Journal of the Knowledge Economy
https://doi.org/10.1007/s13132-024-01811-5

Asymmetric Impacts of Renewable Energy on Human Development: Exploring the Role of Carbon Emissions, Economic Growth, and Urbanization in European Union Countries

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Received: 29 November 2022 / Accepted: 2 February 2024
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Abstract

Human development is one of the critical and standard criteria in evaluating countries' development levels. Although the impact of renewable energy consumption on the human development index (HDI) has been investigated in previous research, the results are contradictory. In addition, there are no studies that examine the asymmetric role of renewable energy, carbon emissions, economic growth, and urbanization on human development in European Union countries. Therefore, this research seeks to fill this gap. In doing so, this study employed a novel method of moments quantile regression (MMQR) using annual data from 2000 to 2019. The preliminary results reject the assumption of data normality; therefore, it is necessary to use MMQR, which can deal with structural changes and non-normality of data. The empirical findings indicate that renewable energy consumption promotes the human development index in all quantiles except the 0.9 quantile, and it decreases in higher quantiles. Furthermore, economic growth is the strongest influencing variable, and in higher quantiles, the impact of economic growth on HDI increases. Also, urbanization positively and significantly improves HDI in all quantiles (0.1–0.9), although the impact of carbon emissions on human development in all quantiles except 0.9 quantile is negative and significant. The results of this study suggest insights for policymakers to improve human development by investing more in the development of renewable energy, facilitating higher quality infrastructure and services such as education, and health services.

Keywords CO_2 emissions · Renewable energy · HDI · Method of moments quantile regression

Extended author information available on the last page of the article

Published online: 14 February 2024

Introduction

Enhancing human prosperity and alleviating poverty are paramount concerns in contemporary society. Consequently, the implementation of fundamental measures to ameliorate well-being and reduce poverty has garnered significant attention in recent decades. Mainly, the way societies enjoy health, education, and living standards can determine the level of prosperity or poverty of countries (Jin et al., 2020; Long et al., 2020). For instance, a qualified educational system contributes to the acquisition of skills and knowledge that are crucial for amplifying productivity in the labor market, leading to an elevated standard of living (Fraisl et al., 2020; Sachs et al., 2019). Moreover, ensuring that the communities have access to safe water, nutritious food, and proper sanitation facilities enhances overall public health, which directly impacts the well-being of societies (Ebenso et al., 2022). Simultaneously, achieving higher income levels is essential in a country's journey towards increasing prosperity and reducing poverty (Janjua & Kamal, 2011). The concept of human development, as gauged by composite indices like the Human Development Index (HDI), serves as a critical metric to assess the prosperity and poverty levels within societies. The HDI takes into account three key dimensions: health (life expectancy at birth), education (measured by mean and expected years of schooling and literacy rates), and per capita income (Hickel, 2020). An emphasis on human development fosters fair opportunities and choices for citizens. Furthermore, it empowers individuals to attain improved living standards, access to quality healthcare, and higher education, ultimately contributing to longer and healthier lives (Haller, 2012). Consequently, the pursuit of greater prosperity and the reduction of poverty are multidimensional goals that hinge on fostering education, healthcare, and economic well-being. Monitoring and enhancing human development through indices such as the HDI provides a valuable framework for understanding and addressing these complex challenges (Allen & Thomas, 2000; Hou et al., 2015). Thus, many efforts have been made by policymakers and governments in recent decades to achieve higher levels of human development in order to bring more welfare to their societies.

Human development is strongly connected with several pivotal factors and other human challenges that exert a substantial influence on the human condition, such as countries' energy portfolios, CO_2 emissions, economic growth, and the process of urbanization (Bedir & Yilmaz, 2016; Van Tran et al., 2019). Economic growth can directly increase the income of countries (Chica-Olmo et al., 2020). Economic growth can occur in various ways, including increased investment, improved productivity, technological advancements, and enhanced trade, among others (Garegnani & Trezzini, 2010; Rahman & Alam, 2021). Economic growth poses a multifaceted influence on the human HDI that extends beyond its impact on the income dimension. Specifically, economic expansion empowers governments to allocate resources for the enhancement of educational and healthcare infrastructures (Bedir, 2016; Hanushek & Woessmann, 2010). Furthermore, the rise in economic prosperity stimulates a heightened societal demand for education and healthcare services, manifesting as constructive catalysts for advancing the broader spectrum of human development (Busemeyer & Garritzmann, 2019).

Urbanization is one of the most critical characteristics of human, social, and economic development. This indicator is an inherent hallmark of human development, closely entwined with economic and social progress (Jedwab & Vollrath, 2015). As such, adeptly managed urbanization results in a pronounced, direct favorable impact on a nation's income and fiscal prosperity. This is rooted in urbanization's potential to spur economic activity, broaden the spectrum of employment opportunities, and augment access to fundamental services (Nguea, 2023). Indeed, cities collectively account for an estimated 70% of the global GDP; hence, urbanization can enhance the income of countries. Moreover, educational facilities and healthcare are more accessible in cities (Tripathi, 2019, 2021).

On the contrary, inadequately managed urbanization and economic growth can give rise to environmental challenges and exacerbate the utilization of environmentally deleterious energy sources, thereby posing a significant impediment to human development (Asongu et al., 2020; Behera & Dash, 2017). Carbon emissions are a critical environmental factor that has both direct and indirect consequences for human development, and it can significantly influence a nation's HDI (Li & Chen, 2021). Air pollution and carbon emissions lead to a range of health issues, including respiratory diseases, cardiovascular problems, and premature mortality (Lelieveld et al., 2020; Mirabelli et al., 2018). A high burden of diseases due to air pollution can negatively affect the health dimension of HDI, primarily life expectancy (Karimi Alavijeh et al., 2023a). Hence, poor air quality can lead to increased healthcare costs and reduced labor productivity, which can directly influence the income dimension of HDI (Liu et al., 2020). Furthermore, CO_2 emissions contribute to environmental degradation, including damage to ecosystems and the climate (Salehnia et al., 2020). Such degradation can have long-term consequences on food security, clean water availability, and overall environmental sustainability, which indirectly affects the human development dimensions (Boyd, 2019; Koengkan et al., 2022; Sun et al., 2017).

