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Nexus of Human Development and Environmental Quality in Low-Income and Developing Countries: Do Renewable Energy and Good Governance Matter?

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Abstract: The relationship between human development and environmental quality has been explored in this study by examining the human-development status and carbon (CO_2)-emissions levels of 60 countries from the low, lower-middle, and upper-middle income categories. The roles of renewable energy and some economic and institutional factors such as GDP, the rule of law, regulatory quality, and corruption control have also been investigated to ascertain their impacts on the relationship. The empirical investigations apply the generalized method of moments (GMM), fixed effects (FE), and random effects (RE) methods, and the long-run associations among the variables are investigated by applying the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) techniques. The robust findings support the trade-off relationship between human development and environmental quality in the selected low-income and developing countries. With evidence of an environmental Kuznets's relationship between economic growth and environmental quality, these findings reveal that the measures pursued to improve human-development status have a contributory impact on CO_2 emissions in the selected countries. However, an increased demand for renewable energy, effective enforcement of the rule of law, and improved control over corruption have a mitigating effect on CO_2 emissions. The result has also highlighted the policy issues instrumental to increased emissions levels in these countries. Consequently, it is recommended to formulate policies for resolving disparities within the various dimensions of human development while also making deliberate investments in the socio-economic aspects of human development to ensure both sustainable human development and environmental quality.

Keywords: carbon emissions; human development index (HDI); renewable energy; good governance; low-income and developing countries

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1. Introduction

Human development stands as a key social dimension of sustainable development [1,2]. It reflects the economic and social progress of a country by assessing its achievement in terms of longevity (life expectancy), educational accessibility (literacy rate), and income levels (Gross Domestic Product per capita) [1–4]. Human development also provides a comprehensive measure of human advancement [2]. A higher level of human development which is a crucial pillar of sustainable development, is pivotal from an environmental perspective, as it fosters a healthy lifestyle, environmentally friendly technology, and environmental awareness [5,6]. However, countries that are projecting improvement in human development and that secure higher rankings in human-development databases often face associated challenges related to rapid environmental degradation and increased pollution levels [1]. The justifying role of human development depends, in various ways, on the quality of institutions, particularly those promoting good governance and supporting organizations engaged in social services, policy research, and scientific innovations that contribute to pro-environmental activities [6]. Developing countries have experienced enormous challenges in terms of institutional quality, especially concerning political instability, corruption, and the effectiveness of their governments [7]. Given the non-monotonic relationship observed between human development and environmental quality based on a country's level of development, it is crucial to explore their interaction within the context of poorer and developing regions across the globe. In these countries, a complex dilemma exists between human development and environmental quality, largely due to socio-economic conflicts [1]. Therefore, the Human Development Index (HDI) is used in this study as a metric for evaluating the economic and social development of nations, rather than relying solely on Gross Domestic Product (GDP). This strategic choice is driven by the goal of comprehensively understanding the intricate relationship between economic and social development and environmental considerations. It is worth noting that GDP frequently fails to capture the saturation of human welfare, income, and consumption, as well as the nuanced connection between education and health in the environmental context [1,3,8]. Furthermore, it is important to examine the relationship between HDI and the environment within the specific context of low-income and developing countries, as these nations are actively pursuing development primarily through income growth, a critical component of HDI. This pursuit of higher income can inadvertently result in heightened pollution, underscoring the importance of this analysis [9,10].

Environmental sustainability is one of the conditions for human development [11]. There exists a positive relationship between the management of environmental quality and human development [12]. However, comprehending human development requires a thorough examination of various aspects of how people live and thrive in each society [13]. Human activities are often regarded as a crucial factor behind environmental-quality degradation and climate change [14]. In some developing countries (BRICS countries), human capital, often represented by education (a component of HDI), has not yet reached a level at which it can effectively mitigate environmental degradation [2]). Since human capital, as captured by HDI, does not fully encompass the concept of human development, it is crucial to investigate the relationship between human development and environmental quality within the economic, technological, and institutional context of low-income and developing countries.

Environmental quality is affected by various emissions, with carbon dioxide (CO_2) standing out as the most prominent contributor. Consequently, CO_2 emissions serve as a robust proxy for assessing environmental-quality degradation [6,14,15]. This proxy is particularly suitable for developing countries, as these countries are increasingly becoming responsible for heightened carbon emissions in comparison to their developed counterparts [16]. Considering the perspective of developing nations, some scholars argue that conventional economic growth is the preferred route to achieving environmental sustainability, positing that the environmental crisis can be resolved without forsaking economic growth [17]. Nevertheless, an upswing in economic growth, driven by increased industrial production, energy consumption, and greater trade openness, amplifies pollution levels [9,18]. Some researchers also contend that higher income levels facilitate investments in human-capital development, which, in turn, stimulate the consumption of economic goods and social services, leading to elevated CO_2 emissions [19]. In contrast, advanced countries with higher human capital tend to reduce their reliance on fossil energy and exhibit greater demand for clean energy sources [20]. Consequently, a country's economic growth and income levels wield significant influence over human development, which, in a cascading manner, affects environmental quality. This study delves into the examination of the Environmental Kuznets Curve (EKC) to shed light on these dynamics.

