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The role of renewable energy technologies in enhancing human development: Empirical evidence from selected countries

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Abstract

Human development is crucial for a country's prosperity, reflecting its economic growth and social progress. This study examines how using renewable energy can boost human development across 77 countries, including high-income and 33 middle-income, from 2000 to 2019. This paper employs the panel-corrected standard error (PCSE) model to generate appropriate outcomes for the existence of heteroscedasticity, serial correlations, and sectional dependencies (CD). The results reveal a positive link between renewable energy adoption and human development across three dimensions-health, education, and income. This connection holds for various renewable sources like hydropower, solar, and wind energy. Additionally, when the research sample is separated into high- and middle-income nations, we find differing impacts of renewable energy on human development dimensions, such as hydro energy has a negative impact on the income dimension in high-income countries; meanwhile, the solar, wind, and hydro energy are insignificant or less pronounced in middle-income countries. This study highlights the importance of renewable energy for human development but emphasizes the need for tailored approaches considering income levels and specific renewable energy sources.

Based on findings, theoretical and practical implications have been proposed to promote the use of renewable energy towards sustainable development goals.

Previous Next

Keywords

Renewable energy; Human development; Health; Education; Income; Panel corrected standard error model (PCSE); Sustainable development goals (SGDs)

1. Introduction

In recent times, renewable energy sources have gained substantial significance in response to two pressing concerns: the depletion of non-renewable energy resources and the adverse environmental consequences associated with their consumption [[1], [2], [3]]. Because energy stands as a pivotal component of societal advancements and bolstering productivity, but the utilization of fossil fuels, a prevalent energy source, poses significant environmental challenges, chief among them being the emission of substantial quantities of carbon dioxide (CO_2) and other greenhouse gases [4,5]. The discourse surrounding primary fossil fuels, encompassing coal products, oil and petroleum products, and natural gas, has come to the forefront of global attention [6]. When scrutinizing CO_2 emissions on a sectoral basis, the energy sector emerges as the foremost contributor, responsible for a staggering 80% of total global CO_2 emissions. Within this sector, electricity generation commands the largest share at 42%, trailed by transportation and industry, contributing 25% and 18% of emissions, respectively [6,7]. As the report of International Energy Outlook, there is an escalating annual surge in energy demand, projected to have increased by 56% from 2010 to the year 2040, and an estimation of the world's energy supply remaining reliant on fossil fuels, with coal constituting 26,8%, oil 30.9%, and natural gas 23.2% [8]. Nonetheless, it is imperative to recognize that excessive dependence on fossil fuels carries the potential to inflict long-term harm on economic growth and precipitate environmental degradation [[9], [10], [11]]. Consequently, securing access to clean, dependable, and cost-effective energy becomes paramount in pursuing sustainable social and economic development goals [12,13].

The United Nations' proclamation of the Sustainable Development Goals (SDGs) emphasizes the global imperative of reducing air pollution, limiting the share of traditional energy in the energy mix, and promoting the adoption of sustainable energy sources. Renewable energy resources have been recognized as a productive and effective solution to increase energy volume while countering environmental concerns and economic development [[14], [15], [16]]. Consequently, many nations are striving to develop renewable energy solutions to mitigate environmental degradation and achieve the goals set by the SDGs [17]. Using more renewable energy sources will reduce environmental pollution, positively impacting human health and contributing to sustainable development [18,19]. However, the initial stages of deploying renewable energy technologies are often accompanied by costs and risks. The development of renewable energy infrastructure requires significant investments, involving high initial capital costs and long payback periods. This financial burden can divert resources away from other sectors of the economy ([20,21]. Additionally, implementing renewable energy technologies presents policy, technical, economic, information, and human resource challenges [22,23].

Even so, according to the United Nations Development Program, clean and reliable energy affects the determinants of human development, including education, health, environmental safety, and gender equality [24]. As the infrastructure for renewable energy becomes more developed, it not only holds the potential to yield significant benefits for human development but also brings huge challenges. Numerous empirical studies have explored the relationship between renewable energy technologies and various dimensions of human development, such as health, education, and income. These studies have provided valuable insights into the impact of renewable energy on human development, highlighting both positive [19,25,26]) and negative associations [[27], [28], [29]]. Moreover, the relationship between renewable energy and human development exhibits non-linear characteristics depending on the energy mix ratio between non-renewable and renewable energy [23,30].

However, despite its significance, limited knowledge exists regarding the role of renewable energy and human development in mitigating environmental degradation and achieving environmental sustainability. While human development and economic growth have undeniably advanced through the utilization of non-renewable energies, it is crucial to acknowledge the consequential side effects of this approach. The heavy reliance on fossil fuels, such as coal, oil, and natural gas, which has been a cornerstone of economic progress in many parts of the world, has cast a shadow over our environment. The burning of these fossil fuels not only contributes to harmful emissions like Sulphur dioxide but also stands as a primary driver of global warming. This environmental degradation has far-reaching implications, including disruptions to ecosystems, rising sea levels, extreme weather events, and threats to biodiversity. Moreover, it poses direct risks to human health, leading to respiratory illnesses and exacerbating conditions like asthma. Additionally, the economic growth achieved through non-renewable energies can be vulnerable to price volatility and geopolitical tensions related to resource access. Because human development, often characterized by educational advancements and the enhancement of human capital, is recognized as a significant driver of economic growth and a catalyst for technological progress in nations [31,32]. In this context, human development assumes importance as individuals with higher education levels are presumed to possess greater productivity, responsibility, and innovation, leading to the generation of novel ideas and improved methodologies [31,33,34]. Furthermore, human development becomes indispensable and advantageous in environmental sustainability, as understanding the environment, climate change, and its consequences is essential for formulating effective mitigation measures [35,36].

Hence, the adoption of renewable energy holds the potential to impact human development positively. However, the relationship between renewable energy and human development is complex, and its outcomes depend on various factors. This paper aims to provide a comprehensive analysis of the empirical evidence on the impact of renewable energy on human development, focusing on the factors that may mediate or moderate this relationship. By synthesizing the findings from various studies, this study seeks to highlight this relationship's multifaceted nature and identify the factors that influence its outcomes. This study will focus on studies conducted in different countries and regions to identify any variations and identify the possible reasons behind them. The paper will conclude with policy recommendations for promoting renewable energy adoption and enhancing human development, particularly in low-middle-income countries, where the negative impact of renewable energy on human development has been reported. Thus, this paper provides a deep understanding of the complex interplay between renewable energy and human development, which is crucial for policymakers, energy planners, and stakeholders to make informed decisions and develop effective strategies for a sustainable future.

The subsequent sections of this paper are organized as follows: A concise overview of the existing literature is presented in the following section. The data and methodology employed in this study are outlined in Section 3, while Section 4 provides an analysis and interpretation of the results obtained. Finally, this study is concluded in Section 5.