Environmental degradation has led many countries to use eco-friendly energy sources to provide the energy demanded by economic activities and avoid the negative consequences of environmental pollution. This has a significant potential to increase human development (Pervaiz et al., 2021). The increase in adoption of renewable energy sources, such as solar, wind, and hydropower, leads to reduction of greenhouse gases (Alvarez-Herranz et al., 2017). This positively affects the environment and contributes to sustainable development. Expanding the use of renewable energy can enhance energy accessibility, particularly in remote or underserved regions. This supports the improvement of living standards and quality of life, contributing to the income and education dimensions of HDI (Mboumboue & Njomo, 2016). Investments in renewable energy infrastructure can create jobs and stimulate economic growth. A growing renewable energy sector can have a positive impact on income levels and employment opportunities, thus directly affecting the income dimension of HDI (Wang et al., 2018a, 2018b). Reliable access to energy, powered by renewables, can improve healthcare services through electrified medical facilities and enable educational advancements through access to technology and information. These factors can positively influence the health and education dimensions of HDI (Azam et al., 2021; Oke et al., 2021).

According to the above discussion, the study of human development and its determinants has found a special place among scholars and academics. Thus, the intention of this article is to investigate the impact of renewable energy, carbon emissions, economic growth, and urbanization on human development using the method of moments quantile regression for the European Union (EU) countries. According to this goal, this research answers four questions:

1. Q1. What is the impact of renewable energy on human development?
2. Q2. Do carbon emissions have an impact on human development?
3. Q3. To what extent does economic growth have an impact on human development?
4. Q4. What is the impact of urbanization on human development in the European Union countries?

Considering the previous reasoning, this study contributes to the literature in three routes. (1) Although several researchers have studied and identified the determinants of human development, the novelty of the present research is that few studies have paid attention to the position of urbanization in human development for a period of 20 years (2000–2019). (2) The present research uses the method of moments quantile regression of Machado and Silva (2019) (MMQR) as a statistical method to achieve the goal. This method is helpful in examining the asymmetric impact of renewable energy, carbon emissions, economic growth, and urbanization on human development, which is not possible through traditional regressions. In fact, unlike MMQR, ordinary linear models assume the normality of the data, which is not an acceptable assumption (Sun et al., 2022). (3) To our knowledge, this is the first paper to use MMQR to investigate the factors affecting human development in EU countries.

This research focuses on EU countries for some reasons. The European Union countries consist of 27 countries that have high levels of human development (see Fig. 1). According to HDR (2022), the highest value of human development was related to Sweden in 2000, and the lowest human development was observed in Romania in 2000. Meanwhile, the highest and lowest value of human development was related to Ireland and Bulgaria in 2019, respectively. European member countries, despite their overall high level of human development, confront a range of socio-economic challenges as they strive to achieve high levels of human development (Krylovas et al., 2020; Sourander et al., 2018). Income inequality, youth unemployment, demographic challenges, unequal access to quality education and healthcare, migration, environmental sustainability, and global economic uncertainty are among these challenges (Galvin and Sunikka-Blank, 2018; Schneider, 2016). Therefore, the study of factors affecting HDI is vital for EU members in several ways. For instance, HDI serves as an important criterion for measuring the progress and development of countries, and its evaluation allows these countries to assess their relative status not only among European countries but also with other countries (Jezek, 2014). In this regard, EU countries are able to develop evidence-based policies that target specific areas that need improvement.

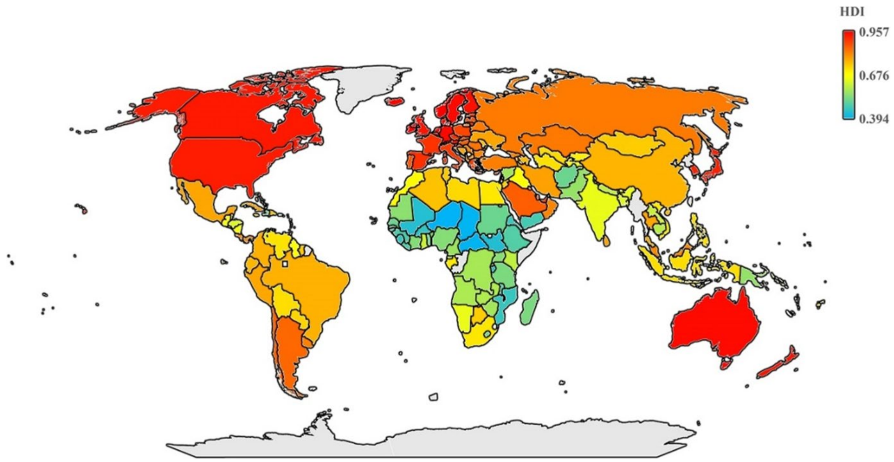

Fig. 1 Geographical mapping of HDI rank. Source: Human Development Report (2019)

Moreover, studying the HDI and its stimulus assists these countries in the prioritization of policies and investments in areas that have the most significant impact on overall human development, which can guide resource allocation and decision-making (Fahrika et al., 2020). Further, efforts to enhance human development can be effective for EU countries on the way to achieving sustainable development goals. Additionally, the implementation of policies to increase HDI can have a positive impact on the economic competitiveness of European countries, investment absorption, and trade and, in turn, improve the quality of life and welfare of European citizens (Lonska & Boronenko, 2015).

