Vatamanu *et al.*
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Renewable energy consumption, institutional quality and life expectancy in EU countries: a cointegration analysis

Anca-Florentina Vatamanu[1*], Mihaela Onofrei[1], Elena Cigu[1] and Florin Oprea[1]

Abstract

Background Although some socioeconomic, environmental, and political factors could impact life expectancy, the economic literature loses sight of the relationship between the widespread adoption of renewable energy technologies and their potential effect on global life expectancy. An insightful analysis of the socio-economic and environmental benefits associated with renewable sources forms the foundation for investigating the broader implications for public health and well-being. Using panel data from 27 European countries over the period 2000–2020, this study examines the effects of renewable energy consumption on human life expectancy as well as how institutional quality and investment in renewable energy projects might promote better health outcomes.

Methods The methodological approach is carefully selected to address salient estimation issues and includes a qualitative sequential methodology involving empiric analysis that provides coherence and viability for our study, but also quantitative methods, including factor analysis, panel fully modified least squares (FMOLS), unit root tests, and cointegration techniques.

Results We find that renewable energy consumption and institutional quality can improve life expectancy in EU countries. Furthermore, the empirical evidence indicates that sustaining longevity as a new government strategy requires strong institutional quality, capable of influencing the status of renewable energy and promoting long-term sustainability.

Conclusions Our findings bear essential policy implications regarding sustaining longevity as new government strategies and exploring the scale of the target to increase healthy life expectancy. The entire EU health policy and the government's recommitment to narrowing the gap in healthy life expectancy should be focused on improving institutional quality and reducing carbon emissions through promoting projects capable of increasing renewable energy consumption. The results suggest that, on average, a 1% change in renewable energy consumption leads to a 0.331 change in life expectancy, and a 1% change in institutional quality leads to a 0.316 change in life expectancy.

Keywords Renewable energy consumption, Global warming, Life expectancy, Climate change

Background

The holistic perspective on the intricate interplay between renewable energy adoption and life expectancy is administering changes for the global economy, accentuating the need to understand environmental challenges and promote strategies to develop inclusive policies for maximizing positive health impacts across populations.

*Correspondence:
Anca-Florentina Vatamanu
anca.vatamanu@uaic.ro
[1] Department of Finance, Money and Public Administration, Alexandru Ioan Cuza University, Iasi, Romania

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The effect of renewable energy consumption on human life expectancy has been investigated empirically only recently and is still subject to debate. The European Green Deal commits European member countries to a clean and circular economy. It lays out a roadmap for Europe's transition to a clean and circular economy through resource efficiency, restoration of degraded ecosystems, and pollution reduction in all forms. According to the European Commission, the European Green Deal aims to eliminate net greenhouse gas emissions by 2050, decoupling economic growth from resource use and avoiding environmental pressure, leaving no person or place behind. However, life expectancy represents an essential measure of health quality, and according to literature, the average expected life span of a population is affected by various factors, including socio-economic, environmental, and political [1].

In empirical studies, most authors investigating renewable energy consumption in Europe and other economies have focused on the relationship between energy consumption and economic growth. For example, Yazdi and Shakouri [2] find that economic growth is favourable for the development of the renewable energy sector, and similar to this point of view Lin and Moubarak [3], validate the existence of a bi-directional long-term causality between renewable energy consumption and economic growth on the profile of China. The evidence in the literature [4–7] on the profile of the EU countries reports similar results and suggests the causality between renewable energy consumption and economic growth. Concerning the relationship between energy prices, economic growth, and renewable energy consumption in Europe, Li and Leung [8] find the existence of long-term causality for all three indicators. Mele et al. [9] investigate whether increasing renewable energy production benefits the Brazilian economy. They discovered that increasing the use of renewable energy may help to maintain the economic recovery and produce a faster GDP than other energy-related variables. Other authors [10, 11] reveal that regional development policy should consider renewable energy solutions and that a green economy's transition process and core process are related to renewable energy status and low carbon levels.

However, a few studies can provide information about the relationship between renewable energy consumption, institutional quality, and life expectancy [12–17].

