements in human development could enable a higher level of economic growth without compromising environmental quality.

The reviewed literature emphasizes the nuanced and interdependent nature of the relationships between human development, economic performance, and environmental quality, often shaped by country-specific conditions. This complexity necessitates focused empirical analysis to generate evidence-based policy insights tailored to national development paths. Against this backdrop, the present study investigates the long-term cointegration and causal linkages among the Human Development Index, GDP per capita, and carbon dioxide emissions per capita in South Korea from 1996 to 2021. The hypotheses are:

H1:   *There is a long-term cointegrating relationship between the HDI and GDP per capita in South Korea.*

H2:   *Higher levels of HDI are linked to a reduction in CO_2 emissions per capita in South Korea.*

H3:   *Renewable energy consumption does not have a significant impact on GDP per capita in South Korea.*

H4:   *HDI Granger causes GDP per capita in South Korea.*

2. METHODOLOGY

The analysis explores the interplay between human development, economic growth, and environmental conditions in South Korea, focusing on three core indicators. First, the Human Development Index (HDI), as a composite measure, evaluates average achievements in key dimensions of human development. Data are obtained from the United Nations Development Programme (UNDP, n.d.). Second, GDP per capita (GDPPC) is an economic metric representing the gross domestic product divided by the total population, sourced from the World Bank (n.d.). Third, carbon dioxide emissions (CO_2) are measured as per capita CO_2 emissions (excluding land use, land-use change, and forestry) in metric tons. Data are drawn from the World Bank (n.d.) and Worldometer (n.d.). Finally, renewable energy consumption (REC) is the share of renewable energy consumption in total energy use, typically measured as a percentage. Data are sourced from the World Bank (n.d.).

The dataset comprises annual observations for a specified period, ensuring consistency among the variables. To facilitate uniform comparisons, all indicators are expressed per capita.

Table 1 presents the descriptive statistics for all variables. Key observations include a relatively low standard deviation for HDI, signifying that its values are closely centered around the mean. In contrast, LGDPPC exhibits a higher standard deviation, indicating greater variability in GDP per capita. Furthermore, all three variables show negative skewness, implying that their distributions possess a longer tail on the left side.

Table 1. Descriptive statistics of the variables

Statistic	HDI	GDPPC	CO_2	REC
Mean	0.871808	23712.97	11.29254	1.638462
Median	0.875000	23919.94	11.12713	1.150000
Maximum	0.926000	32771.07	13.00846	3.600000
Minimum	0.791000	14198.39	8.413381	0.600000
Std. Dev.	0.041901	5899.711	1.321404	1.040030
Skewness	−0.441484	−0.145820	−0.368843	0.740897
Kurtosis	1.952358	1.763262	2.070750	1.952956
Jarque-Bera	2.033620	1.749122	1.524993	3.566349
Probability	0.361747	0.417045	0.466500	0.168104