EU countries are also of particular importance in terms of human development determinants considered in this study. The economic situation of EU countries has been affected by various factors. However, the economic growth rate is different among the member countries, with some nations experiencing robust growth and others facing economic challenges, including high debt levels. The EU's economic policies and fiscal measures aimed to foster stability and growth across the region (Alola et al., 2019; Bilan et al., 2019). Urbanization is a dominant trend in EU countries, which has received much attention in recent decades. Thereby, an increasing population of these countries has moved to urban areas, which has led to the formation of crowded megacities (Amin et al., 2020; Armeanu et al., 2021). Besides, many of these countries have implemented strict environmental regulations to reduce air pollution. Nevertheless, environmental challenges are one of the significant problems in EU countries (Armeanu et al., 2021; Zhang et al., 2022). Finally, EU countries, especially after Russia's invasion of Ukraine, pursue serious goals to reduce dependence on fossil fuels and move towards renewable energies (Armeanu et al., 2021). Consequently, the study of HDI and its influencing factors seems crucial for EU countries. This research can also help statesmen in legislation in line with the Sustainable Development Goals (SDGs), namely, good health and well-being, and reduced inequalities.

The present study is organized as follows: existing literature is reviewed in the second section; the methodology and data used are analyzed in the third section; the fourth section displays the results and discussion; eventually, the study is concluded in fifth section with the conclusion and policy recommendations.

Literature Review

Theoretical Literature

The importance of human development encourages countries to provide a proper program to improve HDI to achieve sustainable development. Human development is one of the critical and standard criteria for evaluating countries' development levels (Kristjanpoller et al., 2018; Wang et al., 2021). For the first time, the United Nations Development Programme (UNDP) presented the HDI based on Amartya Sen's capabilities approach in 1990, which is considered a novel approach for evaluating human development (Wang et al., 2021). HDI is obtained through the geometric mean of the normalized indices of these three mentioned dimensions, which assigns the numbers zero to one to the countries and ranks them (Feruni et al., 2020). A country's human development is very high if the country's score is between 0.8 to 1. Furthermore, if the score of countries is between 0.7 to 0.79 and 0.55 to 0.7, they are considered to have high and medium human development, respectively. Eventually, countries with low human development are countries whose score is below 0.55 (HDR, 2022).

Economic growth can affect human development through households and the activities of governments and non-governmental organizations. In other words, the level of human development depends on economic growth in several ways. Households can spend their income in sectors that enhance human development level. For instance, households can take an effective step in human development enhancement by allocating their income to better nutrition, clean water, education, and health. It can be stated that the more households spend in these areas, the higher the levels of human development will be (Babatunde & Qaim, 2009; Meyer & Nishimwe-Niyimbanira, 2016; Sulistyowati et al., 2017). Similarly, governments can improve the level of human development by improving the health network, increasing the health of drinking water and proper nutrition, reducing air pollution, and providing appropriate infrastructure to increase the quality of education (Howden-Chapman et al., 2017). Hence, the expenditure spent on health, education, and health can increase by the government along with economic growth, which leads to the promotion of human development. Moreover, non-governmental organizations are formed for public benefit activity purposes. The activities of these organizations include income-generating for the poor and building schools, health centers, and hospitals, which have a direct impact on human development (Chao & McAllister, 2022; Koch et al., 2009). Economic growth causes social development and increases the activity of such organizations and, in turn, improves the level of human development (Chao & McAllister, 2022).

Empirical evidence also indicates that there is a close relationship between urbanization and human development (Huang & Jiang, 2017). The impact of urbanization on HDI is debatable in many aspects. Considering the extensive benefits of urbanization for economic performance, urbanization may improve healthcare conditions in societies. On the other hand, exposure of people to dangerous and chronic factors such as air pollution, unhealthy diets, sedentary lifestyles, and life stress may have negative consequences on life expectancy (City and Assessment, 2010; Hawkes et al., 2017; Qing, 2018; Wang et al., 2020). Urbanization also affects per capita income as a critical dimension of human development. Modernization and economic growth following the increase of urbanization are considered an inevitable process for human development. Urbanization can create productivity in economic activities, and attract better jobs, and higher income opportunities, leading to promote human development (Tadjoeddin & Mercer-Blackman, 2018). Regarding the impact of urbanization on the education dimension of HDI, it can be stated that a large population of rural residents migrates to cities. Urban areas, compared to rural, have better infrastructure for education; hence, the possibilities of education are higher in cities. Consequently, urbanization positively influences education and can improve human development (Gupta et al., 2018; Tripathi, 2019, 2021).

Findings revealed that in the countries that experience a growing trends of HDI, the trend of carbon emissions is increasing (Adekoya et al., 2021). Carbon emissions can lead to respiratory diseases, cardiovascular problems, and premature mortality, which directly impact the health dimension of HDI. Also, it can influence the standard of living and income through higher healthcare costs, reduce labor productivity, and lower accessibility to clean water availability and food security (Kumar et al., 2023; Săndică et al., 2018).

The theoretical background of energy consumption on HDI can also be discussed. A fundamental driver of human development is energy utilization (Ejemeyovwi et al., 2019). However, the type and efficiency of energy sources play a key role in the impact of energy consumption on HDI. Accessing to modern and eco-friendly energy sources is essential for improving living standards and achieving higher levels of education, healthcare, and overall well-being (Tu et al., 2011). Besides, energy consumption is closely linked to economic growth. Increased energy availability and efficiency can stimulate economic activities, creating employment opportunities and augmenting income levels, directly impacting the income dimension of HDI (Amer, 2020; Wang et al, 2018a, 2018b; Wu et al., 2010; Yumashev et al., 2020).