Economic growth, the paramount focus in developing nations, is intricately interwoven with CO_2 emissions, and this correlation can be attributed to the inherent interplay between economic growth and energy utilization [9]. Energy serves as a crucial catalyst for economic expansion, alongside capital and labor in the production process, but it has also emerged as a primary driver of environmental deterioration in developing nations. Notably, several developing countries are advancing towards industrialization, significantly increasing their energy consumption (examples include India, Brazil, Mexico, and China, all of which ranked among the top ten primary energy-consuming nations in 2018) and concurrently emerged as leading CO_2-emissions producers [21]. Since approximately 90% of global carbon emissions result from the combustion of non-renewable energy sources, embracing renewable energy emerges as a viable strategy to mitigate CO_2 emissions without hindering economic growth [9,22]. Therefore, renewable energy presents a potential pathway to striking a balance between economic growth and environmental well-being, which, in turn, supports human development [23]. This rationale serves as the impetus behind the exploration of renewables' role in the interconnected realms of human development and environmental quality.

Furthermore, many countries, primarily those in lower income brackets and still in the early stages of development, exhibit hesitancy to address environmental degradation when such actions require sacrificing substantial income [9]. In this context, institutions, particularly government bodies, can play a pivotal role in mitigating this dilemma through the effective implementation of their tools and by advocating for the adoption of renewable energy sources. The qualitative enhancement of institutions, such as the strengthening of governmental capacity and the practice of good governance principles, can substantially boost both economic growth and environmental quality by fostering the adoption of renewable energy, upholding the rule of law, curbing corruption, and implementing high-quality regulations that collectively contribute to human well-being [24]. Hence, this study is driven by a keen interest in delving into the role of good governance, which encompasses regulatory quality, the rule of law, and corruption control, in the complex interplay between human development and environmental quality in the selected group of countries.

This study will make several valuable contributions to the existing literature. Firstly, it assesses environmental-quality degradation by considering the levels of human development that capture not only the economic aspect but also the social perspective of the countries. Given that the concept and measurement of human development were established in response to sustainable economic growth [12], this study has the potential to explore the intricate connection between the socioeconomic life of people and its impact on the environment, which in turn can aid in achieving sustainable development. Secondly, taking a broader developmental perspective into account, this study will emphasize the critical importance of significant improvements in social dimensions alongside improvements in income dimensions for sustainable development. Thirdly, the study will re-examine the roles of two key drivers of environmental-quality management—renewable energy and government capacity—within the context of the human–environment relationship through a comprehensive analytical framework in a dynamic perspective. Lastly, by applying empirical analysis and ensuring the robustness of outcomes, this study will convincingly propose social, technological, and institutional mechanisms for charting a low-carbon development path for the less affluent and developing countries across the globe.

The structure of this paper is as follows: Section 2 offers a comprehensive review of the pertinent literature, while Section 3 details the data and analytical methodology employed. Section 4 presents the empirical results, and Section 5 discusses the details of the empirical results. Section 6 formally concludes the study with concluding remarks and policy recommendations.

2. Literature Review

2.1. Human Capital and Environmental Quality Nexus

The importance of human capital is widely recognized in economic and environmental studies. Human capital augments production as an input and can affect output by raising total factor productivity [5,25,26]. The role of human capital in emissions reduction is much analyzed in the existing literature. The authors of two studies [14,20] have found that human capital reduces CO_2 emissions in the long run but increases them in the short run in OECD countries and in Pakistan, respectively, because the energy transition from dirty to clean fuels and the implementation of cleaner technology take time to realize. Another study [20] also found considerable heterogeneity across different levels of human capital, from basic to advanced levels, and suggests the advancement of human capital to encourage economic growth, as well as to alleviate climate change. In ASEAN countries, [27] has found that the growth of human capital drives increased CO_2 emissions, as it indirectly affects growth. Examining the impact of human capital and its combined impact with Information and Communications Technology (ICT) on CO_2 emissions from different industries, this study finds human capital to be a positive and ICT to be a negative contributing factor to CO_2 emissions in ASEAN countries. However, the association between human capital and CO_2 emissions is found to switch from positive to negative in the context of advanced (OECD) countries by [20].

2.2. Human Development and Environment—A Relatively New Concept

Although the role of human capital is a widely discussed phenomenon in environmental-quality assessment, human development is a relatively new concept in this area. There are a few studies that investigate the nexus between human development and environmental quality. Human development is regarded as a process through which people can expand the real freedoms they enjoy [28]. Ref. [12] confirmed a positive and significant correlation between environmental performance and human development. An increasing effect of human development on environmental quality was also established by [3] for 13 MENA countries. In the context of Sub-Saharan countries, ref. [29] found the effect of increasing CO_2 emissions on inclusive human development to be negative. ICT was identified by [30] as a factor that could be employed to dampen the potentially negative effect of environmental pollution on human development. Their study established that on the one hand, ICT supplemented CO_2 emission from liquid-fuel consumption, increasing inclusive development, while on the other hand, it interacted with CO_2 intensity, which negatively affected inclusive human development. The net effect on inclusive human development was found to be positive based on the complementarity between mobile phones and CO_2 emissions per capita in this study. Ref. [19] revealed that human capital reduced CO_2 emissions in a low-economic-growth regime and increased emissions in high-income-growth regime. This study has also found that human capital increases CO_2 emissions in low-human-development regimes and decreases emissions in high-human-development regimes. A modified human-development index employing many relevant social variables, e.g., health effects, political rights, adult literacy rate, enrollment rate, and civil liberties, was constructed by [31] for 15 countries in the Mediterranean region and showed that human development reduced regional pollution. An inverted-U-shaped relationship was revealed between the Environment Degradation Index (EDI) and Human Development Index (HDI) for Chinese provinces by [4]. An inverted-U-shaped relationship was also revealed by [1] for MENA countries, indicating that improvement in human development in the early stage increases environmental degradation by increasing the country's ecological footprint, but with continuous economic development, a further increase in human development improves the quality of environment. In an earlier study on India, an N-shaped relationship was found between environmental quality and human development by [32].