2. Literature review

The theoretical link between renewable energy and human development is centred on the idea that using renewable energy can drive economic growth, subsequently benefiting human development [30,37]. This notion gains support from Eren, Celik and Kubat [38], who observed a positive relationship between increased human development and income growth in 84 developing countries. Similarly, Chikalipah and Okafor [39] gave evidence for a positive link between economic growth and human development in Nigeria in the long term. However, the utilization of non-renewable energy for economic development is seen as a primary contributor to CO_2 emissions, resulting in environmental degradation and, consequently, adverse effects on human health and income [24]. Meanwhile, the influence of renewable energy consumption on income directly impacts individuals' purchasing power and their ability to access higher-quality healthcare and education services, further promoting human well-being [25].

Most previous studies about the relationship between renewable energy consumption and human development focus on a causal relationship [19,40,41], or unidirectional causality from renewable energy consumption [25,42] or unidirectional causality from human development [43,44] and or no causality [45]. However, these investigations have not yet evaluated the degree of influence of renewable energy technologies on human development to answer whether adopting green energy may promote human development. There is no denying that renewable energy has advantages over non-renewable energy because this renewable source is more environmentally friendly but expensive and has more potential risks in the implementation progress. Basically, utilizing renewable energy technologies initially may require some costs and be inherently risky [20,21], implying that resources may be diverted to the development of renewable energy infrastructure [46]. Unlike non-renewable energy, renewable energy involves high initial capital costs, and the monetary benefits from such projects may take time to materialize [22,23], as displayed in Fig. 1.

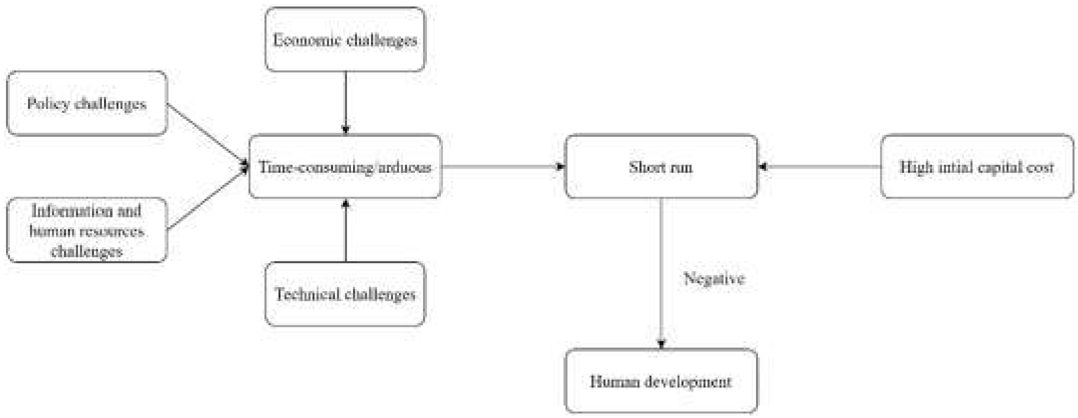

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Fig. 1. The framework of the effects of renewable energy consumption on human development in the short run.

Implementing renewable energy technologies poses policy, technical, economic, information, and human resource challenges, as discussed in the literature [22,23]. Policy-wise challenges include a lack of incentives for private sector involvement and inconsistent policies, while economic challenges include high initial capital costs, long payback periods, the lack of access to credit, and insufficient government financial support. Technical challenges include the limited capacity to design, install, operate, manage, and maintain renewable-based modern energy services. Finally, information and human resource-wise challenges are related to the lack of information on renewable energy and energy efficiency for policy-making and mobilizing civil society and the lack of expertise and services in system design, installation, operation, and maintenance of renewable energy and energy efficiency technologies. However, as the infrastructure for renewable energy develops, an increase in its usage may have positive effects on the environment and subsequently improve health quality [23,47], human capital [48,49], and economic growth [23,50], as illustrated in Fig. 2. At this stage, adopting renewable energy technologies may lead to an increase in the level of human development. The transition to clean energy production may also boost workers' knowledge and skills in these countries, resulting in higher employment rates, lower poverty levels, and improved health outcomes [25,51,52]. Additionally, the Organisation for Economic Co-operation and Development (OECD) highlighted the crucial role of access to energy resources in creating sustainable development by enhancing living standards, health, and education.

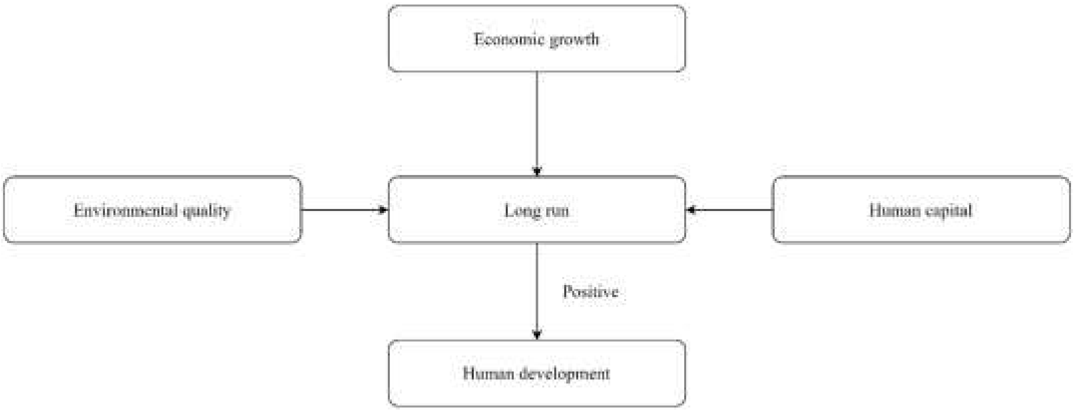

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Fig. 2. The framework of the effect of renewable energy consumption in human development in the long run.

In light of the available empirical evidence concerning the impact of renewable energy on human development, this study can identify three distinct groups. The first group of empirical evidence demonstrates a positive correlation between renewable energy and human development. For example, Azam et al. [41] focused on the dimension of income in human development, using GDP as a proxy, and they analyzed the impact of renewable energy across the ten highest CO_2-emitting countries from 1990 to 2014. Through the application of panel cointegration tests, panel fully modified ordinary least squares (FMOLS), and the heterogenous Dumitrescu and Hurlin causality test, the researchers confirmed the existence of a long-term equilibrium relationship between the variables. The results revealed a statistically significant positive long-term effect of renewable energy on the income dimension of human development. They argued that the accelerated development and utilization of renewable energy sources such as solar, wind, hydro, and others could potentially stimulate economic growth while minimizing CO_2 emissions. Consequently, it is imperative to encourage investments in renewable energy technologies to enhance energy efficiency. Additionally, their findings indicated a positive association between higher foreign direct investment and human development. Similarly, Sasmaz, Sakar, Yayla and Akkucuk [19] examined the relationship between renewable and non-renewable energy and human development in 28 OECD countries from 1990 to 2017. Utilizing the Westerlund and Edgerton panel cointegration test with structural breaks and the Dumitrescu and Hurlin causality test, they discovered a positive correlation between higher renewable energy consumption and elevated levels of human development. The study emphasized that renewable energy sources such as wind and water resources are environmentally friendly and contribute to the creation of a more habitable world, fostering economic and social development within countries.