Empirical Literature

In this section, previous researches are reviewed in details. In the first part, the literature review on the relation between renewable energy consumption and human development is discussed. In the following, previous studies about carbon emissions and human development index have been reviewed. Finally, the literature about the connection between economic growth and human development has been investigated.

Renewable Energy Consumption and Human Development

The effective role of renewable energy consumption in human development has been prominent in many studies. For example, Wang et al. (2021) assessed how renewable energy use influenced human development in BRICS countries from 1990 to 2016 by utilizing methods that consider cross-sectional dependence. They concluded that renewable energy stimulates human development, and enhancing awareness regarding renewable energy investment, in addition to encouraging the utilization of renewable energy, can dramatically amplify human development in BRICS countries. Moreover, with using Dumitrescu and Hurlin causality and Westerlund and Edgerton panel cointegration test, Sasmaz et al. (2020) investigated the impact of renewable energy on human development index for the first time in OECD countries from 1990 to 2017. According to the results of this study, human development and renewable energy utilization have a mutual and positive impact on each other, so the rise in renewable energy, in addition to improving the quality of the environment, enhances human development. Besides, the improvement of human development increases the usage of renewable energy. Moreover, the effective role of renewable energy on human development is confirmed in Basri et al. (2021) study in the OECD countries using the two-stage least square model from 1990 to 2015. In contrast, in another study, Zheng and Wang (2022) studied the impact of the utilization of renewable energy on HDI from 2000 to 2018 for 26 countries by dynamic and static panel models. They concluded that the impact of renewable energy consumption on human development is not significant in the long or short run. Besides et al. (2018) found that renewable energy usage does not impact human development positively and significantly in Pakistan using two-stage east square from 1990 to 2014. In other words, the use of renewable energy does not help human development.

Carbon Emissions and Human Development

Many studies highlighted the helpful impact of environmental quality on human development. CO_2 emissions are the most destructive factor that degrades the environmental quality and is a barrier to enhancing human development. Zheng and Wang (2022) studied the impact of CO_2 emissions on human development from 2000 to 2018 for 26 countries by dynamic and static panel models. Akbar et al. (2021) concluded that healthcare expenditures in the OECD countries increased significantly with CO_2 emissions by using the panel vector autoregression model from 2006 to 2017. Boonyasana and Chinnakum (2020) considered seemingly unrelated regression estimation and three-stage least squares models and found that CO_2 emissions negatively affected human development in OECD countries during 1995–2018. Yumashev et al. (2020) confirmed that CO_2 emissions are destructive to human development in Thailand using the three-stage least squares from 2006 to 2017. Contrary, using a two-stage least square model, Basri et al. (2021) and Wang et al., (2018a, 2018b) found an interesting outcome regarding the impact of CO_2 emissions on human development in Bangladesh from 1990 to 2015 and Pakistan from 1990 to 2014, respectively. Based on their results, CO_2 emissions positively and significantly influence human development. They argued that the enhancement in CO_2 emissions might increase the attention of policymakers on clean and eco-friendly energy resources to adopt strict and encouraging policies, thereby improving human development.

Economic Growth and Human Development

Several studies concluded that economic growth can provide essential and critical resources for human development. Economic growth enhances the income of individuals and their living standards. Hence, it can positively affect human development. By applying Lagrange multiplier bootstrap method, Hashemizadeh et al. (2022) showed that economic growth improves human development for 1990 to 2015 in G-7 countries. Using a two-stage least square model and panel ARDL model, Basri et al. (2021) and Alola et al. (2021) also emphasized economic growth's positive and significant consequences on human development in Bangladesh from 1990 to 2015 and sub-Saharan Africa from 2000 to 2016, respectively. By applying ARDL and VECM approaches, Khan et al. (2019) demonstrated that economic growth improves human development in Pakistan during 1990–2014. Interestingly, another group of studies, such as Wang et al., (2018a, 2018b), concluded that economic growth negatively impacts human development using the two-stage least square from 1990 to 2014. They argued that economic growth in Pakistan created new health challenges, changed production structure, and did not improve access to education; subsequently, economic growth adversely impacted human development.

Urbanization and Human Development

In recent decades, the economy's structure is changed from an agricultural economy to an industrial one, and urbanization is expanded along with these changes. Urbanization happens when a tremendous number of people leave the countryside for the cities. Over the years, the attention of many researchers has been drawn to how urbanization affects economic development, but these studies are not extensive enough. Feruni et al. (2020) studied the impact of urbanization on human development in the European Union and Western Balkan countries through the panel generalized least square model from 2009 to 2018. Based on the results of this study, the enhancement of urbanization is associated with higher human development. They noted that in the development process, urbanization is a common part, and urban regions can be considered as the main core of human development spillovers. Further, cities provide more and quicker access to health and education systems and higher income levels. Consequently, cities perform better in economic and social development and enhance living standards compared to rural regions. In another study, Tripathi (2019) examined the effect of urbanization on human development index in low-, middle-, high-income countries by random effect Tobit estimation from 1990 to 2017. According to the results, urbanization growth significantly improves human development. By using ARDL method, Khan et al. (2018) indicated that urbanization enhance human development in Pakistan from 1990 to 2016. Moreover, Basri et al. (2021) found that urbanization has no significant impact on human development in Bangladesh using a two-stage least square model during 1990–2015.

According to the above four parts, it can be seen that researchers have used different statistical methods for modeling purposes. Nevertheless, the present paper studies the impact of renewable energy, carbon emissions, economic growth, and urbanization on human development through the new method of moments quantile regression. In fact, the use of this method shows a complete picture of the conditional distribution compared to traditional panel methods. Also, according to our knowledge, no study has investigated the asymmetric role of renewable energy, CO_2 emissions, economic growth, and urbanization on human development in the EU countries.