2.3. Role of Institutions and Renewable Energy in the Context of Developing Countries

Institutions and renewable energy were both found to have significant impacts on economic growth and CO_2 emissions [33]. A study [34] has evaluated the institutional and structuralist elements that can be combined to affect environmental degradation in economies heavily reliant on oil. Examining the issues of greenhouse-gas emissions in oil-exporting countries, the study demonstrates how the abundance of fossil fuels generates factors that have diametrically opposing effects on air pollution. Observing 85 developed and developing countries, study [33] found that institutions and renewable energy had significantly positive and negative effects on economic growth and CO_2 emissions, respectively. Institutional quality was identified as a key strategic choice in promoting the use of renewable energy and solving environmental problems by [35] for 66 developing countries. In another study [36] on developing countries, similar findings were revealed where : institutional quality, namely, political stability, administrative capacity, and democratic accountability, had a positive impact on environmental-quality indicators, specifically, CO_2 emissions, CH_4 emissions, and forested area. Improvements in the institutions and regulatory framework of sub-Saharan African countries were also found to be important for promoting renewable energy [37]. Similar findings were revealed for Middle-Eastern and African (MEA) countries and EU countries by [38]. Observing the direct and indirect effects of institutional quality, this study found important roles for institutions and stringent environmental policies in forming the inverted-U-shaped relationship between economic growth and pollution in both regions. Institutional quality was found to be a driving factor for green economic growth in the long run for South Asian economies by [39] and for 18 emerging countries by [40]; in those countries, institutional quality improves ecology through improvements in human capital.

There are numerous economic, social, and environmental benefits to pursuing renewable energy [37]. Currently, renewable energy is considered to be a catalyst that enhances environmental quality, and shifting from non-renewable to renewable is regarded as a strategic approach to reducing emissions. Ref. [22] highlighted the importance of the transition from non-renewable energy to renewable energy in mitigating global warming in the context of sub-Saharan African countries. The importance of renewable energy in cutting down on emissions was also established in a large number of studies [41] for India; [42] for Australia and Canada; [43] for Bangladesh; [44] for emerging countries; [45] for 53 countries; [46] for 25 developing countries; [47] for 107 low-income and high-income countries; [48] for 10 major electricity generators in sub-Saharan Africa; [49] for 37 African countries; and [50] for 107 countries.

From this brief literature review, it has been observed that diverse results prevail in the economic, environmental, social, and institutional nexus across the regions of the world. Tradeoffs between the economic, environmental, and social aspects of growth must be prevented [51]. In order to avoid such tradeoffs, human development should be encouragedthat can facilitate the implementation of sustainable development, particularly in the least developed and developing nations. However, human development is analyzed inadequately in environmental-quality assessment of low- and middle-income countries. It requires attention in these countries due to the possible presence of inequality in their development dimensions, arising as a consequence of their high aspirations for economic growth. This study will address this necessity by employing HDI in the environmental-impact assessment of a panel of low-income and developing countries to provide some insight into policy measures regarding human well-being through inclusive human development and environmental conservation. Reviewing the impact of renewable-energy and governmental-capacity indicators of these countries, this study will assist in finding policy measures that support the development of human beings.

3. Materials and Methods

3.1. Data Sources

The study utilizes a balanced panel of 60 countries, chosen to optimize the authors' capacity to achieve satisfactory results with a short time series by increasing the degrees of freedom. The annual data spanning over the period 2002–2019 for the countries selected from the low-, lower-middle-, and upper-middle-income categories are utilized to achieve the goals of this study. Twenty countries from each income category are were selected, and the names of the countries are provided in Appendix A3. The dimension of human development that is captured in the study is provided by UNDP; it focuses on people, their opportunities, and their choices. Table 1 presents the details of the data, along with their definitions and sources.

Table 1. Data description.

Symbol	Variable Name	Unit	Source	Expected Sign
CO_2	Carbon emissions	metric tons per capita	WDI, 2021 [52]	
HDI	Human Development Index	A composite index measured as an average achievement in three basic dimensions of human development. Those are life expectancy rate, literacy rate, and income level (GDP).	United Nations Development Program (UNDP), Human Development Report, 2020 "URL: http://hdr.undp.org/en/indicators/137506# (accessed on 1 March 2023) [53]	−/+
GDP	Gross Domestic Product per capita	constant 2015 US$	WDI, 2021 [52]	+
RE	Renewable-energy consumption	% of total final energy consumption	WDI, 2021 [52]	−
RQ	Regulatory quality	Percentile rank	Worldwide Governance Indicators (WGI), World Bank, 2021 [54]	−
RL	Rule of law			−
CC	Control of corruption			−

3.2. The Model and Estimation Procedure

3.2.1. Panel Model (Fixed Effects and Random Effects)

A penal model is established that defines CO_2 emissions, representing the quality of the environment, as the dependent variable. Following the relevant earlier studies [20,55–57], CO_2 emissions are projected in this study as a function of income (GDP) and square of income (GDP^2), human development (HD), renewable energy (RE), and all the indicators of governance, namely, regulatory quality (RQ), rule of law (RL), and corruption control (CC) as follows:

$$LCO_{2it} = b_0 + b_1 LHD_{it} + b_2 LGDP_{it} + b_3 LGDP^2{}_{it} + b_4 LRE_{it} + b_5 LRQ_{it} + b_6 LRL_{it} + b_7 LCC_{it} + \delta_i + \varepsilon_{it} \quad (1)$$

Here, all the variables are measured in their logarithmic form, and it is intended that the coefficients b_1 to b_7 of the regressors will be estimated by the regression analysis. In this regression model, countries are denoted by subscript i $(i = 1,2,3,\ldots,N)$ and time period is denoted by subscript t $(t = 1,2,3,\ldots,T)$. δ_i represents the country-specific constant, and ε_{it} is the error term.

