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How Renewable Energy Fuels Human Development: Evidence from Emerging Markets

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Abstract. This study investigates the relationship between renewable energy consumption (RE) and the Human Development Index (HDI) across a diverse sample of countries, employing advanced econometric approaches, including the Common Correlated Effects Mean Group (CCEMG), Augmented Mean Group (AMG), and the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) models. The analysis reveals a significant positive association between RE and HDI, with coefficient estimates indicating that a 1% increase in renewable energy consumption corresponds to a notable improvement in HDI, underscoring the role of sustainable energy in enhancing health, education, and economic opportunities. The AMG model shows a stronger effect of renewable energy on HDI, suggesting that effective policy frameworks and technological advancements amplify these benefits. The CS-ARDL model further confirms both short- and long-run dynamics, indicating a sustainable relationship over time, with adjustment coefficients demonstrating convergence towards equilibrium following shocks to RE. These findings highlight the critical importance of renewable energy in achieving sustainable development, advocating for its prioritization in national policies. This research not only contributes to the discourse on energy and development but also encourages further studies to explore the intricate connections between energy consumption, human development, and sustainability.

Key words: renewable-energy, sustainability, HDI, emerging economies, CS-ARDL.

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Как возобновляемая энергия способствует развитию человечества: данные развивающихся рынков

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Аннотация. В этом исследовании изучается взаимосвязь между потреблением возобновляемой энергии (ВЭ) и индексом развития человеческого потенциала (ИРЧП) в разнообразной выборке стран с использованием передовых эконометрических подходов, включая модели Common Correlated Effects Mean Group (CCEMG), Augmented Mean Group (AMG) и Cross-Sectional Autoregressive Distributed Lag (CS-ARDL). Анализ выявляет значительную положительную связь между ВЭ и ИРЧП, при этом оценки коэффициентов указывают на то, что увеличение потребления возобновляемой энергии на 1 % соответствует заметному улучшению ИРЧП, подчеркивая роль устойчивой энергетики в улучшении здоровья, образования и экономических возможностей. Модель AMG показывает более сильное влияние возобновляемой энергии на ИРЧП, предполагая, что эффективные политические рамки и технологические достижения усиливают эти преимущества. Модель CS-ARDL дополнительно подтверждает как краткосрочную, так и долгосрочную динамику, указывая на устойчивую связь с течением времени, при этом коэффициенты корректировки демонстрируют сходимость к равновесию после шоков в ВЭ. Эти результаты подчеркивают критическую важность возобновляемой энергии в достижении устойчивого развития, выступая за ее приоритетность в национальной политике. Это исследование не только вносит вклад в обсуждение вопросов энергетики и развития, но и поощряет дальнейшие исследования для изучения сложных связей между потреблением энергии, развитием человека и устойчивостью.

Ключевые слова: возобновляемая энергия, устойчивость, ИРЧП, развивающиеся экономики, CS-ARDL.

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I. Introduction

The relationship between energy consumption and human development has gained significant attraction in recent years, particularly in the context of emerging economies. As these nations strive to meet growing energy demands while pursuing sustainable development, renewable energy sources have emerged as a viable solution to address both environmental and socio-economic challenges. The Human Development Index (HDI), which combines indicators of life expectancy, education, and income, serves as a critical framework for assessing human well-being. This paper explores the impact of renewable energy adoption on HDI in emerging economies, highlighting the pathways through which renewable energy can enhance development outcomes. Transitioning to renewable energy is essential for emerging economies to mitigate the adverse effects of climate change while promoting sustainable economic growth [Yadav 2024]. Traditional fossil fuel dependency has not only contributed to environmental degradation but has also limited energy access in underserved regions [Sasmaz 2020]. Studies indicate that renewable energy can significantly improve energy access, particularly in rural areas, thereby enhancing educational facilities and healthcare services, which are crucial for improving HDI [Nguyen 2023].

The economic implications of renewable energy adoption are profound. Investment in renewables can stimulate job creation, drive technological innovation, and foster local economic development [Amer 2020]. For instance, the integration of renewable energy sources such as solar and wind has been linked to improved economic indicators across various countries [Yang 2022]. However, the relationship between renewable energy and HDI is complex, influenced by factors such as carbon emissions and urbanization [Alavijeh 2024]. This paper aims to unravel these dynamics by conducting a panel data analysis that examines the correlation between renewable energy consumption and HDI in emerging economies. By leveraging insights from various studies, including those focusing on other economies and broader panels, the research seeks to provide a nuanced understanding of how renewable energy can serve as a catalyst for sustainable development. In conclusion, as the world grapples with the challenges of climate change and socio-economic inequalities, understanding the role of renewable energy in fostering human development in emerging economies is paramount. This research will provide critical insights into how renewable energy can not only address environmental concerns but also enhance the quality of life for millions, ultimately contributing to a more sustainable and equitable future. In addressing these themes, this study aims to contribute to the existing body of knowledge by examining the correlation between renewable energy utilization and HDI in diverse emerging economies.