Figure 1 shows time series plots illustrating a continuous upward trend in both LGDPPC (logarithmic form) and HDI, signifying persistent economic growth and advancements in human development. Although CO_2 emissions initially increased, the trend has since plateaued or decreased, suggesting potential efforts to decouple economic growth from environmental degradation, with the CO_2 emissions series displaying higher volatility and a recent decline. Another detail is that REC shows an upward trend in this period.
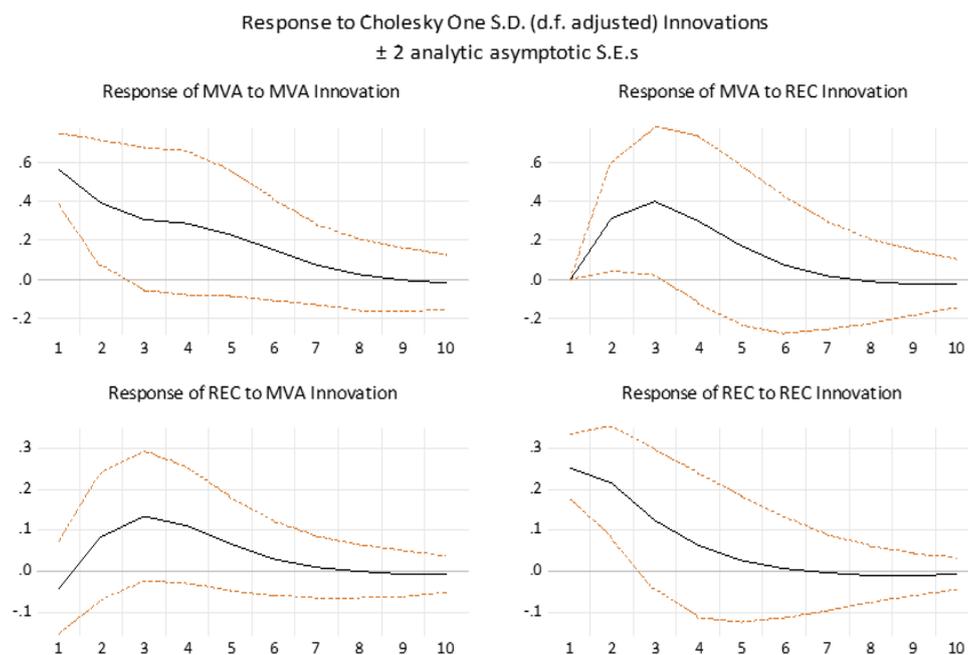

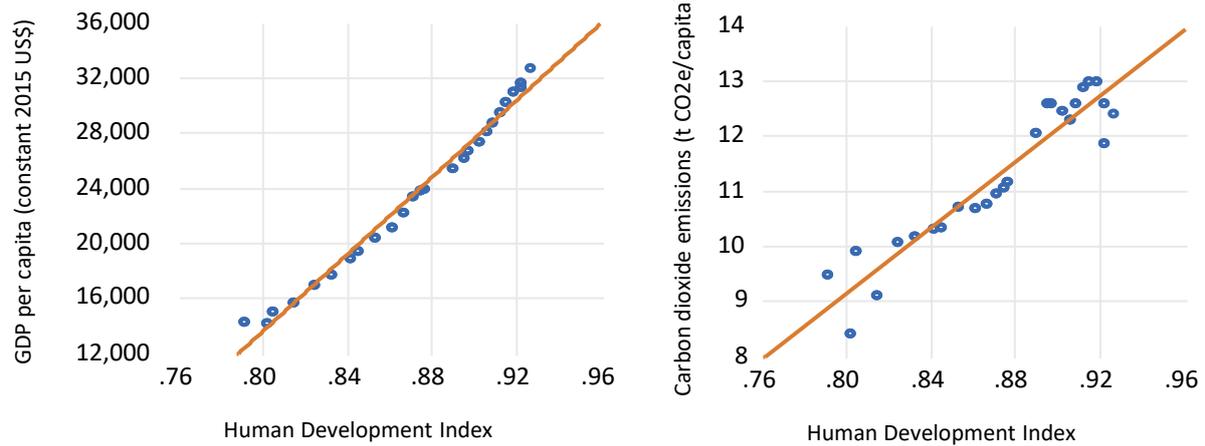**Figure 1.** Time series trends of LGDPPC, HDI, and CO_2

Figure 2. Scatter plot analysis of the relationships between HDI, GDPPC, and CO₂

Figure 2 illustrates a scatter plot analysis that highlights a significant positive correlation between GDP per capita and HDI, reinforcing the idea of a strong link between economic growth and human development. In contrast, the relationship between HDI and CO_2 emissions appears weaker and more variable, indicating that while human development may foster environmental improvements, this effect is inconsistent. The variability in this relationship is likely influenced by factors such as energy infrastructure, technological innovations, and the adoption of environmental policies.