The model is estimated by applying two principal approaches to panel-data analysis: the fixed effects (FE) and the random effects (RE) estimators. Under the FE method, the individual effect (δ_i) is interrelated with regressors, while under the RE method, the individual effect is not correlated with the regressors. The Hausman test has been applied to identify the specific model; the traditional Hausman test assumes the random effects model is fully efficient, implying that both δ_i and ε_{it} are identically and independently distributed [55,58].

3.2.2. System Generalized Method of Moments

Since the FE model is unable to address endogeneity, the model is also estimated using system Generalized Method of Moments (GMM) in order to address potential endogeneity concerns in the econometric model presented in Equation (1). System GMM as proposed by [59] is applied in this study, since system GMM estimators are suitable within a large historical trend in econometric practice towards estimators that employ more sophisticated strategies to extract meaningful information and make fewer assumptions about the underlying data-generating process. It is suitable for panel settings with small T (time) and large N (countries) [60]. Moreover, system GMM uses assumptions of extra moment conditions by using lagged values of independent variables as valid instruments and lagged levels for endogenous variables in the model. This accounts for unobserved heterogeneity in terms of time-invariant omitted variables and controls for simultaneity in explanatory variables by means of instrumentation. It can also be viewed as a generalization of other estimates, i.e., maximum likelihood and ordinary least squares. Therefore, it is more probable that the model will be correctly specified [61–63].

Following [64] and [59], the model can be specified as follows:

$$LCO_{2it} = b_0 + b_1 LCO_{2it-1} + b_2 LHD_{it} + b_3 LGDP_{it} + b_3 LGDP^2{}_{it} + b_4 LRE_{it} + b_5 LRQ_{it} + b_6 LRL_{it} + b_7 LCC_{it} + \delta_i + \eta_t + \varepsilon_{it} \quad (2)$$

This model is an expansion of Equation (1) that includes the lagged value of the dependent variable and η_t as the time-fixed effect.

3.2.3. Long-Run Output (Fully Modified Ordinary Least Squares and Dynamic Ordinary Least Squares)

For further support and confirmation of results for the long-run analysis, the study has established the co-integrating relationship among the variables. Based on the results of co-integration tests, the study has applied the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) techniques to find the long-run elasticity between the dependent and independent variables of the model (1). The FMOLS test proposed by [65] is an asymptotically unbiased and efficient estimator, free from endogeneity and serial correlation. The panel DOLS proposed by [66] involves augmenting the panel co-integrating equation with cross-section-specific lags and leads to the elimination of endogeneity and serial correlation among the variables [50].

3.3. Pre-Estimation Econometric Techniques

3.3.1. Cross-Section-Dependence (CD) Tests

It is important to test the cross-sectional dependence among the variables in a panel data set that might arise due to the interdependence of the cross-sections and cause the cross-sections to disturb each other's outcome [67] (Baltagi and Pesaran, 2007). The study applied four tests—Breusch and Pagan LM, Pesaran scaled LM, bias-corrected scaled LM, and Pesaran CD—to check whether it is possible to transfer the shock in one country to another country.

3.3.2. Panel Unit-Root Tests

Panel unit-root tests are applied to determine the stationarity of panel data. However, the selection of the panel unit-root test is based on the result of CD tests. This study applied one 'first-generation unit-root test', the Breuting and Das (2005) unit-root test, and two 'second generation unit-root tests', namely, the cross-sectional Im-Pesaran-shin (CIPS) test [68] and the Cross-sectional Augmented Dicky-Fuller (CADF) test. The first-generation unit-root test looks for the stationarity of data under the assumption of individual cross-sectional independence, whereas second-generation unit-root tests check the problem of individual cross-sectional dependence [39]. The CIPS test assumes the series to be non-stationary in the null hypothesis and is obtained by averaging the CADF test statistic. The CADF test statistic is obtained by adding the lags and differences of the cross-sectional means to the standard ADF test.

3.3.3. Cointegration Test

Cointegration tests are used to explore the long-run relationship among the variables. This study has applied the Pedroni (1999) [69] and Westerlund (2005) [70] cointegration tests to detect the long-run relationship among the variables.

4. Results

Results of Pre-Estimation Analysis

The data set is described in the Appendix A1, and the correlation matrix is presented in Appendix A2. Next, the hypothesis of no cross-sectional dependency is tested for selecting the appropriate unit-root tests to investigate the stationarity of the series. Table 2 presents the results.

Table 2. The results of the cross-sectional-dependence test.

Variables	Breusch Pagan LM	Pesaran Scaled LM	Bias-Corrected Scaled LM	Pesaran CD
LCO_2	14,613.95 ***	215.872 ***	214.107 ***	61.638 ***
$LGDP$	19,953.70 ***	305.619 ***	303.854 ***	117.729 ***
$LGDP^2$	19,909.13 ***	304.870 ***	303.105 ***	117.505 ***
LHD	28,768.42 ***	453.771 ***	452.006 ***	157.562 ***
LRE	11,741.47 ***	167.593 ***	165.829 ***	34.985 ***
LRQ	6692.388 ***	82.732 ***	80.967 ***	2.591 ***
LRL	7374.059 ***	94.189 ***	92.424 ***	6.121 ***
LCC	6223.534 ***	74.852 ***	73.087 ***	−0.833

Note: *** indicates significance at the 1% level.