II. Literature Review

The role of renewable energy usage in enhancing the Human Development Index (HDI) is increasingly recognized as a vital component of sustainable development, particularly in emerging nations. This relationship not only highlights the importance of clean energy sources but also underscores their potential to drive social and economic progress in regions striving for a sustainable future. This review synthesizes findings from diverse studies, illustrating how renewable energy impacts the Human Development Index (HDI) and broader socioeconomic factors. The World Economic Forum [Unlocking renewable energy... 2024] discusses the transformative potential of renewable energy in emerging markets, emphasizing that investments in clean energy can unlock economic growth, enhance energy security, and improve living standards. This foundational assertion aligns with the focus of this paper on how renewable energy drives improvements in HDI, setting a clear context for further exploration. Moreover, the IEA [World Energy

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Outlook 2021] further supports this by illustrating how renewable energy investments are essential for achieving global sustainable development goals. Their analysis reveals that renewable energy fosters economic growth while addressing environmental challenges, thereby contributing to better social outcomes. This aligns with the paper's focus on how renewable energy can catalyze broader improvements in HDI. In addition, Meyer and Sommer [Meyer 2016] review the employment effects of renewable energy deployment, emphasizing the positive impact on local economies. Their work illustrates how renewable energy can stabilize communities by providing sustainable job opportunities. Additionally, Destek and Aslan [Destek 2017] expand on this by analyzing renewable and non-renewable energy consumption in emerging economies. Their findings suggest that while both types of energy influence growth, a strategic shift towards renewables is necessary for sustainable long-term development, reinforcing the need to prioritize clean energy. Moreover, Kaewnern et al. [Kaewnern 2022] investigate the interplay between research development and renewable energy on human development, finding that countries with higher investments in both areas demonstrate improved HDI scores.

The comprehensive review by Hassan et al. [Hassan 2024] discusses international renewable energy growth and its implications for HDI, asserting that coordinated global efforts are essential to leverage renewable energy as a tool for human development. This collaborative perspective aligns with the paper's emphasis on the need for integrated approaches to energy policy. Additionally, Azam et al. [Azam 2023] provide empirical evidence from Asian countries, highlighting the significant effects of renewable energy consumption on human development. Their findings suggest that countries prioritizing renewable energy are likely to see marked improvements in health and education metrics, reinforcing the direct connection between renewable energy and HDI explored in this paper. Furthermore, the IRENA report [Renewable Energy and Jobs 2020] reiterates the importance of renewable energy for job creation, emphasizing the sector's capacity to improve social and economic indicators. This dual focus illustrates the multifaceted benefits of renewable energy investments, which will be a focal point of the paper's analysis. Continuing the discussion, Ullah et al. [Ullah 2024] discuss the role of regional integration in renewable energy transition, proposing that collaborative efforts can energize pathways to sustainable development. Their research indicates that integrated renewable energy strategies can foster economic growth while improving HDI outcomes. The implications of justice and equity in the energy transition are examined by Carley and Konisky [Carley 2020], who argue that equitable access to renewable energy is essential for ensuring that all communities benefit from the transition, thus positively impacting HDI across different demographics. This perspective will be integrated into the paper's discussion on social equity in energy access.

B. Tufaner analyzes the relationship between renewable energy and human development [Tufaner 2023], concluding that renewable energy plays a vital role in improving HDI through various channels, including increased access to energy, economic stability, and enhanced quality of life. This directly supports the paper's thesis regarding the critical link between energy consumption and development. In addition, R. Lin and J. Ren [Lin 2020] contribute by addressing renewable energy's role in sustainable development, asserting that strategic investments in renewable energy are crucial for achieving long-term development goals. This final perspective reinforces the overarching theme of the paper, linking energy consumption to enhanced HDI in emerging economies. Finally, M. Nosheen et al. [Nosheen 2023] present evidence from a panel of the top 20 countries, demonstrating that renewable energy consumption significantly correlates with economic growth. Their findings further solidify the argument that renewable energy is integral to advancing HDI, which is a central focus of this review. Despite the growing body of literature on renewable energy and its impact on human development, several research gaps remain. First, there is a lack of comprehensive studies that specifically examine the causal mechanisms linking renewable energy consumption to improvements in HDI across diverse emerging economies, particularly in regions where data is scarce. Second, while many studies focus on economic growth, fewer explore the nuanced effects of renewable energy on specific HDI components, such as health and education, making it difficult to understand the pathways through which energy transitions influence overall development. Lastly, there is a need for research that investigates the role of policy frameworks and institutional capacities in facilitating or hindering the effective implementation of renewable energy initiatives, as this can significantly impact their efficacy in promoting sustainable human development. Addressing these gaps will provide a more holistic understanding of how renewable energy can be harnessed to improve HDI in emerging economies.

