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Long-Term Dynamics Between Human Development and Environmental Sustainability: An Empirical Analysis of CO_2 Emissions in Azerbaijan

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Abstract: This study investigates the long-term relationship between human development and environmental sustainability in Azerbaijan, with a particular focus on carbon dioxide (CO_2) emissions as a key indicator of environmental impact. Using data spanning from 1997 to 2022, sourced primarily from World Bank and United Nations databases, the analysis applies the Autoregressive Distributed Lag (ARDL) model to examine how human development—measured by the Human Development Index (HDI), which integrates Gross National Income (GNI), life expectancy, and educational attainment—affects CO_2 emissions. Developing economies, such as Azerbaijan, often face the challenge of balancing economic growth and industrialization with environmental sustainability, as the former can exacerbate environmental pressures, particularly the increase in CO_2 emissions. A long-run equilibrium relationship between HDI and CO_2 emissions is identified, with a one-unit increase in HDI associated with a 2.793-unit reduction in CO_2 emissions. This negative relationship suggests that improvements in human development, reflected in better educational outcomes, higher income levels, and improved healthcare, can foster more sustainable environmental practices. Enhanced energy efficiency, greater adoption of green technologies, and increased environmental awareness are among the mechanisms through which human development may contribute to reducing CO_2 emissions. The findings underscore the need for a synergistic approach to human development and environmental sustainability, advocating for policies that integrate socio-economic growth with environmental stewardship. By aligning human development strategies with sustainability goals, countries like Azerbaijan can mitigate ecological degradation while fostering long-term economic and social well-being. These insights provide important implications for policymakers seeking to achieve sustainable development in Azerbaijan and beyond, contributing to global efforts to reconcile growth with environmental preservation.

Keywords: Environmental sustainability; CO_2 emissions; Human development; Green economics; Econometrics; Azerbaijan

1. Introduction

1.1 Research Background

Azerbaijan is confronted with the challenge of achieving a balance between human development and

environmental sustainability, as exemplified by initiatives such as the Baku Initiative on Human Development for Climate Resilience, which underscores the country's dedication to incorporating social development into climate action. This research examines the current status of human development and environmental sustainability in Azerbaijan, identifies existing gaps in policy and research, and suggests practical strategies for addressing these issues while also offering a long-term outlook on the potential consequences of climate change. The relationship between human development and environmental sustainability has been widely studied at the international level. Research indicates that the adoption of renewable energy sources and effective governance are pivotal in reducing CO_2 emissions while simultaneously fostering human development (Rahman & Sultana, 2024). The connection between economic growth, energy consumption, and environmental quality is a key area of research, as economic development typically drives increased energy use, which may intensify environmental degradation through higher emissions. Achieving a balance between economic expansion and environmental preservation necessitates the formulation of robust policy frameworks that foster the adoption of sustainable energy practices while mitigating ecological damage (Udemba et al., 2024).

Human development serves as a vital gauge of a nation's overall progress, encompassing key dimensions such as life expectancy, education, and income. It reflects the capacity of a country to enhance the well-being of its population by ensuring access to essential services and fostering opportunities for both personal and economic advancement. A higher HDI is indicative of better socio-economic conditions and an improved standard of living. In 2022, Azerbaijan's HDI was 0.76, categorizing it within the "High Human Development" group and positioning the country 86th out of 204 nations and territories (UNDP, 2023). Human development transcends traditional economic indicators like GDP, consumer spending, and national debt by emphasizing the expansion of individual freedoms, opportunities, and overall well-being. Although economic metrics often dominate discussions on national performance, they fail to provide a comprehensive assessment of the population's quality of life (MOE, 2024). Over the past decade, human capital development (HCD) has emerged as a central policy focus in Azerbaijan. Political leaders have frequently underscored the importance of converting the nation’s abundant natural resources, often referred to as "black gold," into human capital or "human gold," highlighting the necessity of fostering sustainable human development alongside economic growth (Mammadova et al., 2016).