Method and Material

Panel Quantile Regression (MMQR)

Panel quantile regression approach was invented by Koenker and Bassett (1978), which estimates the conditional median or different quantiles of the response variables relevant to certain values of the exogenous variables. It offers a systematic way to examine how each determinant affects the dependent variable in the panel of individuals across the entire conditional distribution of the dependent variable (Cheng et al., 2021). While quantile regression has resilience for outliers, it cannot capture the heterogeneity between the cross-sections in a panel dataset (Yang et al., 2022). Hence, due to its drawbacks, the method of moments quantile regression was established by Machado and Silva (2019), to take fixed effects into account, and to measure the distributional and heterogeneous effects of multiple quantiles (Adebayo et al., 2022a). The model of MMQR considers the estimation of location-scale conditional quantiles:

$$\mathrm{Y_{it}} = \alpha_\mathrm{i} + X_{it}\lambda + \left(\delta_\mathrm{i} + Z_{it}\Phi\right) + \mathrm{U_{it}} \tag{1}$$

In Eq. 1, the parameters (α, λ, δ, Φ) are to be evaluated and $\mathrm{P}\left\{\delta_\mathrm{i} + Z_{it}\Phi > 0\right\} = 1$. Z shows a k-vector of recognized parts of $X.U_\mathrm{it}$ is a random variable, and X_{it} and U_it are independent.U_it is normalized to realization the conditions of moment $(E(|U|) = 1 and E(U) = 0)$.Thus Eq. 1 illustrates the following:

$$\mathrm{Q_Y}\left(\Psi|\mathrm{X_{it}}\right) = \left(\alpha_\mathrm{i} + \delta_\mathrm{i}\mathrm{q}(\Psi)\right) + X_{it}\lambda + Z_{it}\Phi\mathrm{q}(\Psi) \tag{2}$$

In Eq. 2, $\alpha_\mathrm{i} + \delta_\mathrm{i}\mathrm{q}(\Psi) \equiv \alpha_\mathrm{i}(\Psi)$ is the effect of distribution at quantile Ψ. The method of moments quantile regression of Eq. 2 is performed by calculating two fixed effects regressions and using a univariate quantile.

In comparison with linear methods, and even over the ordinary panel quantile regression, the MMQR method has a variety of benefits. For instance, one of the drawbacks of linear estimation techniques is that linear methods do not condition the distribution of data, and they only address the averages. In fact, in the quantile method, the assumption must be dropped that the variables at the upper tails of the distribution behave as they do at the mean (Alqaralleh, 2022). In addition, these methods fail to include unobserved heterogeneity across cross-sections in panel data. Moreover, the ordinary quantile regression suffers from a lack of non-crossing estimates when calculating estimators for multiple percentiles leading to an invalid distribution for the responses (Adebayo et al., 2022b). However, applying the MMQR method, estimations do not encounter these issues. MMQR method treats both endogeneity and heterogeneity; as a result, it can provide estimates for non-linear and asymmetric relationships between variables (Rodríguez, 2020; Amegavi, 2022; Lingyan et al., 2022).

Models and Data

In line with Adekoya et al. (2021) and Zheng and Wang (2022), the following function is extended to survey the relationship between renewable energy, carbon emissions, economic growth, urbanization, and human development index in 14 selected European Union countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden):

$$\mathrm{HDI}_{\mathrm{it}} = \mathrm{f}\left(\mathrm{REN}_{\mathrm{it}}, \mathrm{CO2}_{\mathrm{it}}, \mathrm{GDP}_{\mathrm{it}}, \mathrm{URB}_{\mathrm{it}}\right) \tag{3}$$

In Eq. 3, HDI, REN, CO_2, GDP, and URB show human development, renewable energy, carbon emission, economic growth, and urbanization, respectively. i indicated the number of countries, and the time period is stated t. Thus, Eq. 3 is set as follows:

$$\mathrm{HDI}_{\mathrm{it}} = \alpha_{\mathrm{i}} + \beta_1\mathrm{REN}_{\mathrm{it}} + \beta_2\mathrm{CO2}_{\mathrm{it}} + \beta_3\mathrm{GDP}_{\mathrm{it}} + \beta_4\mathrm{URB}_{\mathrm{it}} + \xi_{\mathrm{t}}, \tag{4}$$

In Eq. 4, the constant term defines by α_i. β_1, β_2, β_3, and β_4 represent the long-run elasticities which show the effects of renewable energy usage, CO_2 emissions, economic growth, and urbanization on human development index. The error terms demonstrate by ξ_t. The definition of variables, symbols, and data source is demonstrated in Table 1.

Figure 2 indicates variations of human development index (HDI) and renewable energy consumption, for the 14 selected European countries over during 2000–2019. According to Fig. 2, HDI and renewable energy consumption have increased during the review period, and they reached the maximum in 2019.

Results and Discussion

This section has presented the findings of preliminary and post-estimation tests, the main model and robustness check. First, the descriptive statistics of the model variables are studied. Based on Table 2, the overall mean and standard deviation of the urbanization (URB) are 6.968 and 0.557, respectively, indicating these

Table 1 Definition of variables in this research

Variables	Symbol	Definition	Source of data
Human development	HDI	Human Development Index*	Human Development Report
Renewable energy	REN	Renewable energy consumption (% of total final energy consumption)	World Bank
Carbon emissions	CO_2	Carbon emissions (metric tons per capita)	World Bank
Economic growth	GDP	GDP per capita (constant 2015 US$)	World Bank
Urbanization	URB	Urban population	World Bank

The estimation period is 2000–2019. All variables are logarithmic. * HDI is measured by three dimensions: education, standard of living, and health