III. Data, Estimation Strategy, Results and Discussion

3.1. Data

Annual data from 1990 to 2023 were obtained from the World Bank Development Indicators, for 30 emerging economies based on data availability (World Population Review, 2024). The multivariate framework includes real HDI, Renewable Energy Consumption (RE), Regulatory Quality (RQ), Industrial Value Added (IVA), Technological Innovation (TI), Urbanization (URB) and GDP per Capita. Table 1 provides more details for each of the variables. The data is compiled within a panel data framework in light of the relatively short time span of the data. All variables are in natural logarithms.

Table 1. **Definitions, Measurement, and Data Sources**

Variables	Description and measurement	Source	Expected sign
HDI	Human Development Index	UNDP	-----
RE	Renewables generation/investment Ktoe (kilotonnes of oil equivalent)	WDI	-----
RQ	Regulatory Quality	WDI	M-1: (-) M-2: (+)
IV	Industrial Value Added (%, GDP)	WDI	M-1: (-) M-2: (+)
TI	Technological innovation	WDI	M-1: (+) M-2: (-)
URB	Urbanization	WDI	M-1: (+) M-2: (-)
GDP	Gross domestic product	WDI	M-1: (+) M-2: (+)

3.2. Regression Models

In order to highlight the effect of explanatory variables on dependent variables, algebraic forms have been used in the form of econometric models as follows:

$$HDI_{it}=f(RE_{it}, RQ_{it}, IV_{it}, TI_{it}, URB_{it}, GDP_{it}) \quad (1)$$

Where HDI stand for Human Development Index, RE represents Renewable Energy Consumption, RQ represents Regulatory Quality, IV depicts industrial value added, TI implies technological innovation, URB reports urbanization, and GDP denotes gross domestic product. Moreover, the incorporation of previously mentioned factors is steady with the recent literary work documented in the literature review section in detail. Before the basic empirical estimations, the data is converted into logarithmic specification. This will help us to interpret coefficients efficiently. The data under examination is tested for several preliminary tests. Thus, the final econometric equations for the above demand functions can be given as follows:

$$LnHDI_{it} = \alpha_0 + \beta_1 LnRE_{it} + \beta_i \sum_{i=3}^{n} Ln[C\_V]_{it} + \varepsilon_{it} \quad (2)$$

Where α_0 is the constant term. $\beta_1$to β_i are the respective slope coefficient terms for the variables of Eq. (2), respectively. C_V stands for all control variables.

3.3. Estimation Strategy

Before conducting the basic econometric estimations in this study, we carried out numerous tests to understand the properties and nature of the data being examined. Based on the results of these tests, we selected relevant econometric methodologies to accurately project the long- and short-term effects of the explained variables on the dependent variables, specifically Human Development Index (HDI). When analyzing panel data, it is common to encounter issues such as cross-sectional dependence (CSD) and heterogeneous slopes (SH). Ignoring these checks can lead to inadequate econometric methods and ultimately produce misleading regression results. To address the issue of CSD, this study utilized the Breusch and Pagan (1980) Lagrange Multiplier (LMBP) test as well as the bias-corrected scaled LM test (SLMBC) proposed by Baltagi et al. (2012).

$$LM_{BP} = T \sum_{i=1}^{N-1} \sum_{i=i+1}^{N} \hat{\rho}_{ij}^{2} \quad (3)$$

$$SLM_{BC} = \sqrt{\frac{1}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\hat{\rho}_{ij}^{2} - 1\right) \right) - \frac{N}{2(T-1)} \quad (4)$$

The value $\hat{\rho}_{ij}^{2}$ in Eq. (3) and (4) estimate the pairwise correlation of the residuals. Breusch and Pagan demonstrated that in the absence of cross-sectional dependence, LM_{BP} test statistics are asymptotically distributed (χ^2). In addition, Pesaran and Yamagata's test was employed to overcome slope heterogeneity

(Pesaran and Yamagata 2008). This technique can be carried out to test and suggest to the researcher whether or not to include a heterogeneous slope. Considering the outcomes of this technique, a primarily comprehensive econometric cointegration check could be investigated.