The preservation of the environment demonstrates particular care for the future and the next generation's well-being. Similarly, people's values correspond with their life expectancy, and if they anticipate living longer, they should be ready to invest more in environmental quality. Rahman and Sultana [18] reveal that energy security is essential for economic sustainability in many ways, and related to this point of view, Uzar [19] demonstrates that the political economy of renewable energy is very important and institutional quality makes a difference in renewable energy consumption, positively affecting renewable energy consumption in the long run. According to Sodhi and Adem [20], renewable energy raises life expectancy by lowering CO2 emissions while boosting GDP per capita, technology level, and urbanization on the profile of emerging market economies.

Environmental pollution increases the risk to human health, and polluted air from fossil fuels can affect life expectancy by reducing life expectancy by 2–5 years worldwide. In addition, on the profile of the Europeans, it is found that, on average, they are exposed to 27 percent less particulate pollution than they were two decades ago, gaining 4 months of life expectancy because of it. [21]. According to other researchers, renewable energy consumption positively affects the environment and human health [22–24].

This paper assesses the implication of renewable energy and institutional quality on life expectancy at birth in the EU countries. To this end, panel data from 27 European countries for the periods 2000 and 2020 is used. The methodological background includes quantitative approaches, such as panel fully modified least squares (FMOLS), unit root tests, cointegration procedures, and qualitative sequential methodology, such as empiric analysis, thus assuring coherence and feasibility for our work. This paper has several contributions to the existing literature. First, to the best of our knowledge, this study is among the first to assess and examine how improving institutional quality and funding for renewable energy projects might enhance the quality of life in EU nations. The literature generally covers aspects related to the quality of institutions and economic growth or the renewable energy and economic growth nexus. Second, given that the economic literature loses sight of the implications of institutional variables in testing the relationship between global warming and well-being, we reduce the controversy over the contributing elements and provide additional findings for the variables that determine life expectancy in EU countries. Third, the study reveals a new type of adaptability of the existing theories or methods in the context of EU countries and significantly contributes to policy and practice in global warming, climate change, and human health.

Overall, our results highlight the importance of socio-economic, environmental, and political factors in achieving human well-being and reveal that institutional quality and health outcomes are directly linked. When we talk about an efficient legal framework, a stable macroeconomic environment, and efficient institutions overall, we can agree that these can be associated with improved health outcomes. In addition to the already documented asymmetric effect of renewable energy consumption on the environment, we lay out that strong institutions can impact the status of sustainability. These findings are relevant for policymakers and global health organizations interested in analyzing and seeing energy consumption as an essential part of people's daily lives and as a backbone of economic development and human well-being. The rest of this paper is organized as follows: Sect. "Review of the literature" presents the retrospective of the literature; in Sect. "Methods", we describe the sample, data, and the methodology we employ; in Sect. "Discussion", we present the empirical results; and in Sect. "Conclusions", we discuss the empirical findings, and then we conclude.