This paper adopts an econometric approach to investigate the long-term interactions among economic growth, human development, and environmental conditions in South Korea. The study applies advanced cointegration techniques and robust estimation methods to ensure accurate and meaningful findings. The Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR) techniques are employed to estimate long-run parameters. FMOLS corrects for endogeneity and serial correlation, while CCR enhances efficiency by transforming data to accommodate non-stationarity. These methods produce consistent and efficient estimators, ensuring reliable insights into equilibrium relationships. Covariance matrix analysis is conducted to evaluate the stability and variability of these relationships, further verifying the robustness of the findings. The final analysis tests for long-term relationships using the Engle-Granger (1987) and Phillips-Ouliaris (1990) cointegration tests. The Engle-Granger test evaluates the null hypothesis of no cointegration using tau and z-statistics, while the Phillips-Ouliaris test provides additional robustness. Together, these tests are essential for assessing whether the variables exhibit long-term convergence despite short-term variations. This methodological framework, which integrates cointegration tests, FMOLS, CCR, and covariance matrix analysis, offers a holistic approach to examining the intricate relationships among the variables.

Granger causality is a well-established statistical method to investigate the causal relationships between time series variables. The core assumption of this method is that if one variable (X) "Granger causes" another variable (Y), past values of X will provide useful information in forecasting future values of Y, under the condition that the variables are integrated and stationary. This approach is particularly effective for assessing temporal causality without implying direct causality. This study employs the Toda-Yamamoto (1995) Granger causality technique to examine the causal relationships between independent and dependent variables. This method is chosen for its robustness in handling non-stationary time series data, offering more reliable results even when structural breaks or cointegration are present. The Toda-Yamamoto approach also facilitates the selection of an appropriate lag length, ensuring the accurate capture of both short- and long-term causal effects. By applying this method, the study aims to explore the causal interactions between key economic variables such as renewable energy consumption

(REC), the Human Development Index (HDI), and GDP per capita (GDPPC), thereby deepening the understanding of their interconnections and their role in economic growth.

3. RESULTS

Table 2 presents the results from the Augmented Dickey-Fuller (1979) (ADF) and Phillips-Perron (1988) (PP) unit root tests for HDI, LGDPPC, CO_2, and REC. The findings indicate that all three variables are non-stationary at their levels, as evidenced by p-values greater than 0.05. However, after first differencing the series, both tests reveal stationarity with p-values below 0.05, suggesting that the variables are integrated of order 1 (I(1)). This is a crucial prerequisite for conducting cointegration tests, which require the variables to be I(1). The unit root tests help mitigate the risk of spurious regression, ensuring the validity of subsequent analyses.

Table 3 shows the covariance matrix analysis between HDI, LGDPPC, and CO_2. Matrix 1 indicates a weak inverse association between HDI and

LGDPPC, characterized by relatively small variances for both variables, suggesting that their values are tightly clustered around the mean. In contrast, Matrix 2 demonstrates a more pronounced negative relationship between HDI and CO_2 emissions, with both HDI and CO_2 exhibiting larger variances. The increased variability of HDI in this context implies that human development is subject to greater fluctuations when correlated with CO_2 emissions than with GDP per capita. The negative covariance between HDI and CO_2 emissions implies that higher levels of human development are associated with a significant reduction in CO_2 emissions. In summary, the inverse relationship between HDI and CO_2 emissions is more robust than that between HDI and LGDPPC.

Cointegration analysis in Table 4 reveals a stable long-term relationship between logarithmic GDP per capita (LGDPPC) and the Human Development Index (HDI) in South Korea. The Engle-Granger test results show significant tau and z-statistics (p-values of 0.0094 and 0.0000, respectively), rejecting the null hypothesis of no cointegration. Similarly, the Phillips-Ouliaris test confirms coin-

Table 2. Unit root test

Variable	ADF Test (Level)	ADF Test (1st Diff.)	PP Test (Level)	PP Test (1st Diff.)	Result
HDI	−1.220	−6.093	−0.657	−12.659	Stationary at I(1)
	(0.884)	(0.000)***	(0.965)	(0.000)***	
LGDPPC	−2.640	−9.729	−0.881	−7.767	Stationary at I(1)
	(0.268)	(0.000)***	(0.942)	(0.000)***	
CO_2	−2.592	−4.988	−2.332	−5.303	Stationary at I(1)
	(0.286)	(0.002)***	(0.402)	(0.001)***	
REC	0.685	−4.855	1.111	−4.855	Stationary at I(1)
	(0.989)	(0.000)***	(0.996)	(0.000)***	

Note: *** Significant at 1% level.