The analysis of CO_2 emissions is essential for evaluating the environmental consequences of a country's industrial activities and its contribution to global climate change. This is particularly significant for Azerbaijan, which continues to depend heavily on fossil fuels and a dominant industrial sector. In 2022, Azerbaijan’s CO_2 emissions totaled 37.13 megatons, ranking 117th among 184 countries (CE, 2023). This ranking accentuates the urgent need for the implementation of sustainable development strategies aimed at curbing CO_2 emissions and addressing the challenges of climate change. Despite global efforts, CO_2 emissions remain significantly higher than the levels required to mitigate the most severe impacts of climate change. In light of this, understanding the interplay between human development and CO_2 emissions is critical for Azerbaijan’s policymakers, as it can inform strategies that balance economic growth with long-term environmental sustainability.

Despite existing efforts, there is a notable gap in the research regarding the long-term relationship between human development and environmental sustainability in Azerbaijan, particularly with respect to the influence of human development on CO_2 emissions. Additionally, while global studies have addressed these issues, more localized research is needed to account for Azerbaijan's specific socio-economic and environmental contexts. This study investigates the long-run relationship between human development, as captured by HDI, and CO_2 emissions in Azerbaijan, with a focus on the potential impact of these factors on national policy formulation.

1.2 Literature Review

The global scientific literature contains numerous studies that examine the positive impacts of human development on the environment. Khan (2020) tested the Environmental Kuznets Curve hypothesis, suggesting that the effect of economic development on CO_2 emissions depends on human capital. The study found that while education initially increases pollution, beyond a certain threshold, higher education reduces CO_2 emissions by fostering environmental awareness and sustainable technologies. Yao et al. (2020) investigated the connection between human capital accumulation, specifically higher education, and enhancements in environmental quality through reductions in CO_2 emissions across 20 OECD nations from 1870 to 2014. Their findings indicate a notable association between increased years of tertiary education and substantial declines in CO_2 emissions, with this relationship becoming progressively more negative over time, suggesting that the development of advanced human capital can effectively address climate change while supporting economic growth. Sezgin et al. (2021) analyzed the impact of environmental policies and human development on CO_2 emissions from 1995 to 2015 in the G7 and BRICS economies, finding varying causality relationships across countries. Their results indicated that environmental policies and human development both had a long-term negative effect on CO_2 emissions, with different patterns of causality observed between countries. Gulaliyev et al. (2016) analyzed the economic liberalization processes in Turkey and Azerbaijan, using a comparative approach based on development indices. The study found that Azerbaijan's economy is more liberalized and less regulated, while Turkey’s economy is

more prone to fluctuations and focuses on liberalization alongside human development growth. Other studies have explored the relationship between human development and the environment from various perspectives, demonstrating that the human capital factor exerts positive effects on environmental outcomes (Alakbarov et al., 2020; Gulaliyev et al., 2024; Huseynli, 2024).

2. Methodology

2.1 Data Collection

This research explores the long-term relationship between the HDI and CO_2 emissions in Azerbaijan, drawing on data from the UNDP (2024), World Bank (2024), and Worldometers (2024). The primary focus is on CO_2 emissions (measured in metric tons per capita) and HDI, with CO_2 emissions serving as the dependent variable. The dataset spans the period from 1990 to 2022, providing a comprehensive analysis of trends in both CO_2 emissions and human development in Azerbaijan. The key data sources for the variables are as follows:

- CO_2 Emissions (CO2PC): The annual CO_2 emissions per capita, expressed in metric tons, are sourced from the World Bank, reflecting the environmental impact in terms of greenhouse gas emissions in Azerbaijan.
- HDI: The HDI, sourced from the United Nations Development Programme (UNDP), serves as the independent variable. It is a composite index calculated using the following components (UNDP, 2022):

$$\text{HDI} = \sqrt[3]{(\text{GNI} \times \text{Life Expectancy} \times \text{Education Index})} \quad (1)$$

- GNI: GNI per capita, taken from World Bank data, represents the total economic output of a country, adjusted for income from abroad.
- Life Expectancy: Life expectancy at birth, obtained from World Bank data, is used as an indicator of health and longevity.
- Education Index: The Education Index, a composite measure of educational attainment, is sourced from the UNDP.