According to the results of four different tests, the null hypothesis is rejected for all series, and it is confirmed that all series have cross-sectional dependency. Based on this result, the widely used second-generation unit-root test, the CIPS test, and the CADF test are the preferred means to detect the unit root. The result of the first-generation unit-root test is presented here as an additional outcome of the unit-root test. The results of all the performed unit-root tests are presented in Table 3.

Table 3. Results of unit-root tests.

Variables	Breitung (Intercept and Trend)		CADF		CIPS	
	At Level	1st Difference	At Level	1st Difference	At Level	1st Difference
LCO_2	1.301	−5.248 ***	−1.872	−2.265 ***	−2.127 **	−3.662 ***
$LGDP$	3.060	−4.001 ***	−1.394	−2.215 ***	−1.442	−2.997 ***
$LGDP^2$	2.571	−3.734 ***	−1.399	−2.138 ***	−1.422	−2.910 ***
LHD	4.038	−7.407 ***	−2.372 ***	−3.022 ***	−2.186 **	−3.738 ***
LRE	0.647	−2.781 ***	−2.075 ***	−2.514 ***	−2.124 **	−3.656 ***
LRQ	−1.824 **	−8.990 ***	−1.749	−2.679 ***	−2.056 *	−4.628 ***
LRL	−0.751	−8.514 ***	−2.091 ***	−2.784 ***	−2.275 ***	−4.135 ***
LCC	−0.053	−7.655 ***	−1.969 **	−2.558 ***	−2.388 ***	−4.054 ***

Note: *** indicates significance at the 1% level, ** indicates significance at 5% level, * indicates significance at 10% level (critical values for CIPS: −2.2 for 1%, −2.08 for 5%, and −2.01 for the 10% level).

The results of both first-generation and second-generation tests reject the basic hypothesis of non-stationarity at their first differences, although a few variables are found to be stationary at their levels. Next, the results of long-run elasticity, as calculated by applying the Pedroni and Westerlund cointegration tests, are presented in Table 4. The results of both tests support the existence of a long-run relationship among the variables by rejecting the null hypothesis of no co-integration in the model.

Table 4. The results of the tests for co-integration.

Pedroni Test for Cointegration		
H_0 No cointegration		
H_1: All panels are cointegrated		
	Statistic	*p*-value
Modified variance ratio	−6.942 ***	0.000
Modified Phillips Perron t	7.108 ***	0.000
Phillips Perron t	−9.985 ***	0.000
Augmented Dickey Fuller t	−9.111 ***	0.000
Westerlund test for cointegration		
H_0: No cointegration		
H_1: Some panels are cointegrated		
	Statistic	*p*-value
Variance ratio	−2.066 ***	0.019
H_0: No cointegration		
H_1: All panels are cointegrated		
	Statistic	*p*-value
Variance ratio	2.799 ***	0.002

Note: *** indicates significance at the 1% level.

In an empirical estimation procedure, this study has performed regressions for the model and estimated outcomes for the panel of countries. The results of the estimated models are presented in Table 5, and the results are discussed below.

Table 5. The results of FE, RE, and GMM.

Variables	**FE**	**RE**	**Sys-GMM**
LCO_{2t-1}			0.763 *** (46.06)
$LGDP$	1.927 *** (8.28)	2.037 *** (9.16)	0.749 *** (4.61)
$LGDP^2$	−0.082 *** (−5.64)	−0.085 *** (−6.14)	−0.044 *** (−4.62)
LHD	0.420 *** (3.69)	0.372 *** (3.38)	0.301 *** (3.09)
LRE	−0.406 *** (−13.90)	−0.403 *** (−15.36)	−0.146 *** (−10.04)
LRQ	0.121 *** (5.90)	0.117 *** (5.76)	0.032 *** (9.06)
LRL	−0.114 *** (−6.04)	−0.115 *** (−6.15)	−0.020 *** (−3.83)
LCC	−0.044 *** (−3.02)	−0.045 *** (−3.03)	−0.022 *** (−6.36)
Constant	−8.379 *** (−8.51)	−9.063 *** (−9.63)	−2.434 *** (−3.47)
Hausman test	Chi2 32.70 (*p*-value 0.000)		
Hansen J test			55.812 (*p*-value 0.333)
AR(2) test			−0.675 (*p*-value 0.499)

Note: *** indicates significance at the 1% level.

Table 5 presents the empirical findings from three estimators: fixed effects (FE), random effects (RE), and two-step system generalized method of moments (GMM). The result (*p*-value) of the Hausman test projects the rejection of the null hypothesis, meaning that the fixed effects model is more efficient than the random effects model for this study. However, the estimates from both FE and RE models yield similar results, albeit with slightly varying coefficient values. In GMM estimation, the result of the lagged dependent variable is found to be positive and statistically significant at the 1% level, implying a continuous and significant trend in CO_2 emissions from the past into the future in low and middle-income countries. The results of the system GMM are consistent with those of the other two applied models (FE and RE).