Table 3. Covariance matrix analyses of HDI, LGDPPC, and CO_2

Variable	HDI (Matrix 1)	C (Matrix 1)	HDI (Matrix 2)	C (Matrix 2)
HDI	0.00779142	−0.0068178	7.35167328	−6.4330081
C	−0.0068178	0.00597741	−6.4330081	5.64004965

Table 4. Cointegration test results for LGDPPC and HDI

Test	Statistic	Value	p-value
Engle-Granger Cointegration Test	Tau-statistic	−4.419124	0.0094*
	z-statistic	−37.46415	0.0000*
Phillips-Ouliaris Cointegration Test	Tau-statistic	−4.063639	0.0192*
	z-statistic	−18.57163	0.0245*

Note: * MacKinnon (1996) *p*-values. Significant at the 5% level.

tegration with significant tau and z-statistics (p-values of 0.0192 and 0.0245). These findings indicate that economic growth (LGDPPC) and human development (HDI) move together in the long run, despite short-term deviations. The results suggest that South Korea's economic growth has a persistent impact on human development, and improvements in HDI reinforce sustainable economic growth. This highlights the importance of policies that integrate economic and social development to ensure long-term progress.

In Table 5, the Engle-Granger test suggests a significant likelihood of a long-term equilibrium relationship between CO_2 emissions per capita and HDI, as indicated by the significant tau statistic ($p = 0.015$) and z-statistic ($p = 0.000$). In contrast, the Phillips-Ouliaris test does not provide evidence to support cointegration, with both its tau statistic ($p = 0.128$) and z-statistic ($p = 0.112$) failing to reach significance. Cointegration, which implies a stable long-term association between variables despite short-term variability, appears to be supported by the results of the Engle-Granger test. The rejection of the null hypothesis of no cointegration based on the Engle-Granger test results indicates the possibility of a long-run relationship. However, the lack of significance in the Phillips-Ouliaris test raises questions about the robustness of this relationship. These conflicting findings underscore the need for further investigation to clarify the presence of cointegration.

The impact of HDI and REC on economic growth is examined using the Vector Autoregression

(VAR) model. Table 6 highlights the results of the VAR Lag Order Selection Criteria, identifying a lag length of 1 as optimal based on the minimum values of AIC and FPE. Given that the unit root test in Table 2 indicates a maximum integration order (Dmax) of 1, the appropriate lag length for the Toda-Yamamoto Granger causality test becomes $k + D_{max} = 1 + 1 = 2$. This implies that incorporating one lag plus the integration order provides the most suitable framework for accurate estimation and causal inference.

Table 7 presents the findings of the Toda-Yamamoto Granger causality test, indicating that renewable energy consumption (REC) does not have a statistically significant influence on GDP per capita (GDPPC), as evidenced by a p-value of 0.132, which exceeds the 0.05 threshold. This suggests insufficient evidence to establish that REC Granger causes GDPPC. In contrast, the results demonstrate a strong causal relationship between the Human Development Index (HDI) and GDPPC, supported by a Chi-square value of 20.627 and a p-value below 0.001. These findings imply that variations in HDI serve as a significant predictor of changes in GDP per capita.

Table 8 presents the results of the VAR diagnostic tests, which reveal no significant concerns related to serial correlation or heteroskedasticity in the model residuals. The non-significant p-values for the serial correlation LM tests across lags 1, 2, and 3 indicate the absence of serial correlation, fulfilling a crucial assumption of VAR

Table 5. Cointegration test results for CO_2 and HDI

Test	Statistic	Value	p-value
Engle-Granger Cointegration Test	Tau-Statistic	−4.172	0.015*
	Z-Statistic	−38.828	0.000*
Phillips-Ouliaris Cointegration Test	Tau-Statistic	−3.076	0.128
	Z-Statistic	−13.689	0.112

Note: * MacKinnon (1996) *p*-values. Significant at the 5% level.