Additionally, data on CO_2 emissions and HDI are complemented with supplementary indicators from Worldometers to provide a broader environmental and socio-economic context.

Figure 1 illustrates the trends in CO_2 emissions and HDI over time. Both indicators show upward trajectories, but the relationship between them is nuanced, with instances of decoupling where HDI rises without a corresponding increase in CO_2 emissions.

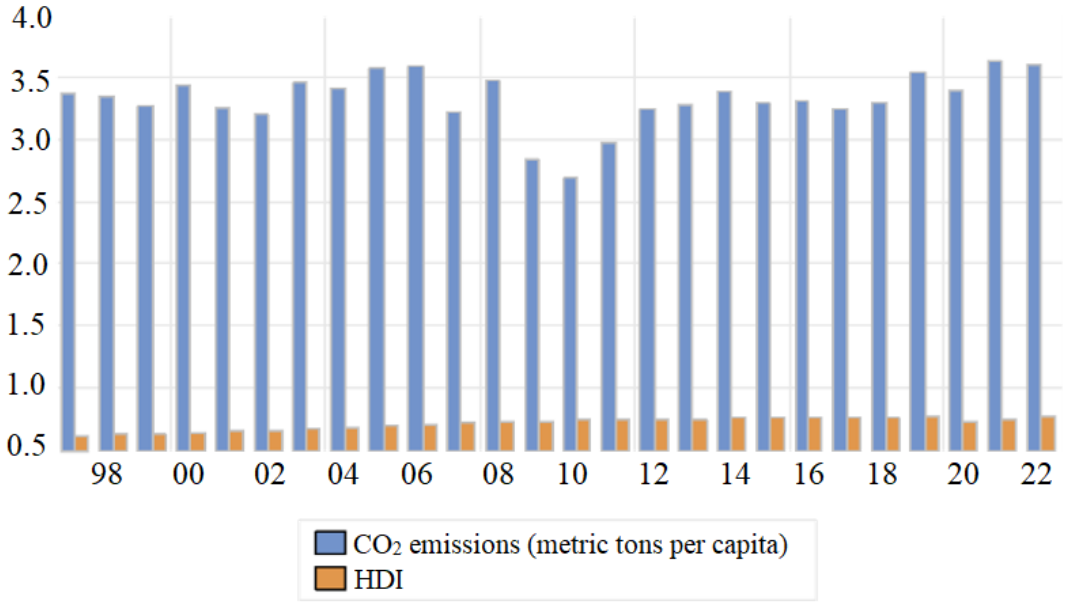

Figure 1. Trends in CO_2 emissions and HDI from 1997 to 2022
Source: World Bank, UNDP, Worldmeter

Table 1 presents key statistical measures for CO_2 emissions and HDI. Both variables display deviations from normality, with CO_2 emissions exhibiting more pronounced skewness and heavier tails than HDI.

Table 1. Descriptive statistics of variables

Statistic	CO2PC	HDI
Mean	3.322	0.706
Median	3.325	0.726
Maximum	3.63	0.762
Minimum	2.685	0.609
Std. Dev.	0.223	0.049
Skewness	-1.098	-0.658
Kurtosis	4.343	1.973
Jarque-Bera	7.186	3.020
Probability	0.027	0.220
Sum	86.372	18.367

2.2 Method

To examine the long-run relationship between CO_2 emissions and HDI in Azerbaijan, we utilize an ARDL model, which is particularly effective for analyzing variables with different integration orders. The ARDL model enables the investigation of both short-term dynamics and long-term relationships between the variables, even when they are integrated of order 0 (I(0)) or order 1 (I(1)), but not of higher orders. The general ARDL model employed in this study is specified as follows:

$$\mathrm{CO2PC}_t = \alpha + \sum_{i=1}^{p} \beta_i \mathrm{CO2PC}_{t-i} + \sum_{j=0}^{q} \gamma_j \mathrm{HDI}_{t-j} + \epsilon_t \quad (2)$$

To analyze the long-term relationship between CO_2 emissions and HDI, the cointegration tests will use the bounds testing approach introduced by Pesaran et al. (2001). Unit root tests (ADF and PP) will first assess stationarity, and if the variables are I(1), cointegration analysis will follow. The ARDL model will also incorporate error correction mechanisms to capture short-term dynamics and adjustment to long-run equilibrium, shedding light on the relationship between human development and CO_2 emissions in Azerbaijan.