Empirical results from Table 5 also show that $LGDP$ has a positive coefficient, while $LGDP^2$ has a negative coefficient. This result signals the possible presence of an environmental Kuznets curve (EKC)hypothesis in the selected countries. However, this result explores a trade-off relationship between the status of human development and CO_2 emissions in the selected low- and middle-income countries, as the coefficient of human development is positive, with strong statistical significance. The coefficient of renewable energy is significant and negative, indicating its beneficial impact on environmental quality. Among the indicators linked to governance quality, two—rule of law and corruption control—are negative and statistically significant, while regulatory quality, another indicator of good governance, is positive, indicating its contribution to environmental-quality degradation in the selected countries.

The acceptance of the GMM estimations depends on the absence of overidentification and serial correlation in the error term. Since the p-value of Hansen test is >0.1, it confirms that the restrictions for overidentification are satisfied. Furthermore, the AR(2) test result shows that the regressions do not suffer from a second-order serial-correlation problem. Hence, the instrument set applied in these regressions is valid.

In an investigation for the consistency of the results in the long run, FMOLS and DOLS are applied based on the co-integration outcome. The results for long-run CO_2 emissions are presented in Table 6, and it is found that the results do not overturn the earlier findings from FE, RE and Sys-GMM. The long-run results also evidence the presence of a trade-off between human development and environmental quality for low- and middle-income countries, as the coefficient of the human-development indicator is positive and statistically significant. The environmental Kuznets' curve is also evident in the long-run result, as the coefficients of GDP and GDP^2 are positive and negative, respectively, and both are statistically significant.

Table 6. The results of FMOLS and DOLS.

Variables	**FMOLS**		**DOLS**	
	Coefficient	**S.E**	**Coefficient**	**S.E**
$LGDP$	1.903 ***	0.005	1.927 ***	0.356
$LGDP^2$	−0.102 ***	0.007	−0.082 ***	0.022
LHD	0.431 ***	0.005	0.420 **	0.174
LRE	−0.406 ***	0.009	−0.406 ***	0.044
LRQ	0.098 ***	0.008	0.121 ***	0.031
LRL	−0.042 ***	0.007	−0.114 ***	0.028
LCC	−0.055 ***	0.006	−0.044 ***	0.022
R-squared	0.988		R-squared	0.989
Adjusted R-squared	0.987		Adjusted R-squared	0.988
S.E of regression	0.169		S.E of regression	0.162
Mean Dependent var	−0.428		Mean Dependent var	−0.443
Sum squared resid	27.435		Sum squared resid	26.603

Note: *** indicates significance at the 1% level and ** indicates significance at the 5% level. S.E. indicates standard errors.

Additionally, the impacts of renewable-energy consumption and the indicators of good governance align with prior findings. The high R^2 and adjusted R^2-values underscore the robust fit of these two models.

We have conducted an additional analysis based on the income groups of the countries (low income, lower-middle income and upper-middle income) utilizing long-run regression models (FMOLS and DOLS) and presented the results in Appendix A4. The findings reveal convincingly similar outcomes across all groups of countries, particularly for the human-development and renewable-energy variables. Human development plays a contributory role in CO_2 emissions, while the use of renewable energy improves environmental quality across all three categories of countries considered in this study. The U-shaped environmental Kuznets curve (EKC) was observed for low-income countries, and the inverted-U-shaped EKC hypothesis was found to be valid for the lower-middle and upper-middle-income countries. Among governance-quality indicators, the rule of law significantly contributes to environmental quality in middle- and upper-middle-income countries, while stringent measures on corruption control appear to improve environmental quality in low-income countries.

5. Discussion

These results indicate that the characteristics of development in the selected countries have the potential to form an environmental Kuznets curve (EKC). This implies that as income grows, it initially leads to an increase in CO_2 emissions in these countries, but once a certain threshold is reached, the expanded economic activity on a larger scale will create a positive effect on economic growth, which in turn results in a diminishing impact on environmental degradation. This result is consistent with the findings of [22] for SSA countries and [14] for Pakistan. However, the explored trade-off relationship between human-development status and CO_2 emissions implies that the prevailing activities aimed at enhancing human development inadvertently lead to an increase in CO_2 emissions, thereby compromising environmental quality in these countries. This outcome aligns with expectations, given the relatively low baseline of human development and income level in these countries. Efforts to improve human-development status can stimulate CO_2 emissions, particularly since the Human Development Index (HDI) encompasses income per capita, reflecting a higher standard of living attainable through economic growth, and the acceleration of income typically results in increased CO_2 emissions for the selected countries in this study. This finding concurs with the results of similar research by [3] for the MENA region and [27] for ASEAN countries. It corroborates the argument posited by [19], suggesting that when human-capital development remains below a certain threshold of human development, an increase in human capital increases CO_2 emissions. Beyond this threshold, CO_2 emissions decrease. Therefore, although this study provides an indication of the presence of an EKC, which is suggestive of a policy of "grow first and clean up later" [51], it is not sufficient enough to mitigate the ongoing environmental crisis without addressing the social components of development, such as human development. Nevertheless, research on a global scale conducted by [71] indicated that increased human capital reduces emissions.

In the context of the Human Development Index (HDI), which encompasses income alongside mean years of schooling and life expectancy as key human-development indicators, a higher emphasis on income tends to correspond with a lower human-development score. This, in turn, is associated with suboptimal environmental performance, as observed in the study [12]. This correlation may be attributed to the fact that an increase in income frequently correlates with heightened industrialization, greater demand for natural-resource extraction, and increased energy consumption, leading to elevated emissions that exert adverse effects on the environment. Within the selected groups of countries under consideration, income is accorded paramount importance, and this particular observation regarding human development aligns with results in the established literature. Regulatory quality, which serves as an essential indicator of governance quality within these countries and is measured by the policies formulated and implemented to facilitate and promote the private sector (encompassing aspects such as price control, investment and financial freedom, the burden of government regulations, tax consistency, non-tariff barriers, and the ease of starting a business, among others), is also found to contribute to CO_2 emissions. This result suggests that the quality of business investment, financial management, and bureaucratic policies within the selected countries is suboptimal, which in turn is not conducive to maintaining environmental quality. Conversely, the utilization of renewable energy sources, the prevalence of the rule of law, and corruption control measures within these nations play a substantial role in upholding environmental quality by mitigating CO_2 emissions.