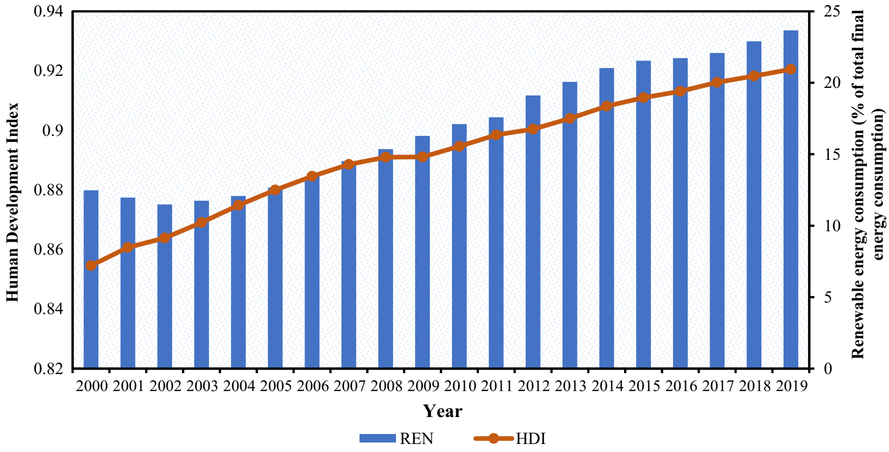

Fig. 2 Human Development Index and renewable energy consumption in the studied European countries. Source: created by the authors

parameters' higher efficiency and minor variability across European Union countries. Also, the overall mean and standard deviation of the human development index (HDI) and renewable energy consumption (REN) are − 0.049, 0.01, and 1.080, 0.391, respectively, implying that these two indicators have smaller variableness over time and across sample countries. The standard deviation of HDI is closer and marginal in the "between" and "within" options.

Normality has investigated with skewness/kurtosis test and Shapiro–Wilk test. The results from these tests are shown in Table 3. Based on the results, the variables are positively skewed. Also, the results of skewness/kurtosis test indicate to reject normal distribution of variables (D'agostino et al., 1990). In addition, the Shapiro–Wilk test results reject the normal distribution for all data. These results support the use of quantile-based estimation method.

Table 2 Summary of descriptive statistics (after logarithmic)

Variables		Mean	Std. Dev	Minimum	Maximum	Observations
HDI	Overall	−0.049	0.016	−0.101	−0.019	$N=280$
	Between		0.013	−0.082	−0.035	$n=14$
	Within		0.010	−0.077	−0.029	$T=20$
REN	Overall	1.080	0.391	0.107	1.723	$N=280$
	Between		0.353	0.581	1.642	$n=14$
	Within		0.191	0.532	1.641	$T=20$
CO_2	Overall	0.903	0.165	0.532	1.408	$N=280$
	Between		0.156	0.678	1.298	$n=14$
	Within		0.066	0.710	1.043	$T=20$
GDP	Overall	4.591	0.180	4.250	5.050	$N=280$
	Between		0.183	4.289	5.016	$n=14$
	Within		0.031	4.500	4.757	$T=20$
URB	Overall	6.968	0.557	5.565	7.808	$N=280$
	Between		0.576	5.652	7.797	$n=14$
	Within		0.027	6.881	7.068	$T=20$

Table 3 Normal distribution tests

Variables	Skewness	Kurtosis	Skewness/kurtosis test prob > chi2	Shapiro–Wilk test prob > z
HDI	0.0001	0.5434	0.000***	0.000***
REN	0.0023	0.0451	0.002***	0.000***
CO_2	0.0001	0.0231	0.000***	0.000***
GDP	0.0359	0.0834	0.029**	0.000***
URB	0.0021	0.5257	0.011**	0.000***

***significance at the 1% level, **significance at the 5% level

Table 4 Correlation matrix and VIF statistics

Variables	HDI	REN	CO_2	GDP	URB	VIF	1/VIF
HDI	1.000					-	-
REN	0.133**	1.000				1.90	0.527
CO_2	0.092	−0.592***	1.000			3.16	0.316
GDP	0.596***	−0.179***	0.591***	1.000		1.80	0.555
URB	−0.048	0.052	−0.556***	−0.569***	1.000	1.90	0.525
Mean	-	-	-	-	-	2.19	-

***significance at the 1% level, **significance at the 5% level

In Table 4 has indicated the correlation between the variables and the findings of variance inflation factor (VIF statistics). All the correlation matrix coefficients are less than 0.8 in absolute values. Therefore, there is not the multicollinearity, and the outcomes of regression will be reliable (Karimi Alavijeh et al., 2023b). Also, the mean VIF is 2.19 (less than 5). Thus, there is no severe multicollinearity problem.

Pesaran and Yamagata's (2008) test was used to check the heterogeneity of slope in data, and the test results are shown in Table 5. According to findings, the null hypothesis of homogeneous slope is rejected, due to both the delta and adjusted delta tildes being statistically significant at the 1% level. Given that there is a slope heterogeneity among the cross-sectional units, the cross-sectional dependence test can be investigated (Islam et al., 2022).

Table 6 shows the results of cross-sectional dependence (CD) test (Pesaran et al., 2004). All the variables have significant *p*-values at the 1% level so the null hypothesis is rejected, and there is the cross-sectional dependence between the variables. Due to the CD problem, the second-generation unit root test is used to review the stationary of variables (Dogan et al., 2022; Du et al., 2022). The findings of Pesaran (2007) panel unit root test are illustrated in Table 6. Conforming to the outcomes, all the variables are stationary at first difference (I(1)).

The Hausman test is used to verify heterogeneity, that is, whether the panel has fixed effects (FE) or random effects (RE). The results of the Hausman test (Table 7) reject the null hypotheses; thus, there are fixed effects in the research model. This result is acceptable because the MMQR model and OLS fixed require fixed effects.