$$\tilde{\Delta}_{Slope-Heterogeneity} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S}-k\right) \quad (5)$$

$$\tilde{\Delta}_{Adjusted-Slope-Heterogeneity} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S}-2k\right)$$

(6)

To assess stationarity in the data, we employed the cross-sectional augmented Im, Pesaran, and Shin (CIPS) test, as well as the cross-sectional augmented Dickey-Fuller (CADF) test. These methods effectively address both cross-sectional dependence (CSD) and slope homogeneity (SH) issues in the model, as highlighted by Pesaran (2007). In contrast, traditional panel unit root tests tend to focus on only one of these issues, making CIPS and CADF the preferred options for our analysis. Below, we present the test statistics for CADF and CIPS in Eq. (7) and (8), respectively.

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \delta_i \bar{y}_{it-1} + \lambda_i \Delta\bar{y}_{it} + \varepsilon_{it} \quad (7)$$

$$C\widehat{IPS} = N^{-1}\sum_{i=0}^{n} CADF_i \qquad (8)$$

The panel cointegration test proposed by Westerlund (2007) was employed to establish a long-run cointegrating relationship between the regressors and the dependent variables (RE and NRE). This test is superior to traditional methods as it takes into account cross-sectional dependency, accommodates diverse slope models, and addresses heterogeneous orders of variable integration. Additionally, it provides reliable results even with modest sample sizes and requires less computational effort compared to residual-based cointegration approaches (Bhattacharya et al., 2018). The equations for the test are as follows:

$$G_t = N^{-1}\sum_{i=1}^{N}\frac{\hat{\vartheta}_i}{Standard\ Error\ (\hat{\vartheta}_i)} \quad (9a)$$

$$G_a = N^{-1}\sum_{i=1}^{N}\frac{T\hat{\vartheta}_i}{\hat{\vartheta}_i(1)} \quad (9b)$$

$$P_t = \frac{\hat{\vartheta}}{SE\ (\hat{\vartheta}} \quad (9c)$$

$$P_a = T\hat{\vartheta} \quad (9d)$$

In equations 9a and 9b, the group tests scrutinize the null hypothesis for cointegration in the model and the other for the presence of a cointegration relationship. In contrast, the panel tests outlined in equations 9c and 9d show that at least a single unit is cointegrated throughout the panel.

This study employs the second-generation cross-section augmented autoregressive distributed lag model (CS-ARDL) to estimate both long-term and short-term parameters for Models 1 and 2, following the methodology established by Chudik and Pesaran in 2015. The choice of this method is based on its strong performance and superior effectiveness compared to conventional estimation techniques. Firstly, unlike traditional modeling approaches, the CS-ARDL framework effectively addresses issues related to cross-section dependence (CSD) and short-run dynamics (SH). Secondly, this method is particularly advantageous when confronted with mixed orders of integration or problems of non-stationarity, as highlighted by Chudik et al. in 2017. Thirdly, to deal with the spillover effects arising from cross-section dependence, the CS-ARDL technique computes averages across all cross-sections for the variables under consideration, as noted by Liddle in 2018. Finally, this modeling approach is adept at incorporating exogenous shocks, such as fluctuations in oil prices, financial crises, and internal spillover effects. Below is the fundamental mathematical representation of the CS-ARDL model:

$$\Delta RE/NRE_2 = \vartheta_i + \sum_{l=1}^{p}\vartheta_{il}\,\Delta CCO_{2,i,t} + \sum_{l=0}^{p}\hat{\vartheta}_{il}\,\bar{Z}_{s,i,t-1} + \sum_{l=0}^{1}\hat{\vartheta}_{il}\,\overline{AC}_{i,t-1} + \varepsilon_{i,t}$$

(10)

HDI represents dependent variable, and Z represents explanatory variables.

This study employs the Common Correlated Effect Mean Group (CCEMG) and Augmented Mean Group (AMG) estimating strategies to assess robustness. Both AMG (Eberhardt and Teal, 2010) and CCEMG (Pesaran, 2006) effectively address issues related to stationary and non-stationary common components, as well as unobserved common factors, providing reliable results. Additionally, we utilize the paired Dumitrescu and Hurlin (2012) panel causality test to explore the causal relationships among the measured variables. This test is particularly effective when the residuals exhibit dependence across cross-sections. It is well-suited for our panel data, where the time dimension (T) is greater than the number of cross-sections (N). The equation form of the test is as follows:

$$Z_{i,t} = \alpha_i + \sum_{j=1}^{p} \gamma_t^j Z_{i,t-j} + \sum_{j}^{p} \gamma_t^j T_{i,t-j} \quad (11)$$

where γ_t^j signifies autoregressive characteristics, and j denotes lag length.