Table 6. VAR lag order selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	98.08649	NA	7.27e-08	−7.923874	−7.776617	−7.884807
1	181.3055*	138.6983*	1.51e-10*	−14.10879*	−13.51976*	−13.95252*
2	189.6207	11.77996	1.67e-10	−14.05173	−13.02093	−13.77826

Note: * marks the optimal value in each column for each statistical criterion.

Table 7. Granger causality test results

Hypothesis	Lag (k)	Chi-Square Value	p-value	Conclusion
H_0: REC does not Granger cause GDPPC	1	2.261	0.132	Fail to reject
H_0: HDI does not Granger cause GDPPC	1	20.627	0.000*	Reject

Note: *Significant at 1% level.

Table 8. VAR diagnostic tests

Test Methods	Lag	Statistic	df	Prob.	Conclusion
Serial Correlation LM Test	1	LRE = 10.54305	9	0.3083	No serial correlation
	2	LRE = 13.02286	9	0.1616	No serial correlation
	3	LRE = 9.43368	9	0.3982	No serial correlation
Heteroskedasticity Test	-	Chi-sq = 81.56295	72	0.2064	No heteroskedasticity

models. Additionally, the high *p*-value from the heteroskedasticity test suggests that the residuals exhibit a constant variance, supporting the reliability of the model's coefficient estimates.

The hypotheses were examined and tested through the appropriate cointegration and causality tests, as detailed in the analysis. The first hypothesis posited the existence of a long-term cointegrating relationship between the HDI and GDP per capita in South Korea. Another hypothesis suggested that higher levels of HDI are linked to a reduction in CO_2 emissions per capita. Additionally, it was hypothesized that renewable energy consumption does not significantly impact GDP per capita in South Korea. The final hypothesis proposed that HDI Granger causes GDP per capita in South Korea.

The analysis provides evidence of a long-run cointegrating relationship between the Human Development Index (HDI) and GDP per capita in South Korea, as indicated by the significant results from both the Engle-Granger and Phillips-Ouliaris tests. The proposed negative association between HDI and CO_2 emissions per capita receives partial support, with cointegration confirmed only through the Engle-Granger test. Furthermore, the results validate the hypothesis that renewable energy consumption does not exert a significant impact on GDP per capita, whereas HDI demonstrates a strong Granger-causal effect on GDP per capita, underscoring its role as a key determinant of economic performance.

4. DISCUSSION

In a similar context, Fang and Chang (2016) analyzed the cointegration and causal relationship between energy consumption and economic development in 16 Asia-Pacific countries from 1970 to 2011, integrating human capital into the augmented production function. Their findings reveal a long-run cointegrating relationship, where economic growth Granger causes energy consumption, although the nature of this relationship varies across countries. Additionally, using structural unit root and cointegration tests, Ustabaş and Ersin (2016) investigated the link between high-tech exports and GDP per capita in Turkey and South Korea (1989–2014). They found that while both countries exhibit cointegration, South Korea demonstrates a sustained positive impact of high-tech exports on GDP, whereas Turkey only shows a limited short-term effect.