Review of the literature

The nexus between access to clean energy and public health

As nations battle climate change's effects and the need for sustainable development, the confluence of renewable energy and life expectancy is an intriguing research topic. Recent literature is scarce in analyzing the relationship between health outcomes, institutional quality, and renewable energy consumption. According to the World Health Organization (WHO), air pollution has a devastating impact on human health, and even low concentrations of air pollution inflict damage on health. Indeed, the crisis caused by the COVID-19 pandemic amplified the fears about climate change and revealed the importance of increasing sustainability and environmental protection, emphasizing energy efficiency and renewable energy sources. Developing an appropriate renewable energy system is linked to increased access to electricity and clean energy, boosting healthcare improvements and economic opportunities. Several studies explore the connections between access to renewable energy and human health. They cover a wide range of topics, from reducing air pollution to the impact of improvements in energy access on health services and quality of life in communities. Fowler et al. [15] reveal that air pollution has consistently been recognized as a threat to human health. The transition to renewable energy can directly and indirectly influence human health, emphasizing air pollution reduction and quality of life benefits. Neira et al. [17] examine how access to clean energy, including renewable energy, can impact human health and well-being, highlighting the connections between the environment and health and recognizing that health needs to support and help define climate change mitigation policies. Xing et al. [16] analyze the energy consumption and pollutant emission implications on disparity and public health in 33 countries with high GDP and fossil energy consumption and argue that while total fossil energy can power economic growth, technological advancements, and improve life standards, the associated pollution and contribution to climate change pose significant risks to human health, especially in low- and middle-income countries. Related to this point of view, Magazzino [25] examines the relationship between ecological footprint, electricity consumption, and GDP in China and finds that the increase in electricity consumption and real GDP tends to worsen environmental degradation. In contrast, trade and urbanization tend to mitigate ecological footprint, improving environmental quality. Two recent studies explore the relationship between renewable energy and human health and find that contemporary public agendas should call for integrating health policy and renewable energy policy so that renewable energy generates more significant health benefits [13, 14]. The importance of green energy is also highlighted in some recent studies, which demonstrate that environmental degradation leads to elevated temperatures and increased rainfall, consequently amplifying the economic burden on welfare and revealing that long-term sustainable goals hinge on the development of green transportation, renewable energy sources, and investment in research and development [26, 27].

Access to renewable energy can affect human health through several channels. First, renewable energy sources, such as solar and wind energy, improve air quality and reduce the negative impact on the respiratory health of the population because their functionality does not produce polluting emissions [28]. Second, renewable energy consumption contributes to reducing greenhouse gas emissions, thus mitigating climatic changes and positively impacting health. In EU countries, it has been revealed that renewable energy consumption contributes around 1/2 less per unit of energy consumed than fossil energy consumption in terms of GHG (greenhouse gas) emissions [29]. Third, diversifying energy sources and reducing energy consumption from traditional sources, such as fossil fuels, can reduce air pollution and the risk of respiratory diseases. Overall, renewable energy adoption can help societies achieve sustainability goals while benefiting the environment and human health [30].

Environmental stressors and institutional quality

Implementing viable renewable energy projects and increasing renewable energy consumption can reduce the impacts of pollution on the ecosystem and biodiversity, reduce environmental hazards, and improve life expectancy. Governments and policymakers play a pivotal role in shaping energy policies, and only strong institutional quality dictates the path to health outcomes. It is well known that air and water pollution, soil deterioration, and depletion of natural resources directly affect health status, increasing mortality and reducing longevity [31, 32]. However, even if numerous studies analyze the relationship between the quality of institutions and economic growth [33–36], the current literature loses sight of the relationship between institutional quality, life expectancy, and renewable energy consumption. Alexiou et al. [37] analyze the relationship between economic growth and the quality of institutions in 27 post-socialist economies and find strong links between the quality of institutions and economic growth. Related to this, Abaidoo and Agyapong [38] find that among economies in Sub-Saharan Africa, financial development fosters economic growth if there are "good" institutions. Nugroho et al. [39] analyze institutions as the main determinant of economic growth and document similar findings, revealing that low-quality institutions negatively impact the economy. Other scholars reveal that effective governance and policies on resource rents can enhance inclusive growth and improve Human Development Index (HDI) outcomes. The path to achieving a circular economy necessitates the comprehensive development of models for managing emissions [40, 41].

In their study, Ojekemi et al. [12] investigated how renewable energy consumption, economic risk, and financial risk collectively impact the load capacity factor (LF) across BRICS nations. The findings underscore the importance of policymakers in promoting investments in eco-friendly technologies and ensuring economic and financial stability. This approach is crucial for enhancing energy efficiency and fostering the widespread adoption and utilization of energy-saving products.

Energy policy and long-term health planning

Long-term health planning is essential in terms of strategy and financial budgeting. The transition from traditional energy to energy from renewable sources poses economic challenges and requires inclusive policies and strong institutions. The linkages between the environment and human health are complex and multifaceted. Some scholars validate the direct and indirect impacts of the environment on public health and reveal some pillars, such as air quality, climate change, biodiversity and ecosystem status, chemical exposure, or food security [42–44].