3.4. Empirical Results

Table 2 presents descriptive statistics and correlation analysis for the Human Development Index (HDI) and renewable energy consumption (RE). The mean HDI is 0.735 with a standard deviation of 0.086, indicating relatively high human development across the observed countries, while RE has a mean of 2.827 and a standard deviation of 1.000, suggesting variability in renewable energy consumption. The correlation coefficient between HDI and RE is 0.358, indicating a moderate positive relationship; as renewable energy consumption increases, human development tends to improve. This correlation suggests that countries investing in renewable energy may experience better human development outcomes, although the relationship is not strongly pronounced. Other variables, such as GDP and urbanization (URB), also show positive correlations with HDI, further emphasizing the multifaceted nature of development.

Table 3 shows baseline regression analysis through models (1 to 6) and examine the impact of various factors on the Human Development Index (HDI). In model (1), renewable energy consumption (RE) shows a significant positive effect on HDI, with a coefficient of 0.031, indicating that higher renewable energy consumption is associated with improved human development. Model (2) introduces regulatory quality (RQ), which also has a positive and significant effect on HDI (0.022). In model (3), industrial value added (IV) is included, but it shows a negative coefficient, suggesting that its impact on HDI is significant at 10% significance level. Technological innovation (TI) in model (4) has a small positive effect (0.005) that is statistically significant, while urbanization (URB) in model (5) shows a positive but weaker effect (0.003). Finally, model (6) includes GDP per capita, which has a positive and significant coefficient (0.032), indicating a direct relationship. The constant term across all models is significant, reflecting the baseline level of HDI. The adjusted R^2 values indicate that the models explain a substantial portion of the variance in HDI, with model (6) achieving an adjusted R^2 of 0.687. Overall, the results highlight the importance of renewable energy consumption and RQ, TI, GDP in enhancing human development, while the effects of industrial value added require further investigation.

Table 2. **Descriptive Statistics and Correlation Matrix**

Panel A: Descriptive Statistics							
	HDI	**RE**	**RQ**	**IV**	**TI**	**URB**	**GDP**
Mean	0.735	2.827	–1.965	3.444	–0.383	4.041	9.533
Std. Dev.	0.086	1.000	0.948	0.302	0.742	0.442	0.897
Min	0.434	–2.302	–5.332	2.591	–3.162	2.732	7.072
Max	0.915	4.537	0.433	4.314	1.741	4.605	11.255
Obs.	1020	1020	1020	1020	1020	1020	1020
Panel B: Pairwise Correlation Matrix							
Variables	**HDI**	**RE**	**RQ**	**IV**	**TI**	**URB**	**GDP**
HDI	1.000	—	—	—	—	—	—
RE	0.358	1.000	—	—	—	—	—
RQ	0.364	0.139	1.000	—	—	—	—
IV	0.168	0.147	–0.115	1.000	—	—	—
TI	0.115	0.159	0.054	–0.254	1.000	—	—
URB	0.558	0.452	0.294	0.201	–0.072	1.000	—
GDP	0.664	0.461	0.380	0.287	–0.054	0.864	1.000

The coefficient for renewable energy consumption (RE) decreases when moving from model (1) to model

(6), shifting from 0.031 to 0.012, although it remains statistically significant. This change suggests that the introduction of control variables such as RQ, IV, TI, URB and GDP in models (2-6) accounts for some of the variance that was previously attributed solely to RE in model (1). The reduction in the RE coefficient implies that a portion of the positive impact on HDI from renewable energy consumption may be mediated by the control variables; improved RQ, IV, TI, URB and GDP could enhance the effectiveness of renewable energy initiatives in contributing to human development.

Table 3. **Baseline Regression Analysis**

Variables	HDI (1)	HDI (2)	HDI (3)	HDI (4)	HDI (5)	HDI (6)
RE	0.031*** (–12.250)	0.029*** (3.900)	0.025*** (3.980)	0.021*** (3.970)	0.018*** (3.750)	0.012*** (3.750)
RQ	—	0.022*** (8.780)	0.021*** (8.350)	0.021*** (8.340)	0.021*** (8.310)	0.019*** (7.480)
IV	—	—	–0.019* (–1.980)	–0.017 (–1.460)	–0.018* (–1.680)	–0.019* (–1.770)
TI	—	—	—	0.005** (2.750)	0.004** (2.730)	0.003* (0.500)
URB	—	—	—	—	0.0048* (1.690)	0.041* (–1.680)
GDP	—	—	—	—	—	0.032*** (3.080)
Cons.	0.769*** (52.310)	0.840*** (51.610)	0.904*** (21.380)	0.898*** (20.780)	0.885*** (8.930)	0.765*** (7.210)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
adj. R2	0.659	0.684	0.685	0.685	0.684	0.687
Obs.	1020	1020	1020	1020	1020	1020

Note: t-statistics in parentheses, *, **, & *** confirms P<10%, 5%, & 1% respectively.