The long-run results substantiate the claim that initiatives aimed at enhancing the Human Development Index lead to a reduction in environmental quality by elevating CO_2 emissions although the environmental Kuznets curve (EKC) hypothesis holds true for the countries. These findings suggest that the positive association observed between human development status and CO_2 emissions in this study stems from the relatively lower levels of income and human development within the selected countries. These countries prioritize income growth as a means by which to improve their HDI status. This is in line with the findings of [58], which found that both the Human Development Index (HDI) and the Environmental Performance Index (EPI) exhibited a positive relationship with GDP and GNI and that in cases where a country's economy is weaker (better), the result tends to be lower (higher) scores for both the HDI and EPI. Although there is minor variability in the group-wise outcomes of countries based on income, it has been well established by this study that human development demands attention, particularly in its inclusiveness and dimension-wise coordinated progress. Additionally, the use of renewable energy and the implementation of good governance are crucial for maintaining environmental quality across countries of all income groups.

6. Conclusions and Policy Suggestions

This study examines the complex relationship between human development and environmental quality with a specific focus on carbon emissions, using a dataset encompassing 60 countries from low-, lower-middle, and upper-middle-income groups during the period 2002–2019. The study also explores the roles of income, renewable energy, and good governance in this relationship under the prevailing economic condition of the countries. This study has employed the most widely used panel-data-analysis techniques, including fixed effects (FE), random effects (RE), and system generalized method of moments (GMM), to obtain the coefficient values. The empirical findings highlight a significant positive correlation between human-development status and the degradation of environmental quality, as indicated by increased CO_2 emissions. This correlation underscores a lower level of human development in low-income and developing countries.

The pursuit of higher rankings in human development is often associated with increased economic development, which typically entails heightened industrialization and greater energy consumption. However, both of these factors are significant sources of carbon emissions because they are primarily reliant on fossil fuels such as coal, oil, and natural gas. Additionally, higher levels of human development are frequently linked to increased consumption, encompassing the utilization of energy-intensive products and transportation. This, in turn, leads to higher per capita carbon emissions. Renewable-energy consumption, adherence to the rule of law, and effective control of corruption positively contribute to environmental quality. However, the regulatory quality of countries exerts a more significant influence on emissions and can have a deteriorating effect on environmental quality. Employing both first- and second-generation co-integration methods by utilizing the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) techniques, this study also explores the long-run relationships among these variables. The findings for the long run exhibit consistency with the results obtained through the fixed effects (FE), random effects (RE), and system generalized method of moments (System GMM) approaches.

While there exists a positive correlation between higher levels of human development and increased carbon emissions in low-income and developing countries, it is critical to note that this correlation is not a desirable outcome. Therefore, global efforts are imperative to decouple economic growth and human development from carbon emissions. This end is to be achieved through sustainable practices, technological innovation, and international agreements like the Paris Agreement, which aims to mitigate climate change while promoting human development. Progress must be made on multiple fronts to mitigate the ongoing global warming and the record-high levels of CO_2 emissions [6]. Given that climate change is predominantly human-induced (as indicated by [72]), policies that disregard the crucial link between human development and climate change cannot effectively address this multifaceted challenge. In light of the evident trade-off relationship between human--development status and carbon emissions in low-income and developing countries, it is important for institutions to step forward and establish a mutually beneficial scenario that safeguards both human development and environmental quality simultaneously. Greater emphasis should be placed on the integration of economic and social dimensions, such as education, health, skill development, economic freedom, and socio-economic inclusion, in addition to income generation. Developing countries should prioritize management strategies for human development that do not exacerbate emissions and mobilize resources to form a supply chain of talented and skilled individuals who can actively contribute to mitigating the environmental-degradation crisis through research and development as well as environmentally conscious behavior. Capacity enhancement of human capital through public-health services and modern education, international collaboration in knowledge and awareness-building with regard to environmental conservation and renewable technologies can enhance the socio-economic capabilities of these countries.

The positive impact of human development on CO_2 emissions can be mitigated by employing mechanisms such as information and communications technology (ICT). This can save transportation costs from both economic and environmental perspectives while increasing disposable income that can be allocated to bolstering social capital. Many developing countries, particularly those in Africa, possess abundant untapped renewable-energy resources. By making substantial investments, these countries can effectively integrate renewable energy into their energy portfolios. Since renewable energy holds the promise of serving the dual purpose of fostering economic growth and enhancing environmental quality in a sustainable manner [33], a concerted effort by governments to prioritize renewable-energy consumption can significantly drive the demand for both economic development and environmental sustainability. This, in turn, will contribute to human development and improve human capital, which is pivotal in safeguarding the interests of both the economy and the environment.