A complete framework that promotes sustainable development and contributes to societal well-being can be developed by addressing the links between energy policy and population health. The integration of health in the energy policy becomes crucial for a more sustainable future. Each energy source impacts the environment and, implicitly, human health. The sustainable development initiative strives to address climate change by adopting green innovations, renewable energy sources, and taxation measures. Energy consumption emerges as the primary source of pollution across various sectors. At the same time, carbon taxation serves to curb emissions, and innovation and environmental policies are the only instruments contributing to emission reduction over short and long timeframes [45, 46]. According to Hanif [47], fossil fuels are the main contributors to climate change, and the size of toxic emissions affects human health. Therefore, long-term health planning is essential, and the approach of green energy reduces the negative impact on health. In short, the benefits of incorporating health into energy policy can be shown by reducing the emissions of toxic substances into the environment, reducing respiratory diseases, and mitigating climate change, which directly impacts population health.

Methods

Data

Better public health is reflected in higher life expectancy that is essential for a country's overall development. However, several socioeconomic, environmental, and political factors can impact life expectancy. A thorough empirical investigation of the variables determining life expectancy is still required to reduce the controversy over the contributing elements. In this study, we evaluate the effects of using renewable energy on extending human life expectancy and look at how institutional quality and funding for renewable energy projects may promote human life. We use panel data from 27 European Union (EU) countries. Our data set covers the 2000–2020 period, and the sources are World Development Indicators [48] and Energy Information. The current study's methodological approach was carefully chosen to address key estimation issues, and it includes not only qualitative sequential methodology involving empiric analysis, which gives our study coherence and viability, but also quantitative techniques, such as factor analysis, panel fully modified least squares (FMOLS), unit root tests, and cointegration techniques. We use life expectancy (LIFEEXP) at birth "more broadly health," as Shaw et al. [49] point out, as a proxy of the population's health (see Table 1). Five elements comprise the overall Institutional Quality Index (IQINDEX), which is computed based on factor analysis and represents several facets of institutional performance and governance: voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, control of corruption.

Since it reduces reliance on fuel imported from other countries and reduces emissions from sources that utilize fossil fuels, renewable energy sources are seen as a significant element of energy strategy. As a result, renewable energy sources help to mitigate the adverse health effects

Table 1 Definition of variables used in the analysis

Name	Code	Source	Definition
	Variables employed in the regression analysis		
Life expectancy at birth, total (years)	LIFEEXP	World Bank [48] Database	Indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life
Renewable energy consumption (% of total final energy consumption)	RECTEC	Sustainable Energy for All-World Bank Data	Represent the percentage of final consumption of energy that is derived from renewable resources. (%)
Institutional quality index	IQINDEX	World Bank [48] Database	Represent the results of the factor analysis method, which was computed using Stata software and indicates the dimension of institutional quality and governance
Name	**Code**	**Source**	**Definition**
	Variables employed in the factor analysis		
Control of Corruption	CCOR	World Bank [48] Database	It represents the interface of the efforts supported at the institutional, societal and individual level to combat corruption, an essential element for ensuring justice, sustainable economic development and strengthening the rule of law
Government Effectiveness	GEF	World Bank [48] Database	Captures the ability of a public administration to fulfil its objectives effectively, economically, and responsibly, including public services effectiveness, public policy effectiveness, and administrative capacity
Political Stability and Absence of Violence/Terrorism:	PSAV	World Bank [48] Database	Measures the capacity of the government to assure the overall well-being and development of a country, by avoiding instability and violence
Regulatory Quality	RQ	World Bank[48] Database	It measures citizens' perception of the adopted normative acts and regulations, as well as the government's ability to provide a favorable legal framework for the development of the private sector
Voice and Accountability	VA	World Bank [48] Database	It refers to the level to which citizens and stakeholders can express themselves, engage in decision-making processes, and hold government officials accountable for their actions
Rule of Law	RL	World Bank [48] Database	Captures perceptions of how much agents trust and follow social norms, particularly those pertaining to the strength of property rights, the police, the courts, and contract enforcement, as well as the likelihood of crime and violence