In a study involving 31 transitional economies from 1990 to 2015, Omri and Belaïd [53] employed the Generalized method of moments (GMM) method to assess the impact of renewable energy on human development. Their findings indicated that the utilization of renewable energy could potentially promote human development. They highlighted the multiple benefits of renewable energy, including pollution reduction, improved air quality, lower fossil fuel prices, and increased job opportunities compared to fossil fuels. As a result, overall well-being and quality of life may improve. Furthermore, companies involved in the provision of green energy can leverage increased business and household incomes, thereby enhancing the fundamental indicators of human development. Notably, the study also revealed that renewable energy technologies help mitigate the adverse effects of CO_2 emissions on human development. Moreover, their results suggested a positive relationship between higher economic growth, foreign direct investment, government expenditure, financial development, and human development. In a recent study by Sadiq, Wen, Bashir and Amin [26], the authors investigated whether renewable energy consumption contributed to human development in OECD countries from 1990 to 2019. Using the cross-sectional-autoregressive-distributed lag (CS-ARDL) and Dumitrescu and Hurlin panel causality test, they discovered a positive association between renewable energy and human development. Azam, Rafiq, Shafique and Yuan [25] interpreted the dynamic nexus between green energy, non-renewable energy, and human development using a dataset of 30 developing countries from 1990 to 2017. Using FMOLS and dynamic ordinary least squares (DOLS) estimator, Azam, Rafiq, Shafique and Yuan [25] found that while green energy may increase human development, non-renewable energy decreases human development in developing countries. They argued that these countries may still rely on traditional energy sources (oil, coal, and gas) to meet the energy demand. However, replacing traditional energy with renewable energy may bring social and economic development to developing countries. Green energy is the imperative solution for energy security and climate change reductionnot only that, it may be essential to meet the energy needs for transportation, industrial use, electricity production, and domestic cooking. The adoption of renewable energy technologies promotes the creation of job opportunities and increases income levels.

While the majority of evidence supports a positive relationship between renewable energy and human development, specific studies conducted in emerging or low-income countries have shed light on potential negative associations in the second group. These findings highlight the importance of considering contextual factors and circumstances when examining the impact of renewable energy technologies on human development. For example, Ouedraogo [27] conducted research to explore the impact of renewable energy on human development within 15 developing countries during the period from 1988 to 2008. By employing biomass as a proxy for renewable sources, the study revealed a negative relationship, indicating that per capita energy consumption reduces human development. Ouedraogo highlighted the inherent dangers associated with the use of traditional biomass, as it contributes to high levels of indoor air pollution. This pollution, in turn, leads to respiratory diseases, cancer, and tuberculosis, as well as adverse effects such as weight loss and eye diseases among newborns, resulting in a decline in overall health quality. Similarly, Amer [29] proposed that human development encompasses three dimensions: a long and healthy life, access to education, and a decent standard of living. The study focused on analyzing the relationship between energy technologies (both renewable and non-renewable) and human development across 101 countries worldwide. This sample included 32 high-income countries, 31 upper-middle-income countries, 23 lower-middle-income countries, and 15 low-income countries from 1990 to 2015. Employing panel vector autoregressive (PVAR) analysis, the results indicated that the influence of renewable energy on human development was statistically insignificant. However, a significant negative relationship was explicitly observed in lower-middle-income countries. The authors argued that as countries strive to shift their energy consumption from non-renewable sources to clean energy alternatives, the initial high capital costs and extended implementation time contribute to the negative effect of renewable energy on human development. Additionally, the study found that higher levels of trade openness and financial development were positively associated with increased levels of human development.

In the third group, it has been discovered that the relationship between renewable energy technologies and human development is non-linear, meaning that the impact of promoting or reducing green energy on human development is contingent upon specific conditions. Zahid, Arshed, Munir and Hameed [23] conducted an in-depth examination of the relationship between energy sources (renewable and non-renewable energy) and human development in South Asian Association for Regional Co-operation (SAARC) countries from 1990 to 2017. Utilizing the feasible generalized least squares (FGLS) method, they identified a U-shaped relationship between renewable energy and human development. This curve signifies that countries tend to rely more on non-renewable energy during the initial stage of establishing renewable energy technology due to its accessibility and lower cost. However, non-renewable energy sources result in higher CO_2 emissions, which can detrimentally impact health quality. Additionally, countries incur higher costs when adopting green energy technologies, leading to a decline in human development. Nonetheless, once a certain point is reached, where the infrastructure for renewable energy has been fully developed, an increase in renewable energy usage can contribute to a reduction in CO_2 emissions and improvements in health, income, and human capital. This, in turn, leads to increased human development. The study also emphasized that higher industrialization and trade openness levels were associated with more significant human development. Notably, Wang et al. [30] examined the interconnection between renewable energy usage and human development in BRICS countries (Brazil, Russia, India, China and South Africa) from 1990 to 2016 while considering the potential influence of public debt on this relationship. By employing the Westerlund panel cointegration test, Driscoll-Kray robust standard error estimates, and the Dumitrescu-Hurlin causality test to address cross-sectional dependence, they found evidence suggesting that renewable energy consumption can stimulate human development. While the economic growth of BRICS countries continues to rely significantly on non-renewable energy sources, transitioning to renewable energy can yield environmental and health benefits for the community. However, this association holds primarily in countries with low public debt levels. In other words, countries burdened with higher public debt may reduce their investment in renewable energy technologies, thereby diminishing the efficiency of renewable energy. Furthermore, their findings indicated that higher levels of economic growth, industrialization, and lower levels of public debt were associated with elevated levels of human development.

Research into the impact of renewable energy on human development has universally identified three distinct groups of empirical evidence. The first group demonstrates a positive correlation between renewable energy and human development, highlighting the potential of renewable energy. However, a second set of studies conducted in emerging or low-income countries revealed potentially negative associations, highlighting the contextual factors and risks associated with transitioning from traditional to renewable energy. Finally, the third group shows a non-linear relationship between renewable energy and human development, with an initial dependence on non-renewable sources followed by benefits from renewable energy. Therefore, this study needs to consider specific context and condition factors when considering the impact of renewable energy on human development, addressing the shortcomings that remain in previous studies.

3. Data and models

3.1. Data

This study used renewable energy consumption and its sources collected in Our World In Data based on the work of Ritchie, Roser and Rosado [54]. However, because these data are unavailable in African countries, this study excludes this region from our sample. Consequently, this study obtained a sample including 45 high-income countries and 33 middle-income countries from 2000 to 2019 (see Appendix A). Moreover, this study uses a database of the World Bank's World Development Indicators (WDI), the International Monetary Fund (IMF), and the Swiss Federal Institute of Technology. Notably, financial development is collected from the IMF developed by Svirydzenka [55]. This study utilizes globalization from the Swiss Federal Institute of Technology. While indicators related to measures of human development are collected from the Human Development Report of UNDP, other variables are acquired from the database of the WD (Table 1).

3.2. Proposed models

Critical dimensions of human development, including health, education, and income, measure human development. The first dimension of human development – health – reflects a long and healthy life, proxied by life expectancy at birth (LE). *Life expectancy* is defined as the average number of years of life which would remain for males and females reaching the ages specified if they continued to be subjected to the same mortality experienced in the year(s) to which these life expectancies refer. The second component – education – is calculated by Mean years of schooling (MYS) and Expected years of schooling (EYS), In which MYS measures the average number of years of total schooling adults aged 25 years and older have received. EYS shows the number of years of schooling that a child of school entrance age can expect to receive if the current age-specific enrollment rates persist throughout the child's life by country. The third dimension – the standard of living – is measured by Gross National Income per capita (GNIPC). Besides, following the framework of Roser [56], the Human Development Index (HDI) is calculated through two steps.