3. Results

Table 2 presents the results of the Augmented Dickey-Fuller (Dickey & Fuller, 1979) and Phillips-Perron (Phillips & Perron, 1988) tests for stationarity. Both CO2PC and HDI are non-stationary at their levels but become stationary after first differencing, indicating that they are integrated of order 1 (I(1)). This finding is important for selecting the appropriate econometric model, as the presence of I(1) variables suggests that cointegration methods are appropriate for analyzing their long-run relationship.

Table 2. Unit root tests

The Augmented Dickey-Fuller (ADF)			
Variable	Level	1st Difference	Trend
CO2PC	-2.427 (0.358)	-5.914 (0.0004*)	and
HDI	-1.352 (0.850)	-4.814 (0.0043)	Intercept
Phillips-Perron (PP)			
Variable	Level	1st Difference	Trend
CO2PC	-2.420(0.360)	-4.814 (0.0043*)	and
HDI	-1.2121 (0.885)	-6.470 (0.0001*)	Intercept

Figure 2 demonstrates that the ARDL (1,4) model is the most appropriate among the models tested. This model appears to offer the best fit to the data, with coefficient estimates that are statistically significant, indicating a robust relationship between the variables.

Table 3 reveals the ARDL (1, 4) model results, examining the long-run relationship between CO_2 emissions and the HDI in Azerbaijan. The levels equation shows a statistically significant HDI coefficient of -2.793, indicating that a one-unit increase in HDI is associated with a reduction of 2.793 units in CO_2 emissions, assuming other factors remain constant. This negative coefficient suggests an inverse relationship between HDI and CO_2 emissions, implying that as human development progresses in Azerbaijan, CO_2 emissions tend to decline. This finding may

reflect that improvements in human development are linked to sustainable practices or more stringent environmental policies, resulting in reduced environmental impact. The model's F-statistic of 5.551, significant at the 5% level, supports a strong and stable long-run relationship between HDI and CO_2 emissions, emphasizing HDI's enduring negative effect on emissions in Azerbaijan.

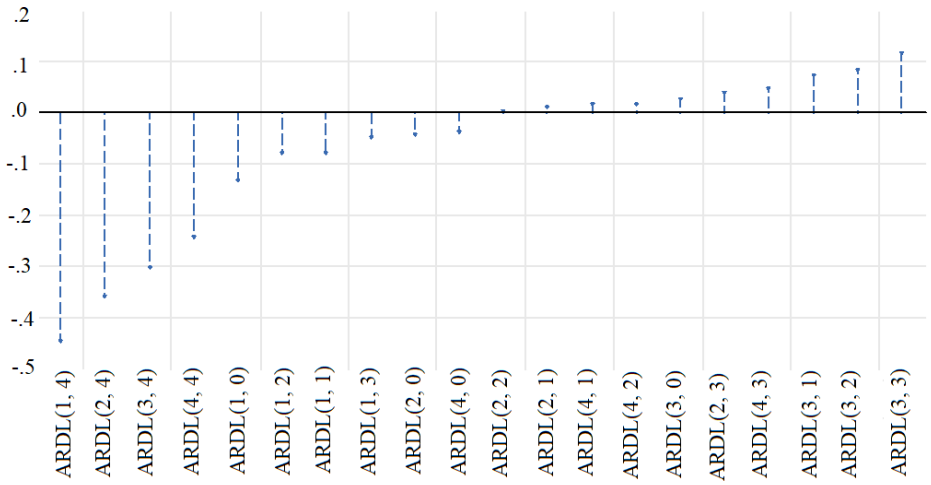

Figure 2. Model selection over Akaike information criteria
Note: Designed by the authors via Eviews