The cointegration analysis offers important insights into the relationship between economic growth, human development, and environmental sustainability in South Korea. The evidence of a long-term equilibrium between LGDPPC and HDI indicates that initiatives aimed at economic growth can have a significant positive impact on human development. Similarly, advancements in human development may contribute to sustained economic progress, emphasizing the need for integrated policies that address both economic and social objectives concurrently. Conversely, the assessment of CO_2 emissions per capita and HDI provides mixed results, as the Engle-Granger test

suggests a possible long-term relationship. In contrast, the Phillips-Ouliaris test does not support this conclusion. If a stable relationship exists, it implies that improvements in human development could influence CO_2 emissions through shifts in energy use and industrial dynamics. Nonetheless, the inconsistency between the tests highlights the necessity for further research employing more rigorous techniques to better understand the nature and strength of this connection. These findings underscore the critical importance of formulating comprehensive policies that integrate economic growth, human development, and environmental objectives, while addressing the complex interactions that underpin these dimensions over the long term. The results from causality tests strongly suggest a predictive relationship running from HDI to GDPPC. This aligns with established economic theory emphasizing the importance of human capital development for economic growth. A higher HDI, reflecting improvements in health, education, and living standards, likely translates into a more productive workforce, fostering innovation

and economic expansion. This finding is consistent with Ozturk and Suluk (2020), Rukiah (2020), and Osiobe (2020). Other important scientific investigations are also similar to the topic, as they demonstrate the relationship between human capital and sustainable growth (Zhang & Wu, 2022; Henderson & Loreau, 2023; Hasanov et al., 2024).

This study highlights the essential role of human capital in driving economic development. The inconclusive results regarding the link between REC and GDP per capita suggest that further investigation is necessary, incorporating additional variables such as energy prices, R&D investment, and environmental regulations. By overcoming these limitations and broadening the scope of the analysis, future research can provide a deeper insight into the relationships between renewable energy consumption, human development, and economic advancement. This is especially important in the context of achieving sustainable development goals and facilitating the transition to a low-carbon economy.

CONCLUSION

This study aimed to investigate the interconnections between economic growth, human development, and environmental factors in South Korea. The results demonstrate a stable, long-term relationship between GDP per capita and the Human Development Index (HDI), confirming that economic growth supports human development and vice versa. However, the relationship between HDI and CO_2 emissions per capita presented mixed outcomes, indicating that further research is required to fully understand the environmental consequences of human development. Additionally, a significant causal link was found between HDI and economic growth, highlighting the need for policies that integrate social, economic, and environmental considerations. These findings stress the importance of adopting a balanced approach to sustainable development. Future research should explore additional variables and employ more advanced methodologies to better understand the complexities of these interactions and guide policy-making.

AUTHOR CONTRIBUTIONS

Conceptualization: Zeynab Giyasova, Liliana Smiech, Irada Nabiyeva.
Data curation: Shafa Guliyeva, Reyhan Azizova, Liliana Smiech.
Formal analysis: Zeynab Giyasova, Shafa Guliyeva, Reyhan Azizova, Irada Nabiyeva.
Investigation: Zeynab Giyasova, Shafa Guliyeva, Liliana Smiech, Irada Nabiyeva.
Methodology: Zeynab Giyasova, Liliana Smiech.
Project administration: Shafa Guliyeva.
Resources: Zeynab Giyasova, Reyhan Azizova, Irada Nabiyeva.
Software: Zeynab Giyasova, Liliana Smiech.
Supervision: Shafa Guliyeva, Reyhan Azizova.

Validation: Shafa Guliyeva, Reyhan Azizova, Irada Nabiyeva.
Visualization: Zeynab Giyasova, Liliana Smiech.
Writing – original draft: Zeynab Giyasova, Liliana Smiech, Irada Nabiyeva.
Writing – review & editing: Shafa Guliyeva, Reyhan Azizova.

REFERENCES

1. Acevedo, S. (2008). Measuring the impact of human capital on the economic growth of South Korea. *Korea and the World Economy, 9*(1), 113-139. Retrieved from https://www.kci.go.kr/kciportal/ci/sereArticleSearch/ciSereArtiView.kci?sereArticleSearchBean.artiId=ART001272357

2. Ahmed, Z., Asghar, M. M., Malik, M. N., & Nawaz, K. (2020). Moving towards a sustainable environment: The dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. *Resources Policy, 67,* Article 101677. https://doi.org/10.1016/j.resourpol.2020.101677