The first step is that this study converts these variables into indices between 0 and 1:

$$Index = \frac{X - Min}{Max - Min} \quad (1)$$

where, *Index* is the variable index, *X* is an indicator proxying for variables, and *Max* and

Min are the maximum and minimum values, respectively. Thus, the index for each variable ranges between 0 and 1.

The second step is that four indexes are combined to form the HDI value using the geometric average:

$$HDI = (He\_index * Edu\_Index * In\_Index)^{1/3} \tag{2}$$

In order to evaluate the effect of renewable energy technologies on human development, this study estimates the following regression equation:

$$HDI = f\,(REC, FDI, URBAN, GDPGR, INFDI, GI) \tag{3}$$

Equation (3) may be re-written in panel data form and adds error term as follows:

$$HDI_{it} = \beta_0 + \beta_1 * REPC_{it} + \beta_2 * FDI_{it} + \beta_3 * URBAN_{it} + \beta_4 * GDPGR_{it} + \beta_5 * INFDI_{it} + \beta_6 * GI_{it} + \varepsilon_{it} \tag{4}$$

In Equation (4), *HDI* proxies for human development which are estimated by Equation (3) , *REPC* reflects renewable energy consumption and is calculated by taking the natural logarithm of renewable energy consumption per capita. *URBAN* shows urbanization, measured by the ratio of urban population to total population. *FDI* is the financial development index – extracted from the IMF [57,58]. *GDPGR* is economic growth and is proxied by the percentage change of GDP in year t over year t – 1. Inward foreign direct investment, *INFDI*, is calculated by FDI inflows as a share of GDP. Globalization, *GI*, is measured by the Globalization index of Dreher [59] and Gygli, Haelg, Potrafke and Sturm [60]. ε_{it} is error term.

In addition, renewable energy technologies involve solar, wind, hydro and other renewable sources.[1] This study reestimates Equation (4) by replacing the REPC with SPC- is calculated by solar energy consumption per capita, WPC- measured by wind energy consumption per capita, HPC- is hydro energy consumption per capita and OPC- OPC is other renewable energy consumption.

Furthermore, dimensions of human development include health, education, and income as Equation (2). This study analyzes whether the influence of renewable energy technologies may be different among dimensions of health, education, and income of human development. This study separates HDI into three indicators – HE_INDEX, EDU_INDEX, and IN_INDEX - proxies for health, education, and income, respectively.

$$HE\_INDEX_{it} = \beta_0 + \beta_1 * REPC_{it} + \beta_2 * FDI_{it} + \beta_3 * URBAN_{it} + \beta_4 * GDPGR_{it} + \beta_5 * INFDI_{it} + \beta_6 * GI_{it} + \varepsilon_{it} \tag{5}$$

$$EDU\_INDEX_{it} = \beta_0 + \beta_1 * REPC_{it} + \beta_2 * FDI_{it} + \beta_3 * URBAN_{it} + \beta_4 * GDPGR_{it} + \beta_5 * INFDI_{it} + \beta_6 * GI_{it} + \varepsilon_{it} \quad (6)$$

$$IN\_INDEX_{it} = \beta_0 + \beta_1 * REPC_{it} + \beta_2 * FDI_{it} + \beta_3 * URBAN_{it} + \beta_4 * GDPGR_{it} + \beta_5 * INFDI_{it} + \beta_6 * GI_{it} + \varepsilon_{it} \quad (7)$$

where, *HE_INDEX*, *EDU_INDEX*, and *IN_INDEX* is calculated as measurement of HDI. The table below shows details of data and variables:

3.3. Econometric method

This study adopts a panel data approach to address issues of heterogeneity and multicollinearity and enhance estimation efficiency. In this study, As suggested by Le and Nguyen [61], Ikpesu, Vincent and Dakare [62], and Rahman, Rana and Khanam [63], this paper employs the panel-corrected standard error (PCSE) model to generate appropriate outcomes in the case of existence of heteroscedasticity, serial correlations, and sectional dependences (CD) to estimate Equation (1) for each sub-sector. This choice is made due to the invalidity of the GMM condition for certain sub-sectors where I<T. In other words, the GMM estimator is only appropriate for short panel data, whereas our sample has a long time with T=20 years. It is worth mentioning that PCSE methodology is suitable for estimating the models using panel data and generating robust results, particularly in the presence of heterogeneity, multicollinearity, unobserved country-fixed effects, endogeneity, contemporaneous correlation, and unit heteroskedasticity concerns.

Indeed, our sample has a large number of cross-sections (N=74 countries) but a relatively shorter time dimension (2000–2019, i.e., T=20 years). Similarities and dependencies in the panel countries may exist irrespective of size, culture, and population, which may increase the probability of heteroscedasticity and serial correlations. Therefore, cross-sectional dependences (CD) is applied to variables to examine the existence of cross-sectional dependence in the sample, following below Equation:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=t+1}^{N} \sqrt{T_{ij}\widehat{p_{ij}}^2} \right) \quad (8)$$

where, T shows time (from 2000 to 2019), N shows cross-sectional dimension (77 countries). $\widehat{p_{ij}}^2$ is the pairwise cross-sectional correlation coefficient. The CD test has the null hypothesis that there is cross-sectional independence. Thus, if the p-value of this test is less than 10%, the null hypothesis is rejected, implying there is cross-sectional dependence. Also, this study uses the Modified Wald and Wooldridge tests for heteroscedasticity and serial correlations.

4. Findings and discussions

Fig. 3 depicts the link between renewable energy per capita and countries in our sample human development index. This paper notices that, in the left-quarter corner of the figure, countries such as Hong Kong, Singapore, United Arab Emirates, Israel, Cyprus, Qatar, Kuwait, and Saudia Arabia show their high level of human development in the context of low renewable energy use. The right quarter is a large developed and developing country with high levels of human development in the context of high use of renewable energy. In the lower half of Fig. 1, the developing countries have low to moderate energy use and similar levels of human development.