Table 3. ARDL (1, 4) long-run relationship test

Section 1: F-Bounds Test				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	5.55	10%	3.02	3.51
k	1	5%	3.62	4.16
Section 2: Levels Equation				
Variable	Coefficient	Std. Error	t-Statistic	P-value
HDI	-2.79	2.12	-1.31	0.208
C	5.71	1.59	3.58	0.0027

Table 4 presents the results of the diagnostic tests for the ARDL model, affirming its proper specification and reliability. The error correction term (CointEq(-1)) shows a statistically significant negative coefficient of -0.570, indicating that approximately 57% of any disequilibrium from the previous period is corrected each period, ensuring convergence towards long-term equilibrium. The t-statistic of -4.344 is highly significant at the 1% level (p-value = 0.0006), underscoring a robust long-run relationship between CO_2 emissions and HDI. The Breusch-Godfrey test (Breusch, 1978; Godfrey, 1978) indicates no serial correlation (p-values of 0.243 and 0.116), suggesting that the residuals are independent, while the Breusch-Pagan-Godfrey test (Breusch & Pagan, 1979) supports homoskedasticity (p-values greater than 0.05), confirming constant variance in the residuals. These diagnostic results collectively verify that the ARDL model is appropriately specified, stable, and effectively captures the long-run dynamics between CO_2 emissions and HDI in Azerbaijan.

Table 4. Diagnostic tests for ARDL model

Panel 1. ECM Regression				
Variable	Coefficient	Std. Error	t-Statistic	P-value
CointEq(-1)	-0.570	0.131	-4.344	0.0006

Panel 2. Breusch-Godfrey Serial Correlation LM Test			
F-statistic	1.576	Prob. F (2,13)	0.243
Obs*R-squared	4.294	Prob.Chi-Square (2)	0.116

Panel 3. Breusch-Pagan-Godfrey Heteroskedasticity Test			
F-statistic	1.415	Prob. F (6,15)	0.272
Obs*R-squared	7.951	Prob. Chi Square (6)	0.241
Scaled Explained SS	4.391	Prob. Chi-Square (6)	0.623

Figure 3 shows that the CUSUM test examines the stability of the ARDL model's coefficients over time. In this instance, the CUSUM plot staying within the 5% significance bounds indicates that the model reliably explains the relationship between human development and CO_2 emissions.

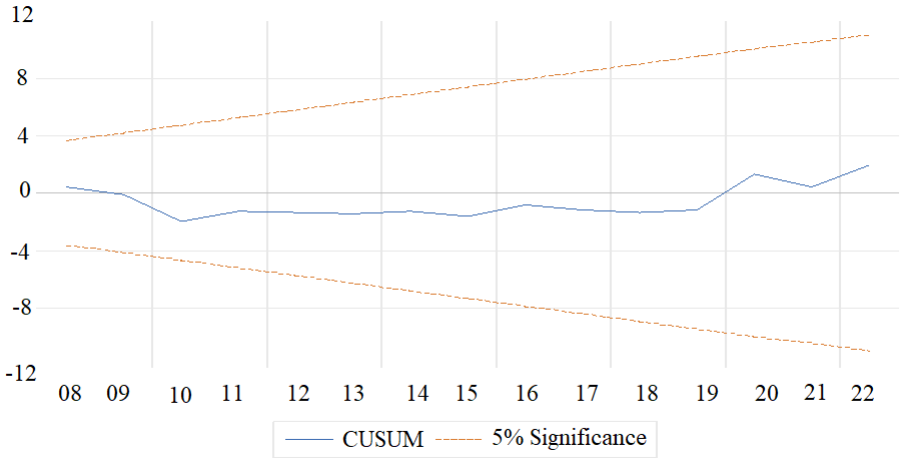

Figure 3. Stability of ARDL model coefficients using the CUSUM test
Note: Designed by the authors via Eviews