In terms of policy measures, a country's economic development should center on people-oriented and welfare-focused strategies, ensuring the well-being of its populace rather than exclusively focusing on national economic growth. The governments of these nations should upgrade their regulatory quality, empowering them to formulate and implement effective policies and regulations that foster private-sector growth and financial development. This can be achieved by streamlining investment processes, reducing governmental regulations, promoting financial freedom, and minimizing discriminatory taxes and excessive protections. Governments must also extend their capacity to combat various forms of corruption and activities that pose threats to the well-being of their citizens, as well as to economic and environmental stability. Building trust and confidence in society's rule, property rights, and the maintenance of law and order within their jurisdiction should be a top priority for governments. The successful implementation of these measures will increase people's overall quality of life and improve environmental conditions.

Inequalities in human development also significantly contribute to the degradation of environmental quality. While the first two decades of the twenty-first century have witnessed many people step above the minimum threshold for human development, widespread disparities still persist, as noted in the human development report 2019 [11]. These disparities exacerbate environmental risks, and their impact varies across different levels of human development. Inequalities in dimensions of human development, such as income, health, and education, can further stress the environment. Consequently, addressing disparities and inequalities in human development is imperative. Economically disadvantaged nations must prioritize human development by investing in social capital and implementing environmentally-conscious development policies to confront environmental challenges and achieve sustainable human development. Failure to do so will result in countries with the lowest HDI making minimal contributions to climate-change mitigation and facing significant obstacles to achieving an emissions-free environment.

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Appendix A

Appendix A1.

Table A1. Descriptive Statistics of Series under Consideration without Their Logarithmic Forms.

	CO_2	$LGDP$	LHD	LRE	LRQ	LRL	CC
Mean	1.722943	3615.703	0.583524	52.08312	35.56689	30.71706	29.85378
Median	0.687066	1474.693	0.569000	52.84225	34.24870	27.88461	27.84475
Maximum	11.63994	42,887.66	0.845000	96.04110	83.66337	89.67136	76.76768
Minimum	0.021725	258.6288	0.273000	0.059000	0.480769	0.469484	0.473934
Std. Dev.	2.419414	5684.811	0.147184	30.84913	20.94214	19.17784	17.99984
Sum	1860.779	3,904,959.	630.2056	56,249.77	38,412.24	33,174.43	32,242.08
Sum Sq. Dev.	6315.998	3.49×10^{10}	23.37443	1,026,851.	473,220.4	396,844.9	349,589.8
Observations	1080	1080	1080	1080	1080	1080	1080

Appendix A2.

Table A2. Correlation Matrix.

	LCO_2	$LGDP$	$LGDP^2$	LHD	LRE	LRQ	LRQ	LCC
LCO_2	1							
$LGDP$	0.922	1						
$LGDP^2$	0.907	0.996	1					
LHD	0.859	0.860	0.845	1				
LRE	−0.743	−0.655	−0.655	−0.625	1			
LRL	0.280	0.345	0.353	0.388	−0.231	1		
LRQ	0.314	0.408	0.409	0.346	−0.140	0.775	1	
LCC	0.385	0.434	0.436	0.401	−0.315	0.785	0.742	1

Appendix A3. Name of Countries

Bangladesh, India, Pakistan, Myanmar, Laos, Vietnam, Indonesia, Cambodia, Kenya, Philippines, Zambia, Algeria, Mauritania, Ghana, Nigeria, Iran, Cameroon, Zimbabwe, Honduras, Bolivia, Niger, Mali, Chad, C.A. Republic, D.R. Congo, Mozambique, Madagascar, Guinea, Uganda, Sierra Leone, Afghanistan, Burundi, Burkina Faso, Ethiopia, Gambia, Liberia, Malawi, Rwanda, Syrian A.R., Togo, Brazil, Argentina, Colombia, Peru, Russia, Romania, Serbia, Bulgaria, Albania, Turkey, China, Thailand, Jordan, Libya, Malaysia, Mexico, Guatemala, Costa Rica, Ecuador, Paraguay.

Appendix A4.

Table A4. Income-Category-Wise Long-Run Regression Analysis for Countries.

Variables	Low Income		Lower-Middle Income		Upper-Middle Income	
	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
LGDP	−2.589 *	−2.683 *	0.433 ***	2.441 ***	3.778	2.045 ***
	(1.473)	(1.512)	(0.006)	(0.960)	(0.777)	(0.682)
*LGDP*²	0.233 **	0.243 **	−0.077 ***	−0.092	−0.199	−0.095 **
	(0.115)	(0.119)	(0.011)	(0.065)	(0.046)	(0.041)
LHD	0.665 ***	0.597 ***	0.225 ***	−0.174	0.965	0.685 **
	(0.189)	(0.185)	(0.009)	(0.217)	(0.344)	(0.336)
LRE	−1.501 ***	−1.485 ***	−0.172 ***	−0.141 ***	−0.226	−0.248 ***
	(0.122)	(0.125)	(0.018)	(0.046)	(0.032)	(0.031)
LRL	0.040	0.044	−0.064 ***	−0.083 ***	−0.092	−0.109 ***
	(0.037)	(0.035)	(0.012)	(0.031)	(0.043)	(0.043)
LRQ	0.026	0.027	0.147 ***	0.015	−0.111	−0.069 *
	(0.043)	(0.046)	(0.013)	(0.034)	(0.042)	(0.041)
LCC	−0.134 ***	−0.105 ***	0.006	0.004	0.069	0.031
	(0.033)	(0.034)	(0.008)	(0.021)	(0.028)	(0.025)
R-squared	0.968	0.967	0.835	0.956	0.994	0.993
Adjusted R-squared	0.965	0.964	0.821	0.953	0.993	0.992
SE of regression	0.136	0.138	0.385	0.198	0.072	0.078
Long-run variance	0.033	0.039	0.005	0.082	0.011	0.012

*** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

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