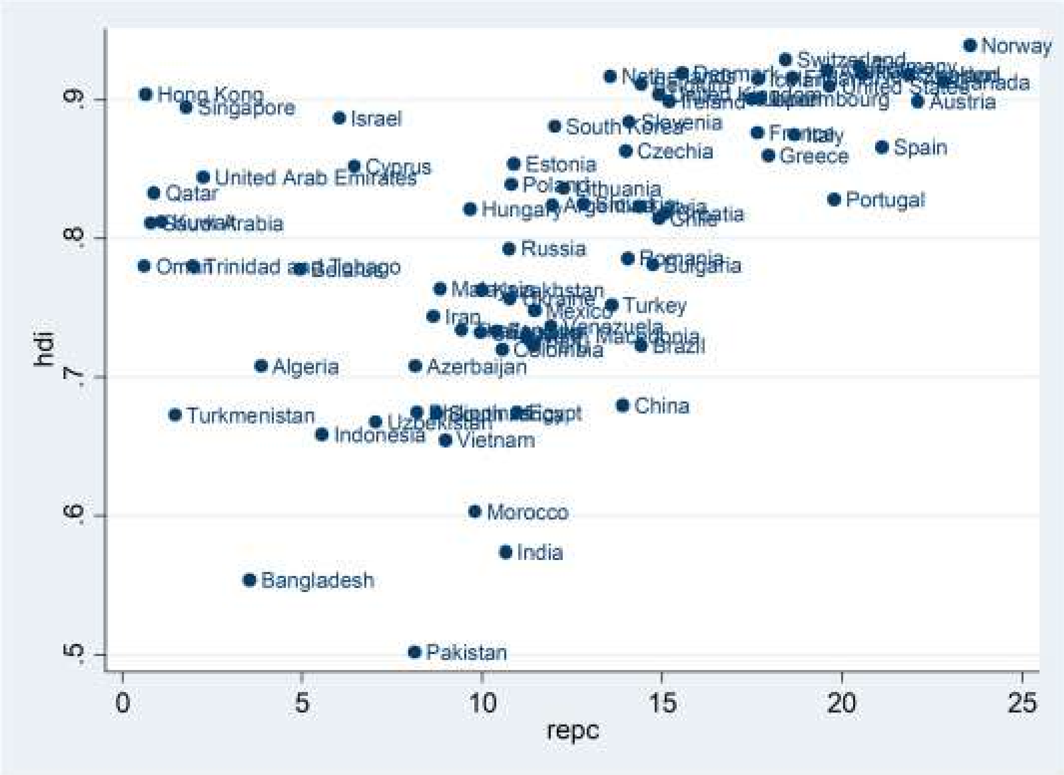

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Fig. 3. Renewable energy per capita and Human Development Index.

Moreover, this study presents the descriptive statistics and CD test of variables in Table 2. The average human development (HDI) is around 80%, in which HE, EDU, and IN are 85.80%, 74.12%, and 81.74%, respectively. Regarding renewable energy sources, on average, REPC, SPC, WPC, HPC, and OPC have a mean of 6.4691, 1.7931, 3.0268, 5.8997, and 1.1188. These values show that countries consume about 644, 5, 19, 360, and 2 kWh per capita of renewable, solar, wind, hydro, and other renewable energy. Besides, based on the p-value of the CD test, this study suggests that the null hypothesis is rejected, implying that cross-sectional dependence exists. This test indicates that this study should apply the PCSE estimate to regress the effect of renewable energy technologies on human development.

Table 1. Details of data and variables.

ID	Variables	Symbols	Measurements	Sources
1	Human development	HDI	Calculation according to the framework of Roser (2014)	HDR
2	Dimension of health	HE	Based on life expectancy at birth	HDR
3	Dimension of education	EDU	Calculated by Mean years of schooling and Expected years of schooling.	HDR
4	Dimension of income	IN	Calculated by Gross National Income per capita	HDR
5	Renewable energy	REPC	Natural logarithm of Renewable energy consumption Per capita	OurWorldInData
6	Solar energy	SPC	Natural logarithm of Solar energy consumption Per capita	OurWorldInData
7	Wind energy	WPC	Natural logarithm of Wind energy consumption Per capita	OurWorldInData
8	Hydro energy	HPC	Natural logarithm of Hydro energy consumption Per capita	OurWorldInData
9	Other renewable	OPC	Natural logarithm of Other energy consumption Per capita	OurWorldInData
10	Financial development	FDI	Financial development index	IMF
11	Urbanization	URBAN	The ratio of urban population to total population	WDI
12	Economic growth	GDPGR	Percentage change of GDP in year t over year t – 1	WDI
13	Inwards foreign direct investment	INFDI	FDI inflows as a share of GDP	WDI
14	Globalization	GI	Globalization index	Swiss Federal Institute of Technology

(Source: author's collection)

Table 2. Descriptive statistics and Cross-sectional dependence test.

Variable	Mean	Sd	Min	Max	Cd-test	P-value
HDI	0.8019	0.1045	0.4406	0.9621	231.46	0.0000
HE	0.8580	0.0791	0.5228	1.0000	224.609	0.0000
EDU	0.7412	0.1338	0.2532	0.9576	215.062	0.0000
IN	0.8174	0.1233	0.4527	1.0000	151.02	0.0000
REPC	6.4691	2.6297	0.0000	11.6317	68.202	0.0000
SPC	1.7931	2.1885	0.0000	7.5573	193.845	0.0000
WPC	3.0268	2.7991	0.0000	8.9061	146.242	0.0000
HPC	5.8897	2.9509	0.0000	11.6296	5.895	0.0000
OPC	1.1188	1.0225	0.0000	5.0427	85.023	0.0000
FDI	0.4820	0.2303	0.0609	1.0000	73.99	0.0000
URBAN	0.6961	0.1817	0.1820	1.0000	126.164	0.0000
GDPGR	0.0352	0.0408	−0.3500	0.3450	87.467	0.0000
INFDI	0.0560	0.1613	−0.5753	2.8013	21.95	0.0000
GI	0.7076	0.1257	0.0048	0.9091	191.025	0.0000

(Source: author's collection)

The impact of renewable energy resources on human development in Equation (4) is illustrated in Table 3. The coefficient for renewable energy consumption (REPC) is 0.0043, signifying its significant contribution to promoting human development. Additionally, a significant positive relationship is observed between renewable energy sources, such as solar, wind, hydro, and others, and human development. The results indicate that the utilization of renewable energies facilitates economic growth and reduces CO_2 emissions, thereby fostering human development. The adoption of renewable energy technologies brings multiple benefits, including pollution reduction, improved air quality, and lower fossil fuel prices [23,47]. These advantages positively impact environmental quality and subsequently enhance health conditions [23,49]. Furthermore, businesses engaged in green energy provision can leverage increased incomes from both households and enterprises, thus contributing to the income dimension of human development and overall economic growth [23,50]. It is worth noting that the implementation of green energy technologies necessitates skilled workers and knowledge, leading to higher human capital in countries with greater renewable energy consumption [25,41]. For other independent variables, FDI, URBAN, GDPGR, and GI are positively associated with human development at a 10% level, suggesting that financial development, urbanization, economic growth, and globalization lead to positive associations with human development. These are essential aspects that policymakers must pay attention to harmonize the relationship between economic growth and human development.

Table 3. Estimated results related to the effect of renewable energy resources on human development.