3. Costantini, V., & Monni, S. (2008). Environment, human development and economic growth. *Ecological Economics, 64*(4), 867-880. https://doi.org/10.1016/j.ecolecon.2007.05.011

4. Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association, 74*(366), 427-431. https://doi.org/10.2307/2286348

5. Engle, R. F., & Granger, C. W. J. (1987). Cointegration and error correction: Representation, estimation, and testing. *Econometrica, 55*(2), 251-276. https://doi.org/10.2307/1913236

6. Fang, Z., & Chang, Y. (2016). Energy, human capital and economic growth in Asia Pacific countries – Evidence from a panel cointegration and causality analysis. *Energy Economics, 56,* 177-184. https://doi.org/10.1016/j.eneco.2016.03.020

7. FocusEconomics (FE). (n.d.). *Economic Growth in Korea*. Retrieved from https://www.focus-economics.com/country-indicator/korea/gdp/#:~:text=In%202022%2C%20the%20real%20GDP%20growth%20was%202.6%25.

8. Gürlük, S. (2009). Economic growth, industrial pollution and human development in the Mediterranean Region. *Ecological Economics, 68*(8-9), 2327-2335. https://doi.org/10.1016/j.ecolecon.2009.03.001

9. Han, J., Du, T., Zhang, C., & Qian, X. (2018). Correlation analysis of CO_2 emissions, material stocks and economic growth nexus: Evidence from Chinese provinces. *Journal of Cleaner Production, 180,* 395-406. https://doi.org/10.1016/j.jclepro.2018.01.168

10. Hasanov, R. I., & Safarli, A. J. (2023). New structural design for green supply chain management: The case of the aluminum industry. *New Design Ideas, 7*(2), 343-355. Retrieved from https://jomard-publishing.com/UploadFiles/Files/journals/NDI/V7N2/Hasanov_Safarli.pdf

11. Hasanov, R. I., Giyasova, Z., Azizova, R., Huseynova, S., & Zemri, B. E. (2024). Long-term dynamics between human development and environmental sustainability: An empirical analysis of CO_2 emissions in Azerbaijan. *Challenges in Sustainability, 12*(4), 273-280. https://doi.org/10.56578/cis120403

12. Henderson, K., & Loreau, M. (2023). A model of Sustainable Development Goals: Challenges and opportunities in promoting human well-being and environmental sustainability. *Ecological Modelling, 475,* Article 110164. https://doi.org/10.1016/j.ecolmodel.2022.110164

13. Hitka, M., Kucharčíková, A., Štarchoň, P., Balážová, Ž., Lukáč, M., & Stacho, Z. (2019). Knowledge and human capital as sustainable competitive advantage in human resource management. *Sustainability, 11*(18), Article 4985. https://doi.org/10.3390/su11184985

14. IEA. (n.d.). *Countries & regions, Korea. How much CO_2 does Korea emit?* Retrieved from https://www.iea.org/countries/korea/emissions

15. Isozaki, N. (2019). Education, development, and politics in South Korea. In K. Tsunekawa & Y. Todo (Eds.), *Emerging States at Crossroads* (pp. 209-229). Singapore: Springer. https://doi.org/10.1007/978-981-13-2859-6_10

16. Jeremic, V., Isljamovic, S., Petrovic, N., Radojecic, Z., Markovic, A., & Bulajic, M. (2011). Human development index and sustainability: What's the correlation? *Metalurgia International, 16*(7), 86-90. Retrieved from https://rfos.fon.bg.ac.rs/handle/123456789/811

17. Kim, U., & Kim, J. (2022). Economic development, sociocultural change and quality of life in Korea: Analysis of three generations growing up in colonial, industrial and digital age. *Psychology and Developing Societies, 34*(2), 200-239. https://doi.org/10.1177/09713336221115550

18. Lee, J. W. (2005). Human capital and productivity for Korea's sustained economic growth. *Journal of Asian Economics, 16*(4), 663-687. https://doi.org/10.1016/j.asieco.2005.06.009