In Table 4, the CS-ARDL model results, the coefficients for the independent variables indicate their impacts on the Human Development Index (HDI) in both the short and long run, along with their significance levels.

In the short run, the coefficient for RE is 0.074, which is significant at the 1% level. This indicates that a 1% increase in renewable energy consumption is associated with a 0.074-unit increase in HDI, suggesting that higher renewable energy consumption positively enhances human development. The coefficient for RQ is 0.021 and is significant at the 5% level, implying that improvements in regulatory quality lead to a corresponding increase in HDI, reflecting the importance of effective governance in development. The coefficient for IV is -0.038 and significant at the 5% level, indicating a negative relationship; as industrial value-added increases, HDI tends to decrease, possibly due to the reliance on traditional industries over sustainable practices. TI has a coefficient of 0.005, significant at the 10% level, indicating a weaker positive effect on HDI, suggesting that advancements in technology can contribute to human development, albeit not as strongly as the other factors. Furthermore, URB with a coefficient of 0.081 and significant at the 5% level, indicates a positive relationship, suggesting that urbanization contributes positively to human development. Lastly, GDP per capita (GDP) has a coefficient of 0.042, significant at the 5% level, demonstrating that higher economic output per person is positively correlated with improvements in HDI.

Table 4. **CS-ARDL Long-run and Short-run Analysis**

Variables	Short-run results		Long-run results	
	Coefficient	t-statistics	Coefficient	t-statistics
Dependent variable: HDI				
RE	0.074***	3.540	0.085**	2.083
RQ	0.021**	2.520	0.024***	3.154
IV	–0.038**	0.033	–0.015**	2.051
TI	0.005*	1.675	0.002	1.320

URB	0.081**	2.351	0.072**	2.358
GDP	0.042**	2.680	0.027***	3.285
ECT(-1)	-0.802***	–15.18	—	—

Note: *, **, & *** confirms P<10%, 5%, & 1% respectively.

In the long run, the coefficient for RE increases to 0.085, remaining significant at the 5% level, which reinforces the positive contribution of renewable energy consumption to HDI over time. The long-run coefficient for RQ is 0.024, significant at the 1% level, indicating a sustained positive impact on HDI from better regulatory environments. The long-run coefficient for IV is –0.015, significant at the 5% level, suggesting that the negative effect of industrial value added on HDI persists over time. URB coefficient in the long run is 0.072, significant at the 5% level, confirming its continued positive influence on human development. Finally, the long-run coefficient for GDP is 0.027, statistically significant at the 1% level, indicating a reliable positive relationship with HDI.

The error correction term (ECT) of -0.802, significant at the 1% level, suggests a strong adjustment mechanism toward long-run equilibrium, indicating that deviations from the long-run path of HDI will be corrected at a rate of approximately 80.2% per period. Overall, the results demonstrate the importance of independent variables significantly affect in promoting human development both in short- and long-run except TI with coefficient of 0.002 which is not significant in long-run.

In the robustness check results for the effect of RE on the HDI has presented in Table 5, the coefficients from both the CCEMG and AMG models indicate a positive relationship.

Table 5. **Robustness Analysis**

Regressors	CCEMG		AMG	
	Coefficient	t-statistics	Coefficient	t-statistics
Dependent variable: HDI				
RE	0.072**	2.540	0.085***	3.581
RQ	0.025**	2.520	0.054**	2.463
IV	–0.041*	1.733	–0.034*	1.821
TI	0.003*	1.679	0.028**	2.389
URB	0.073**	2.351	0.068*	1.864
GDP	0.052***	3.680	0.063***	4.579