Table 5 Results of slope heterogeneity test

Statistics	Test value	*p*-value
$\tilde{\Delta}$	14.797***	0.000
$\tilde{\Delta}_{adjusted}$	17.686***	0.000

***significance at the 1% level

Table 6 Results of CD and Pesaran CADF unit root test

Variables	CD test	CADF test	
		Level	First difference
HDI	39.80***	−1.131	−2.311**
REN	38.57***	−2.057	−2.344**
CO_2	37.98***	−1.023	−2.884***
GDP	23.58***	−0.892	−2.670***
URB	38.01***	−1.721	−2.980***

(1) ***significance at the 1% level, **significance at the 5% level. (2) The critical values for CADF test at the 10%, 5%, and 1% levels of significance are −2.140, −2.260, and −2.470, respectively

Table 7 Hausman test results

chi2(4) = 21.772 ***

(1)***significance at the 1% level. (2) The results of Hausman for H0: difference in coefficients not systematic

Table 8 The results of MMQR and OLS fixed effects

Quantiles						
Variable	Q10	Q25	Q50	Q75	Q90	OLS fixed
REN	0.025***	0.021***	0.017**	0.007*	−0.0002	0.011***
CO_2	−0.053***	−0.044***	−0.026**	−0.010**	0.0005	−0.023**
GDP	0.113***	0.120***	0.144**	0.151***	0.158***	0.138***
URB	0.031***	0.029***	0.023***	0.021***	0.019***	0.024***
Observations	280	280	280	280	280	280
Post-estimation test for the panel quantile model						
F/Wald test Chi2(4) = 80.24*** Chi2(4) = 526.12*** Chi2(4) = 188.09***						

***significance at the 1% level, **significance at the 5% level, *significance at the 10% level

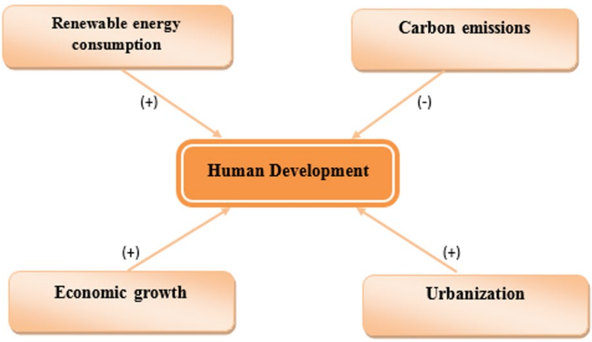

Fig. 3 Graphical image of estimation results. Source: created by the authors

Panel Quantile Regression Results

As described in the “Panel Quantile Regression (MMQR)” section, the method of moments quantile regression is used to study the effects of renewable energy, carbon emissions, economic growth, and urbanization on human development index. The model has been estimated in various quantiles (0.1, 0.25, 0.5, 0.75, and 0.9), and the outcomes are displayed in Table 8. In addition, to facilitate comparative analysis, the results of OLS fixed effect regression estimation are brought in the last column of Table 8. Besides, Fig. 3 provides a graphical image of the results showing that human development has positive links with renewable energy consumption, urbanization, and GDP, but carbon emissions have a negative effect on human development.

As shown in Table 8, the relationship between renewable energy consumption (REN) and human development index (HDI) in all quantiles except the 0.9 quantile is positive and significant. Also, the effect of renewable energy consumption on HDI reduces in higher quantiles; thus, the impact of REN on 0.1 quantile of HDI is more than other quantiles. The interpretation of coefficients in each quantile is like OLS fixed effect regression; therefore, a 1% increase in REN enhances human development index by 0.025% in 0.1 quantile. This finding displays that REN plays an important role in human development in selected European Union countries. Therefore, the use of renewable energy, which is considered clean energy, has significant environmental benefits. European Union countries have proposed the European Green Deal to accelerate the transition from fossil fuels to clean energy, which must reduce 55% of greenhouse gas emissions to zero by 2030 compared to 1990 levels. Therefore, replacing non-renewable energy sources with renewable energy contributes to environmental and health benefits for people. Therefore, the increase of renewable energies confronts challenges such as environmental degradation, greenhouse gas emissions, and diseases caused by air pollution and, in turn, leads to the improvement of human development in EU countries. Our results are consistent with Wang et al. (2021) for BRICS, Sasmaz et al. (2020) for OECD, and Pirlogea (2012) for EU countries. In addition, Kaewnern et al. (2023) stated that renewable energy consumption has positive influence on HDI in the top ten human development countries.

On the other hand, the results indicate that the effect of CO_2 emissions on HDI is negative and significant in all quantiles except the 0.9 quantile. By considering Table 8, it can be noticed that the impact of carbon emissions on human development index enhances with increasing quantiles. Thus, a 1% rise CO_2 emissions in 0.1 quantile will decrease HDI by 0.053% in EU countries. In fact, the increase in pollutants, especially carbon emissions, endangers the quality of the environment. It is also a serious threat to human health, which can reduce HDI. The negative impact of carbon emissions on HDI is also supported by the papers such as Banday and Kocoglu (2022) for emerging economies and Adekoya et al. (2021) for Oceania and Australia, while Zaman et al. (2016) results contradict our findings as they found that carbon emissions increases HDI in African countries.

Based on the outcomes reported in Table 8, the economic growth's (GDP) impact on human development index is positive and significant across all the quantiles and has an upward trend in case study countries. This is the highest significant coefficient in relationship to HDI. Also, the OLS fixed effect regression results confirm a significant and positive relationship between GDP and HDI. So, the enhancement of GDP creates more HDI, and economic growth is considered as the biggest factor of human development in EU countries. The European Union consists mainly of high-income countries and the best infrastructure. The economic growth of the European Union has increased by 60% between 1990 and 2019 (Hodžić et al., 2023). Therefore, it can be interpreted that an enhancement in economic growth leads to a decline in the unemployment rate and an increase in wages and helps the people's livelihoods to have better living standards. Therefore, folk prefer to spend more money on their education and health, which promotes the human development index (Engo, 2018; Ranis, 2004). Our finding is similar to that of Sangaji (2016) for Buddhist Countries, Arisman (2018) for ASEAN, and Alola et al. (2021) for sub-Saharan Africa nations. Our results contradict the outcomes of Khan et al. (2018) in Pakistan and Roshaniza and Selvaratnam (2015) in Malaysia. This issue may be due to the difference in the level of development and economies among the countries.