4. Discussion

The findings of this study reveal a significant inverse relationship between human development, as measured by the HDI, and CO_2 emissions in Azerbaijan. This result aligns with previous research, which indicates that higher levels of human development often lead to improved environmental governance, the adoption of cleaner technologies, and sustainable strategies (Abdouli & Omri, 2021; Luo et al., 2024). In particular, countries with higher HDI benefit from technological advancements that promote more environmentally friendly production methods, which in turn reduce carbon emissions. Additionally, high-HDI nations often have service-based economies, which generally result in lower carbon footprints compared to manufacturing-heavy economies. These patterns suggest that improvements in human development not only foster better socio-economic conditions but also contribute to mitigating environmental degradation.

Moreover, higher HDI is commonly linked to greater public awareness and concern about environmental issues, leading to increased demand for eco-friendly policies and practices. In such countries, investments in renewable energy sources are typically higher, further reducing CO_2 emissions. These findings are consistent with global trends where nations with high HDI scores tend to exhibit stronger environmental regulations and a shift toward sustainable energy systems (Ngo et al., 2022; Thong, 2024). The results underscore the importance of integrating environmental sustainability into national development frameworks to ensure that economic growth does not come at the cost of environmental well-being.

The global analysis by Xu et al. (2024) indicates that high HDI countries are progressing toward a state of relative decoupling between human development and CO_2 emissions, as well as material footprints, whereas countries with medium HDI continue to experience significant coupling. In contrast, Azerbaijan exhibits a negative correlation between HDI and CO_2 emissions, suggesting that targeted advancements in education, healthcare, and income can simultaneously foster human development and mitigate environmental impacts. These findings underscore the importance of implementing contextually appropriate policies that harmonize human development with environmental sustainability, particularly in developing economies striving for sustainable growth.

The implications of this study are particularly relevant for Azerbaijan, where economic growth has traditionally been driven by energy sectors, which contribute significantly to CO_2 emissions. While the global trends observed in high-HDI nations hold in part, Azerbaijan's unique socio-economic context presents challenges for balancing human development and environmental sustainability. Nevertheless, the study suggests that focusing on human development, particularly in education, healthcare, and income, could provide a pathway to achieving both sustainable growth and reduced emissions. Future research should explore how specific policy interventions in Azerbaijan can further optimize the relationship between socio-economic development and environmental sustainability, particularly through the adoption of green technologies and renewable energy.

5. Conclusion

The findings of this study underscore the critical importance of incorporating environmental sustainability into

Azerbaijan's human development strategy. Utilizing the ARDL (1,4) model, the analysis demonstrates a robust and enduring long-term relationship between the HDI and CO_2 emissions, with an F-statistic of 5.551, significant at the 5% level. These results suggest that improvements in HDI over time are linked to a notable reduction in CO_2 emissions. The impact of HDI on CO_2 emissions indicates that as Azerbaijan progresses in key economic and social dimensions, there is a corresponding positive effect on environmental sustainability.

The implications of these findings are crucial for policymakers in Azerbaijan, stressing the need for a balanced approach to socio-economic development and environmental sustainability. By aligning human development policies with environmental goals, Azerbaijan can promote long-term sustainable growth that meets both social and ecological objectives. While this study makes a valuable contribution to the discourse on sustainable development, its scope is limited to the relationship between HDI and CO_2 emissions. Future research could expand on this by incorporating additional environmental factors, such as renewable energy adoption and technological advancements, to offer a more comprehensive understanding of the dynamics between development and sustainability. Moreover, further investigations could assess the effectiveness of specific policy interventions designed to enhance both human development and environmental resilience.

Author Contributions

Ramil I. Hasanov is the corresponding author and the first author, responsible for developing the conceptual framework of the research, particularly the econometric analysis section, as well as the abstract and conclusion. Zeynab Giyasova, as the second author, contributed to the preparation of the introduction. Reyhan Azizova and Shahla Huseynova, serving as co-authors, were responsible for the literature review section. Bouazza Elamine Zemri made contributions to the discussion section.

Data Availability

Not applicable.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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