Note: *, **, & *** confirms P<10%, 5%, & 1% respectively

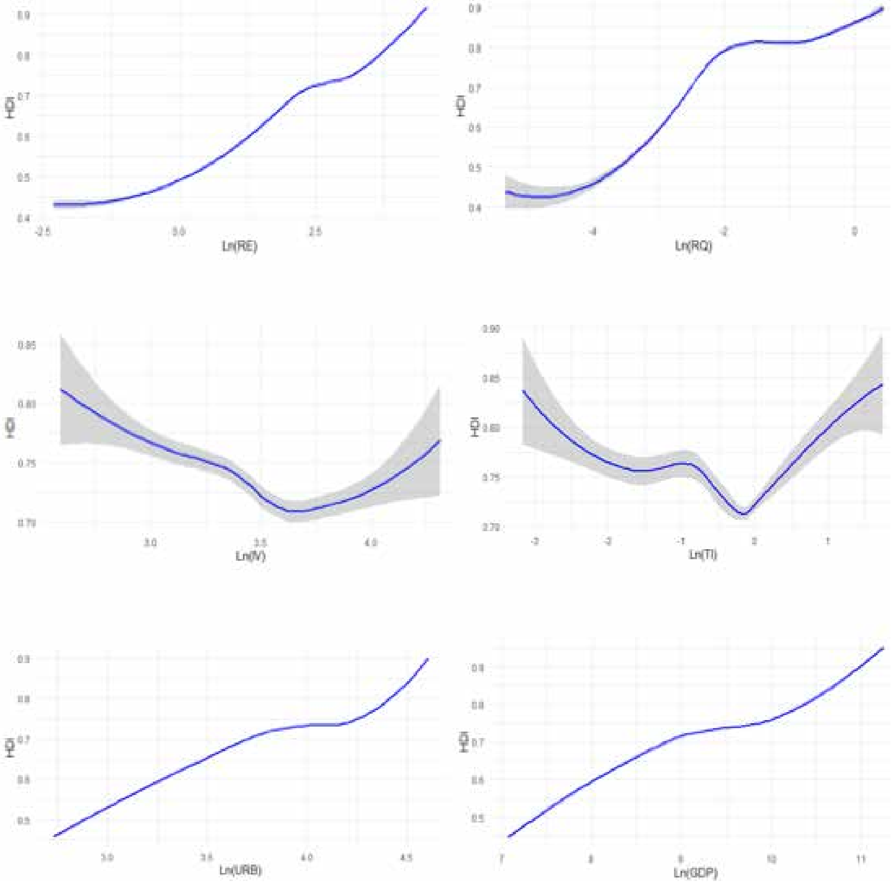

Figure. Relationship between explanatory variables and HDI

This stronger coefficient implies that the positive effect of RE on HDI is even more pronounced in this model, with a 1-unit increase in RE leading to an 0.085-unit increase in HDI. Overall, both models confirm that RE significantly enhances HDI, with the AMG model indicating a slightly stronger effect compared to the CCEMG model. In the appendix, several tables present key diagnostic tests that bolster the robustness of the study's findings related to the relationship between RE and HDI. In addition to the robustness check, Figure 1 provides compelling evidence of the long-term positive effects of RE, RQ, URB, and GDP on the HDI. In sharp contrast, the graphical analysis reveals that IV and TI exert negative influences on HDI. These findings underscore the complex interplay of various factors contributing to human development.

Furthermore, in Appendix section, Table A-I denotes, the CSD tests which indicate the extent of interdependencies among the sample countries, highlighting the importance of considering these correlations in panel data analyses. Additionally, in Table A-II, the unit root tests confirm the stationarity properties of the variables, establishing a solid foundation for subsequent econometric modeling. In Table A-III, the Westerlund cointegration tests provide robust evidence of long-term relationships among the variables of interest, affirming that RE and HDI are not only linked in the short run but also exhibit a stable long-term association. Lastly, in Table A-IV, the causality analysis elucidates the one-way influence of RE and other control variables on HDI, enhancing our understanding of the underlying dynamics. Collectively, these tables establish a comprehensive methodological framework that supports the validity of the study's conclusions and emphasizes the intricate connections between RE and HDI.

3.5. Discussion

The positive relationship between RE and HDI observed in both the CCEMG and AMG models highlights the critical role that sustainable energy sources play in enhancing human development outcomes. The findings suggest that increasing the share of renewable energy in a country's energy mix not only contributes to environmental sustainability but also fosters economic growth and improved social well-being. Studies, such as those by Kaewnern et al. (2023), have shown that countries emphasizing renewable energy can achieve both economic and developmental benefits, as renewable energy investments create jobs, reduce energy costs, and improve access to energy, particularly in underdeveloped regions. Furthermore, [Amer et al. (2020)] emphasizes that transitioning to renewable energy is essential for achieving the Sustainable Development Goals (SDGs), as it directly affects health, education, and economic opportunities, thereby enhancing the overall quality of life. Moreover, the stronger effect of RE on HDI in the AMG model suggests that the mechanisms behind this relationship may become more pronounced in regions or contexts that fully adopt and implement renewable technologies. Recent literature underscores the importance of regulatory frameworks and technological innovation in maximizing the benefits of renewable energy. According to Sasmaz et al. (2021), effective policies and governmental support can significantly amplify the developmental impacts of renewables. Additionally, urbanization plays a critical role, as highlighted by [Hao (2022)], who argue that urban areas harness the advantages of technology and infrastructure needed for renewable energy integration, thereby driving socio-economic development. Collectively, these studies support the notion that prioritizing renewable energy consumption can significantly accelerate human development, showcasing its multifaceted benefits beyond mere environmental considerations.