Lastly, urbanization (URB) improves the human development index in all the quantiles; however, by moving towards higher quantiles of HDI, the impact of urbanization reduces. Also, the OLS fixed effect regression results demonstrated that a 1% rise in urbanization increases HDI by 0.024%. The European Union is one of the most urban areas in the world. According to United Nations estimates, three-quarters of its population lives in urban regions, and Europe's level of urbanization is expected to increase to over 80% in 2050. Thus, the increase in urbanization is associated with more job opportunities and better access to health and educational services, which can improve the human development index in EU countries. Therefore, it is obvious that urbanization will affect the process of human development. Our findings is consistent with the paper of Huang and Jiang (2017) for Mongolia, Tripathi (2019) for a global sample, and Hashemizadeh et al. (2022) for G-7 countries.

Furthermore, in Table 8, the results of post-estimation test show that the model estimator selected in this research is sufficient to perform this analysis.

Robustness Check

In this section, an alternative model is established in order to study the robustness and the reliability of model findings (Cheng et al., 2018; Salehnia et al., 2022). In the robustness check, GDP was eliminated, and the outcomes are shown in Table 9. Based on Table 9, the findings of REN, CO_2, and URB in terms of significance and the amount of coefficients are almost consistent with the results of Table 8. So the previous results are supported.

Conclusions and Policy Implications

This study investigates the impact of significant determinants of human development, namely, renewable energy consumption, carbon emissions, urbanization, and GDP for European countries over the period from 2000 to 2019, utilizing MMQR method. Results obtained from MMQR method revealed that further usage of renewable energy will lead to an enhancement in human development.

Table 9 Robustness analysis: excluding GDP

Quantiles						
Variable	Q10	Q25	Q50	Q75	Q90	OLS fixed
REN	0.027^{***}	0.024^{***}	0.016^{**}	0.008^{*}	0.0005	0.015^{***}
CO_2	-0.056^{***}	-0.040^{***}	-0.021^{**}	-0.011^{*}	0.001	-0.112^{***}
GDP	-	-	-	-	-	-
URB	0.039^{***}	0.034^{***}	0.020^{***}	0.019^{***}	0.010^{**}	0.013^{***}
Observations	280	280	280	280	280	280
Post-estimation test for the panel quantile model						
F/Wald test Chi2(4) = 84.50^{***} Chi2(4) = 540.02^{***} Chi2(4) = 170.79^{***}						

***significance at the 1% level, **significance at the 5% level, *significance at the 10% level

European governments have constantly made efforts to invest further in renewable energies and adopted targets to achieve a 20% share of renewable energy by 2020 and 32% by the year 2030. This has led to a higher level of human development in these countries, as renewable energies contribute to human well-being through the provision of healthier energy options, and these sources of energy will also stimulate energy security. While investing in renewable energy may result in challenges for the EU governments such as financial concerns, they can potentially tackle this issue by providing incentives for private sector including tax credits, rebates, and loans with lower interest rates.

CO_2 emissions found to have negative impacts on human development, due to the hazardous effects of carbon emissions on human health. Fit-for-55, which is a part of the European Green Deal approved in 2020, suggests a target of achieving climate neutrality by the year 2050. This means that the current level of greenhouse gas emissions has to drop significantly in the next 10 years. Meanwhile, the EU has raised its 2030 targets, planning to cut emissions by at least 55% by 2030. To achieve this, EU plans to plant 3 billion additional trees by 2030. So far, the plan has been implemented successfully as the figures show the value of net-zero start-ups in European ecosystem doubled since 2020 reaching to more than100 billion Euros in 2021, which also stimulated the number of green jobs in the continent. These policies, if continued to be applied by the EU countries, will eventually reduce carbon emissions and will enhance the quality of air and human health.

Higher GDP and urbanization have led to higher human development in EU countries. Provision of further employment opportunities and higher wages through attracting more investment, and also facilitating access to higher quality infrastructure and services such as education, public transportation, and health services, will not only boost local economic growth but also stimulate urbanization and will eventually lead to higher human development. However, European policymakers should choose sustainable options among all investment opportunities; hence, the development does not impose burdens on the health of their citizens. While urbanization and advanced infrastructure significantly improve human development, it should not come at cost of damaging the environment. In doing so, a target of 90% decrease in transport-related greenhouse gas emissions has been planned by the European Union to achieve by 2050; as a result, improving transportation will not affect the quality of air.

There are limitations in this study as in other research. So, (1) other researchers can repeat this paper for other groups of countries such as MENA, BRICS, G-7, and ASEAN countries. Also, (2) future papers can expand this research by adding other variables such as the Gini coefficient, governance index, and industrialization. Future researchers can conduct further studies by focusing on the detailed and specific impacts of each renewable energy source and also by considering different types of greenhouse gas emissions. Comparison between different continents might also be fruitful to see the diverse impacts of the same determinants on human development.

Author Contribution Methodology, software, and writing, review and editing: N.K.A.; conceptualization and writing, review and editing: M.T.A.S.H.; writing, review and editing: P.E.; writing, review and editing: F.D.. All authors read and approved the final manuscript.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval This paper does not contain any studies with human participants or animals performed by any of the authors.

Consent for Publication The authors affirm the informed consent for publication of the article.

Competing Interests The authors declare no competing interests.

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