Dependent variable: Human Development Index (HDI)					
REPC	0.0043***				
	(4.15)				
SPC		0.0051***			
		(8.25)			
WPC			0.0061***		
			(9.36)		
HPC				0.0024***	
				(3.36)	
OPC					0.0130***
					(8.89)
FDI	0.0685***	0.0830***	0.0551***	0.0640***	0.0685***
	(7.61)	(10.32)	(6.98)	(6.59)	(8.33)
URBAN	0.3327***	0.2913***	0.3131***	0.3494***	0.3239***
	(15.35)	(23.99)	(16.90)	(14.06)	(14.26)
GDPGR	0.0183	0.0223**	0.0227**	0.0188	0.0169
	(1.53)	(2.31)	(2.27)	(1.45)	(1.40)
INFDI	0.0017	0.0011	0.0025	0.0016	0.0032
	(0.76)	(0.62)	(1.19)	(0.75)	(1.15)
GI	0.0020***	0.0023***	0.0019***	0.0019***	0.0021***
	(8.80)	(10.72)	(9.03)	(7.66)	(9.29)
Constant	0.3586***	0.3812***	0.3938***	0.3810***	0.3758***
	(26.38)	(42.21)	(32.05)	(23.33)	(28.97)

Dependent variable: Human Development Index (HDI)					
Observations	1540	1540	1540	1540	1540

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

To ensure the findings' robustness, this study examines the dimensions of human development, specifically health, education, and income as Equations (5), (6), (7). Subsequently, this study reestimates the models and presents the results in Table 4, Table 5, and Table 6, corresponding to the dimensions of health, education, and income, respectively. Focusing on the health dimension of human development, Table 4 reveals significant positive coefficients for renewable energy sources at a 10% level. This suggests that various forms of renewable energy, including total renewable energy, solar energy, wind energy, hydro energy, and others, contribute to promoting health in human development. This is achieved by improving environmental quality and increasing life expectancy at birth.

Table 4. Estimated results related to the effect of renewable energy resources on the dimension health of human development.

Dependent variable: Health dimension of Human Development Index (HE)					
REPC	0.0034***				
	(4.58)				
SPC		0.0054***			
		(9.07)			
WPC			0.0050***		
			(7.87)		
HPC				0.0008*	
				(1.68)	
OPC					0.0121***
					(8.30)
FDI	0.0601***	0.0743***	0.0486***	0.0596***	0.0558***
	(7.31)	(12.24)	(6.83)	(6.45)	(7.20)

Dependent variable: Health dimension of Human Development Index (HE)					
URBAN	0.2243***	0.1813***	0.2138***	0.1568***	0.2116***
	(11.43)	(12.11)	(11.03)	(5.40)	(9.75)
GDPGR	−0.0104	−0.0059	−0.0062	−0.0085	−0.0119
	(-0.90)	(-0.66)	(-0.65)	(-0.68)	(-1.07)
INFDI	0.0015	0.0018	0.0022	0.0013	0.0029
	(0.73)	(0.99)	(1.21)	(0.71)	(1.07)
GI	0.0011***	0.0012***	0.0009***	0.0013***	0.0011***
	(5.35)	(7.61)	(5.49)	(6.06)	(5.67)
CONSTANT	0.5697***	0.6046***	0.5978***	0.6280***	0.5897***
	(35.45)	(50.00)	(42.97)	(24.81)	(35.09)
Observations	1540	1540	1540	1540	1540

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

Table 5. Estimated results related to the effect of renewable energy resources on dimension education of human development.

Dependent variable: Education dimension of Human Development Index (EDU)					
REPC	0.0072***				
	(4.51)				
SPC		0.0080***			
		(7.31)			
WPC			0.0093***		
			(8.68)		
HPC				0.0044***	
				(3.78)	
OPC					0.0192***
					(8.63)

Dependent variable: Education dimension of Human Development Index (EDU)					
FDI	0.0367**	0.0519***	0.0451***	0.0563***	0.0354**
	(2.27)	(3.43)	(3.09)	(3.64)	(2.02)
URBAN	0.3070***	0.2638***	0.3081***	0.4339***	0.2934***
	(11.52)	(10.87)	(11.40)	(10.65)	(11.10)
GDPGR	−0.0037	0.0037	0.0046	0.0010	−0.0059
	(-0.19)	(0.22)	(0.27)	(0.05)	(-0.30)
INFDI	0.0029	0.0009	0.0029	0.0036	0.0029
	(1.02)	(0.42)	(1.08)	(1.15)	(1.04)
GI	0.0040***	0.0039***	0.0030***	0.0029***	0.0042***
	(12.92)	(11.02)	(9.17)	(8.30)	(14.03)
Constant	0.1839***	0.2299***	0.2532***	0.1855***	0.2016***
	(9.11)	(11.97)	(12.93)	(7.10)	(10.93)
Observations	1540	1540	1540	1540	1540

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

Table 6. Estimated results related to the effect of renewable energy resources on dimension income of human development.

Dependent variable: Income dimension of Human Development Index (IN)					
REPC	0.0026**				
	(2.22)				
SPC		0.0016**			
		(2.49)			
WPC			0.0034***		
			(4.73)		
HPC				−0.0012	
				(-1.34)	

Dependent variable: Income dimension of Human Development Index (IN)					
OPC					0.0090***
					(3.90)
FDI	0.0974***	0.1069***	0.1066***	0.0942***	0.0952***
	(10.02)	(10.87)	(14.87)	(8.38)	(11.21)
URBAN	0.4328***	0.4017***	0.3813***	0.3540***	0.4027***
	(19.60)	(20.27)	(22.07)	(12.08)	(20.82)
GDPGR	0.0622***	0.0631***	0.0643***	0.0647***	0.0607***
	(5.71)	(5.94)	(6.35)	(6.15)	(5.59)
INFDI	0.0004	0.0010	0.0016	0.0019	0.0012
	(0.17)	(0.37)	(0.58)	(0.71)	(0.45)
GI	0.0017***	0.0020***	0.0018***	0.0019***	0.0019***
	(6.08)	(6.62)	(6.83)	(6.46)	(6.57)
CONSTANT	0.3140***	0.3265***	0.3499***	0.3868***	0.3329***
	(27.41)	(28.15)	(35.84)	(25.69)	(34.48)
Observations	1540	1540	1540	1540	1540

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

Concerning dimension education of human development, Table 5 shows that the coefficients of renewable energy sources are significantly positive at a 1% level, indicating that total renewable energy, solar energy, wind energy, hydro energy, and other renewable energy may boost dimension education of human development through increasing mean years of schooling and expected years of schooling.

Regarding the dimension income of human development, Table 6 shows that excluding hydro energy, the effects of renewable energy sources are significantly positive at a 10% level. These results indicate that total renewable energy, solar energy, wind energy, and other renewable energy may enhance the dimension income of human development by increasing gross national income per capita.

Furthermore, this study analyzes whether income groups may cause differences in the effect of renewable energy consumption on human development and its dimensions. This study divides our sample into high-, and middle-income groups and reestimates Equation (4) – Equation (7). Our results are presented in Table 7, Table 8, Table 9, Table 10 for human development, dimension health, education, and income of human development, respectively.

Table 7. Differential impact of renewable energy resources on human development between high- and middle-income countries.