19. Lee, J. W. (2007). *Economic growth and human development in the Republic of Korea, 1945–1992* (Occasional Paper No. 24). Retrieved from https://hdr.undp.org/system/files/documents/jong-whalee.pdf

20. MacKinnon, J. G. (1996). Numerical distribution functions for unit root and cointegration

tests. *Journal of Applied Econometrics, 11*(6), 601-618. https://doi.org/10.1002/(SICI)1099-1255(199611)11:6<601::AID-JAE417>3.0.CO;2-T

21. Maksymenko, S. V., & Rabbani, M. (2008). Economic reforms, human capital, and economic growth in India and South Korea: A cointegration analysis. *SSRN.* http://dx.doi.org/10.2139/ssrn.1293374

22. McNeill, D., & Ottersen, O. P. (2015). Global governance for health: How to motivate political change? *Public Health, 129*(7), 833-837. https://doi.org/10.1016/j.puhe.2015.05.001

23. Osiobe, E. U. (2020). Human capital, capital stock formation, and economic growth: A panel granger causality analysis. *Journal of Economics and Business, 3*(2). Retrieved from https://ssrn.com/abstract=3581793

24. Ozturk, S., & Suluk, S. (2020). The granger causality relationship between human development and economic growth: The case of Norway. *International Journal of Research in Business and Social Science (2147–4478), 9*(6), 143-153. https://doi.org/10.20525/ijrbs.v9i6.902

25. Park, J. D. (2024). Why holistic human development is crucial for transformative development of nations: Insights from Korea. *Review of Institution and Economics, 18*(1), 17-44. https://doi.org/10.30885/rie.2024.18.1.017

26. Phillips, P. C. B., & Ouliaris, S. (1990). Asymptotic properties of residual based tests for cointegration. *Econometrica, 58*(1), 165-193. https://doi.org/10.2307/2938339

27. Phillips, P. C. B., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika, 75*(2), 335-346. https://doi.org/10.1093/biomet/75.2.335

28. Reyes, G. E., & Useche, A. J. (2019). Competitiveness, economic growth and human development in Latin American and Caribbean countries 2006–2015: A performance and correlation analysis. *Competitiveness Review, 29*(2), 139-159. https://doi.org/10.1108/CR-11-2017-0085

29. Rukiah, R. (2020). Analysis relationship of economic growth, fiscal policies and demographic to Islamic human development index in Indonesia: Granger causality approach. *FITRAH: Jurnal Kajian Ilmu-ilmu Keislaman, 6*(1), 31-46. Retrieved from http://repo.uinsyahada.ac.id/715/

30. Toda, H. Y., & Yamamoto, T. (1995). Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics, 66*(1-2), 225-250. https://doi.org/10.1016/0304-4076(94)01616-8

31. UNDP. (n.d.). *Human Development Reports. Korea (Republic of).* Retrieved from https://hdr.undp.org/data-center/specific-country-data#/countries/KOR

32. Ustabaş, A., & Ersin, Ö. Ö. (2016). The effects of R&D and high technology exports on economic growth: A comparative cointegration analysis for Turkey and South Korea. *International Conference on Eurasian Economies* (pp. 44-55). Retrieved from https://avekon.org/papers/1475.pdf

33. World Bank. (n.d.). *Data. Korea, Rep.* Retrieved from https://data.worldbank.org/country/korea-rep

34. Worldometer. (n.d.). *South Korea CO_2 Emissions.* Retrieved from https://www.worldometers.info/CO_2-emissions/south-korea-CO_2-emissions/

35. Zhang, Y., & Wu, Z. (2022). Environmental performance and human development for sustainability: Towards to a new Environmental Human Index. *Science of the Total Environment, 838,* Article 156491. https://doi.org/10.1016/j.scitotenv.2022.156491

36. Zhou, B., Li, N., Lu, D., & Xia, J. (2022). Correlation analysis between economic growth and environmental quality. *Computer Systems Science and Engineering, 41*(1), 127-140. https://doi.org/10.32604/csse.2022.017750