IV. Conclusion

The ffindings of this study provide compelling evidence of the positive impact of RE and HDI across various modeling approaches, particularly the CCEMG and AMG models. The significant coefficients associated with RE suggest that transitioning to renewable sources can foster improvements in human development outcomes, including enhanced health, education, and economic opportunities. These effects are further amplified by supportive policy frameworks and technological advancements, which enhance the efficacy of renewable energy investments. As nations strive to meet Sustainable Development Goals, prioritizing renewable energy initiatives is not merely beneficial but imperative. This research underscores the critical need for the integration of renewable energy into national policies and advocates for further investigations into the complex interdependencies between energy, development, and sustainability. Future research should focus on examining the impact of renewable energy consumption on HDI in diverse contexts, including BRI countries, OECD nations, and Gulf states, to uncover region-specific dynamics and challenges. Given the limitations encountered in this study, such as data availability and variable scope, it is essential for future analyses to utilize longitudinal data to assess the effects of RE on HDI over time. Additionally, comparative studies could elucidate how different regulatory environments and socio-economic conditions shape this relationship. Investigating sectoral impacts on healthcare and education, evaluating the effectiveness of renewable energy policies across various economies, and assessing technology transfer mechanisms will yield valuable insights. Furthermore, exploring urban versus rural disparities in renewable energy benefits can inform tailored policy strategies, ultimately enhancing overall human development outcomes.

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Appendix to the article

"How Renewable Energy Fuels Human Development: Evidence from Emerging Markets".
By M. W. Sharif Zada, S. M. Mowahed. DOI: 110.25634/MIRBIS.2024.4.2.

A-I: Cross-sectional dependence test

Panel A: CSD tests for data variables							
Tests	**HDI**	**RE**	**RQ**	**IV**	**TI**	**URB**	**GDP**
LM_{BP}	157.6***	179.4***	302.6***	24.6***	157.7***	285.9***	295.7***
SLM_{BC}	112.9***	110.6***	201.1***	15.2***	71.2***	56.7***	121.9***

Panel B: CSD tests for models' residuals	
Tests	**Dependent Variable: HDI**
Pesaran (2004)	4.532***
Frees (1995)	3.268***
Friedman (1937)	10.852***

Note: *, **, & *** confirms P<10%, 5%, & 1% respectively.

A-II: Panel Unit Root Tests

Regressors	**CIPS**		**CADF**	
	Level	**1st difference**	**Level**	**1st difference**
HDI	–1.265	–4.258***	–1.256	–5.362***
RE	–1.025	–4.564***	–1.058	–3.362***
RQ	–2.001	–5.856***	–1.003	–3.154***
IV	–1.568	–3.784***	–1.253	–2.952***
TI	–1.025	–5.742***	–1.562	–4.058***
URB	–1.036	–2.359***	–1.052	–3.652*
GDP	–1.530	–3.456***	–1.521	–2.842***

Note: *, **, & *** confirms P<10%, 5%, & 1% respectively.

A-III: Westerlund Co-integration Test

Dependent Variable: HDI				
Statistics	Value	Z-value	Value	Z-value
Gt	–5.235***	–4.268	–2.938***	5.264
Ga	–5.025***	3.621	–7.187***	5.075
Pt	–9.004***	–4.152	–12.880***	–3.218
Pa	–5.124***	–3.843	–7.858***	3.359

Note: *, **, & *** confirms P<10%, 5%, & 1% respectively.

A-IV: Panel Causality Test

Null Hypothesis:	**Z-value**	**Value**	**Z-value**
RE does not homogeneously cause HDI	3.918	2.395**	One-way
RQ does not homogeneously cause HDI	6.566	6.281***	One-way
IV does not homogeneously cause HDI	3.974	2.457**	One-way
TI does not homogeneously cause HDI	4.288	2.938***	One-way
URB does not homogeneously cause HDI	7.390	7.490***	One-way
GDP does not homogeneously cause HDI	9.389	10.424***	One-way

Note: *, **, & *** confirms P<10%, 5%, & 1% respectively.