	Dependent variable: Human Development Index (IN)							
	High-income					**Middle-income**		
REPC	0.0057***					−0.0022		
	(8.01)					(-1.37)		
SPC		0.0044***					0.0059***	
		(6.45)					(6.36)	
WPC			0.0046***					0.0047*
			(7.55)					(4.96)
HPC				0.0033***				
				(5.34)				
OPC					0.0124***			
					(9.19)			
FDI	0.0254***	0.0292***	0.0173**	0.0240***	0.0243***	0.0321**	0.0273**	0.0099
	(3.35)	(3.91)	(2.28)	(2.97)	(3.39)	(2.43)	(2.34)	(0.69)
URBAN	0.1879***	0.1611***	0.1666***	0.1845***	0.1417***	0.3903***	0.2918***	0.3643*
	(10.39)	(9.37)	(8.22)	(9.37)	(8.89)	(11.06)	(13.20)	(11.51)
GDPGR	0.0049	0.0063	0.0052	0.0030	0.0021	0.0377**	0.0394***	0.0425*
	(0.39)	(0.58)	(0.44)	(0.22)	(0.16)	(2.50)	(2.95)	(3.11)
INFDI	0.0016	0.0010	0.0019	0.0009	0.0018	−0.0130	−0.0120	−0.0105
	(0.95)	(0.79)	(1.36)	(0.62)	(1.11)	(-0.82)	(-0.78)	(-0.68)
GI	0.0025***	0.0028***	0.0024***	0.0029***	0.0029***	0.0015***	0.0013***	0.0012*
	(8.16)	(12.11)	(8.29)	(8.09)	(9.97)	(7.00)	(7.02)	(6.46)

	Dependent variable: Human Development Index (IN)							
	High-income					**Middle-income**		
CONSTANT	0.4696***	0.4972***	0.5176***	0.4592***	0.4941***	0.3714***	0.4349***	0.3952*
	(19.40)	(28.86)	(20.90)	(16.97)	(20.46)	(16.88)	(26.95)	(17.52)
Observations	900	900	900	900	900	640	640	640

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

Table 8. Differential impact of renewable energy resources on dimension health of human development between high- and middle-income countries.

	Dependent variable: Health dimension of Human Development Index (IN)							
	High-income					**Middle-income**		
REPC	0.0042***					0.0025		
	(5.92)					(1.56)		
SPC		0.0049***					0.0051***	
		(8.32)					(5.10)	
WPC			0.0028***					0.0048*
			(5.07)					(5.16)
HPC				0.0011*				
				(1.91)				
OPC					0.0099***			
					(7.18)			
FDI	0.0217***	0.0502***	0.0310***	0.0174*	0.0205**	0.0459***	0.0283**	0.0240*
	(2.70)	(7.25)	(3.87)	(1.94)	(2.51)	(3.68)	(2.43)	(2.35)
URBAN	0.1694***	0.1224***	0.1577***	0.1345***	0.1483***	0.1410***	0.1265***	0.1267*
	(12.68)	(12.19)	(12.10)	(9.31)	(12.05)	(3.73)	(6.02)	(5.61)
GDPGR	−0.0167	−0.0158	−0.0188	−0.0190	−0.0184	−0.0103	−0.0006	0.0008

	Dependent variable: Health dimension of Human Development Index (IN)							
	High-income					Middle-income		
	(-1.29)	(-1.49)	(-1.44)	(-1.36)	(-1.40)	(-0.84)	(-0.05)	(0.07)
INFDI	0.0017	0.0014	0.0011	0.0016	0.0020	−0.0157	−0.0139	−0.0116
	(0.93)	(0.95)	(0.82)	(1.01)	(1.02)	(-1.06)	(-0.97)	(-0.81)
GI	0.0017***	0.0019***	0.0021***	0.0024***	0.0020***	0.0007***	0.0006***	0.0006*
	(6.01)	(10.13)	(9.62)	(7.08)	(7.77)	(3.68)	(2.58)	(3.12)
CONSTANT	0.5957***	0.6184***	0.5878***	0.5979***	0.6030***	0.6313***	0.6634***	0.6561*
	(27.39)	(38.50)	(29.21)	(21.42)	(26.98)	(25.95)	(33.19)	(33.77)
Observations	900	900	900	900	900	640	640	640

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

Table 9. Differential impact of renewable energy resources on the education dimension of human development between high- and middle-income countries.

	Dependent variable: Education dimension of Human Development Index (IN)							
	High-income					Middle-income		
REPC	0.0107***					0.0018		
	(8.78)					(0.78)		
SPC		0.0063***					0.0077***	
		(5.73)					(4.43)	
WPC			0.0080***					0.0069*
			(7.66)					(4.75)
HPC				0.0051***				
				(3.67)				
OPC					0.0209***			
					(6.69)			

	Dependent variable: Education dimension of Human Development Index (IN)							
	High-income					Middle-income		
FDI	−0.0198	0.0106	−0.0059	−0.0038	0.0002	0.0245	0.0213	0.0036
	(-1.32)	(0.89)	(-0.42)	(-0.23)	(0.01)	(1.06)	(0.99)	(0.16)
URBAN	0.1612***	0.1452***	0.1381***	0.2618***	0.0988***	0.3674***	0.2627***	0.3475*
	(5.41)	(4.30)	(3.50)	(4.59)	(2.89)	(6.53)	(6.51)	(6.93)
GDPGR	−0.0184	−0.0135	−0.0126	−0.0134	−0.0166	0.0195	0.0233	0.0290
	(-0.93)	(-0.72)	(-0.66)	(-0.59)	(-0.70)	(0.77)	(0.99)	(1.26)
INFDI	0.0027	−0.0008	0.0001	0.0019	0.0015	0.0079	0.0076	0.0166
	(1.02)	(-0.29)	(0.02)	(0.78)	(0.68)	(0.21)	(0.22)	(0.46)
GI	0.0046***	0.0051***	0.0043***	0.0038***	0.0041***	0.0017***	0.0013***	0.0016*
	(7.51)	(9.41)	(8.26)	(5.14)	(6.67)	(5.07)	(4.22)	(5.00)
CONSTANT	0.2603***	0.2718***	0.3273***	0.2977***	0.3849***	0.2786***	0.3798***	0.3077*
	(5.79)	(7.71)	(8.59)	(4.41)	(6.78)	(6.93)	(9.72)	(7.91)
Observations	900	900	900	900	900	640	640	640

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

Table 10. Differential impact of renewable energy resources on dimension income of human development between high- and middle-income countries.

	Dependent variable: Income dimension of Human Development Index (IN)							
	High-income					Middle-income		
REPC	−0.0003					0.0001		
	(-0.35)					(0.02)		
SPC		0.0020***					0.0018**	
		(3.00)					(2.19)	
WPC			0.0023***					0.002

	Dependent variable: Income dimension of Human Development Index (IN)							
	High-income					Middle-income		
			(2.63)					(3.38)
HPC				−0.0026***				
				(-7.16)				
OPC					0.0028*			
					(1.65)			
FDI	0.0310***	0.0547***	0.0421***	0.0611***	0.0378***	0.0676***	0.0733***	0.053
	(3.50)	(5.30)	(4.70)	(5.85)	(4.00)	(5.31)	(6.42)	(4.84)
URBAN	0.2298***	0.2192***	0.2384***	0.2348***	0.2322***	0.4287***	0.4159***	0.427
	(8.36)	(12.57)	(12.42)	(13.81)	(11.06)	(14.73)	(13.23)	(13.65
GDPGR	0.0485***	0.0483***	0.0480***	0.0461***	0.0485***	0.0793***	0.0804***	0.082
	(3.55)	(3.64)	(3.64)	(3.33)	(3.38)	(5.83)	(6.02)	(6.15)
INFDI	0.0002	0.0026	0.0019	0.0004	0.0001	−0.0166	−0.0174	−0.014
	(0.12)	(1.36)	(1.10)	(0.32)	(0.07)	(-0.91)	(-0.95)	(-0.78
GI	0.0017***	0.0015***	0.0014***	0.0018***	0.0016***	0.0007***	0.0007***	0.000
	(4.99)	(5.81)	(5.47)	(7.38)	(5.23)	(4.01)	(3.84)	(3.42)
CONSTANT	0.5763***	0.5736***	0.5640***	0.5484***	0.5709***	0.3670***	0.3734***	0.373
	(17.13)	(28.84)	(23.28)	(27.34)	(20.18)	(27.87)	(25.17)	(24.44
Observations	900	900	900	900	900	640	640	640

Note: *, **, and *** denote the significant statistics at 10%, 5%, and 1%, respectively. ( ) is the t-statistic value.

(Source: author's estimation)

The findings presented in Table 7 demonstrate a significant positive impact of renewable energy consumption (REPC) on human development in high-income countries, while it appears insignificant in middle-income countries. This implies that the adoption of renewable energy technologies primarily promotes human development in high-income nations, highlighting the developmental disparities between high-income and middle-income countries. It is worth noting that middle-income countries face the challenge of managing the relatively high initial capital costs associated with implementing renewable energy technologies. This creates a balancing act for these countries, weighing the costs against renewable energy's benefits. Consequently, the impact of renewable energy use on human development becomes negligible in middle-income countries. This aligns with the arguments made by Amer [29], who discussed the negative correlation between renewable energy and human development due to the high initial capital costs and longer implementation time. Similarly, Zahid, Arshed, Munir and Hameed [23] also acknowledged the presence of high initial capital costs in establishing renewable energy technologies. However, when analyzing specific renewable energy components such as solar, wind, hydro, and others, this study observed significant positive impacts on human development in high-income and middle-income countries.

Similarly to the impact on overall human development, our analysis reveals that renewable energy has a significant positive influence on the dimensions of health and education in high-income countries, while the effect is not significant in middle-income countries. This indicates that adopting renewable energy technologies does not contribute significantly to improving these dimensions in middle-income countries, reasoning the limitation of technological capacity and investment capital in these countries. Excluding hydropower, this study finds that other renewable energy sources, such as solar, wind, and other renewable sources (SPC, WPC, and OPC), significantly affect health, education, and income in high-income and middle-income countries in Table 8, Table 9, Table 10 However, when it comes to hydro energy, its impact is significantly negative on the dimension of income in high-income countries and is not significant in middle-income countries. This suggests that the use of hydroenergy technologies may lead to a decrease in the dimension of income of human development, potentially due to a lower GNI per capita in high-income countries. These findings show that not all types of renewable energy are suitable for all countries; it depends on economic conditions and technological mastery to best exploit the benefits of renewable energy. Moreover, the public's embrace or dismissal of renewable energy sources plays a pivotal role. The effective implementation of any new technology associated with renewable energy needs to secure social approval and support related to public awareness [64]. These are also different findings of this study compared to previous studies on renewable energy and economic growth or human development.

5. Conclusion

Renewable energy resources are crucial for sustainable social and economic development, as they reduce the environmental damage caused by fossil fuels. However, the transition to renewable energy faces challenges such as high costs and technical complexities. Despite these obstacles, renewable energy plays a significant role in enhancing human development. Empirical studies have shown both positive and negative associations between renewable energy and human development, with non-linear characteristics depending on specific conditions. Understanding the complex relationship between renewable energy and human development is essential for policymakers to make informed decisions and develop effective strategies for a sustainable future, particularly in low-middle-income countries. Hence, the objective of this paper is to deliver an extensive examination of the empirical data concerning the influence of renewable energy on human development, specifically focusing on health, education, and income dimensions along with the impacts of solar, wind, and hydroenergy, respectively. Additionally, this study placed its emphasis on research conducted across various nations and regions, with the intent of unveiling potential variations and delving into the underlying rationales behind such disparities.

Indeed, the findings show that renewable energy consumption positively influences human development. Similar evidence from previous studies supports this relationship [30,65]. Adopting renewable energy leads to various benefits, such as reducing pollution, improving environmental quality, and increasing household and business incomes. Robustness checks reveal that renewable energy sources, including solar, wind, hydro, and others, have significant positive effects on the dimensions of health, education, and income in high-income countries. However, these effects are insignificant or less pronounced in middle-income countries, potentially due to the higher initial capital costs and longer implementation time associated with renewable energy technologies. The use of hydro energy, in particular, has a negative impact on the income dimension in high-income countries. Overall, the study highlights the importance of renewable energy for human development but emphasizes the need for tailored approaches considering income levels and specific renewable energy sources.

This study employs a range of robust checks to illustrate that renewable energy yields environmental benefits and enhances measures of human development. Given the positive correlation between renewable energy production and indicators of human development, policymakers are urged to foster renewable energy initiatives. Prioritizing investments in solar, wind, and other energy projects is crucial for both developed and developing nations. However, it is also important to consider hydropower when making investments, aligning renewable energy projects with each country group's unique goals and development trajectories. Furthermore, policies aimed at attracting foreign direct investment, fostering international integration, developing financial sectors, and promoting green urbanization should be encouraged to bolster the advancement of education, healthcare, and the overall well-being of individuals. It is worth noting that the study's limitations stem from data availability, as it was confined to 77 countries spanning the period 2000–2019 and did not account for the impact of the COVID-19 pandemic. Future research could encompass a broader range of countries and examine the effects of the pandemic for a more comprehensive understanding.

Author contributions

Conceptualization, T.K.T., P.G.Q., and T.T.H.N. methodology, H.M.B., G.Q.P., and T.T.H.N. software, G.Q.P. validation, G.Q.P., and T.K.T..data curation, G.Q.P.writing—original draft preparation, G.Q.P., T.T.H.N. writing—review and editing, T.K.T., and H.M.B. visualization, G.Q.P. supervision, H.M.B. All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A.

List of countries in the sample.

Country	Country	Country	Country
Algeria	Estonia	Malaysia	South Africa
Argentina	Finland	Mexico	South Korea
Australia	France	Morocco	Spain
Austria	Germany	Netherlands	Sri Lanka
Azerbaijan	Greece	New Zealand	Sweden
Bangladesh	Hong Kong	North Macedonia	Switzerland
Belarus	Hungary	Norway	Thailand
Belgium	Iceland	Oman	Trinidad and Tobago
Brazil	India	Pakistan	Turkey
Bulgaria	Indonesia	Peru	Turkmenistan
Canada	Iran	Philippines	Ukraine
Chile	Ireland	Poland	United Arab Emirates

Country	Country	Country	Country
China	Israel	Portugal	United Kingdom
Colombia	Italy	Qatar	United States
Croatia	Japan	Romania	Uzbekistan
Cyprus	Kazakhstan	Russia	Venezuela
Czechia	Kuwait	Saudi Arabia	Vietnam
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Ecuador	Lithuania	Slovakia	

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Data availability

The data that has been used is confidential.

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