of pollutant releases into the atmosphere. Therefore, another variable included in the analysis is the share of energy from renewable sources in total final energy consumption (RENWENC). One of the most critical contributing factors to human capital is health, and population health is a significant economic problem for many emerging nations [50]. Moreover, according to the literature, air pollution is devastating to population health, and energy generation from fuel causes air pollution and increases CO2 emissions, deteriorating environmental quality [51, 52]. As a result, the objective of providing empirical findings support for improved health using renewable energy is pertinent and has a clear, decisive relevance to the boarding literature.

The minimum value in terms of life expectancy was recorded in Estonia in 2001, with a life expectancy of 70.25847 years; in 2000, Latvia was placed in second place, with a life expectancy at birth of 70.31463. The maximum value in terms of life expectancy is found on the profile of Spain, where life expectancy was 83.485357 years in 2020. Spain remains at the top of the countries with the highest life expectancy at birth (83.48536585 in 2019 and 83.43171), along with Italy, which also had similar values in 2018 and 2017 (83.34634 and 83.2439 years).

Regarding renewable energy consumption (% of total final energy consumption), Malta recorded the lowest value of 0.0872% in 2002, and the highest value is found on the profile of Sweden with 52.8915% in 2015. Sweden leads among EU countries, with over 50% of its gross final energy consumption in 2020 derived from renewable sources. Regarding the index of institutional quality (IQINDEX), an indicator that includes different dimensions of institutional quality and governance (voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, control of corruption), Finland recorded the highest value in 2004 (2.008531) and Bulgaria the lowest value in 2014 (-2.010954), the trend being followed by Greece and Romania.

Furthermore, we used the variance inflation factors test (VIF) to avoid multicollinearity issues. We obtained 3.13, less than the threshold (4), validating no multicollinearity among the variables included in the analysis.

Empirical strategy

This study explores the impact of renewable energy consumption on human life expectancy and investigates how institutional quality and investments in renewable energy projects may positively influence human life. To address estimation challenges, we employ a well-thought-out empirical strategy that incorporates both qualitative and quantitative methodologies, ensuring coherence and viability for our investigation, and quantitative methods, such as factor analysis, panel fully modified least squares (FMOLS), unit root tests, and cointegration techniques.

Panel unit root tests—methodology

Macroeconomic variables are typically non-stationary, which can impact the econometric analysis of time series and panels, since non-stationary variables can produce biased results. The first-difference transformation can solve this issue if the model's variables are non-stationary. The stationarity of the various series was investigated using a variety of unit root tests as the first step of the empirical research. The entire empirical strategy is based on the econometric framework developed in one of our previous works [53]. Following prior studies, we find two fundamental types of panel unit root testing. The first one, categorized as first-generation, includes the Levin-Lin-Chu test-LLC [54], Im-Pesaran and Shin test-IPS [49], and Fisher-type tests, with the assumption of cross-sectional independence serving as a specific limit. The second generation of unit root tests has been offered that rejects the cross-sectional independence hypothesis, represents the extension of the standard ADF unit root test (Augmented Dickey-Fuller), and can be represented by the equation below:

$$\Delta_{yt} = \rho y_{t-1} + \sum\nolimits_{P=1}^{P} \phi_P \Delta Y_{t-P} \gamma_l' D_l + \varepsilon_t, t = 1, \cdots, T \quad (1)$$

The Augmented Dickey-Fuller tests are based on two hypotheses. The null hypothesis that yt has the unit root and the series is non-stationary. The alternative hypothesis states that no unit root exists in the time series and yt is stationary ($H_0 : \rho$=0 against $H_1 : \rho$<0). The Augmented Dickey-Fuller test is performed for the panel case using the following equation:

$$\Delta_{yi,t} = \rho_i y_{i,t-1} + \sum_{p=1}^{P_i} \phi_{ip} \Delta_{y_{i,t-p}} + \gamma_{li}' D_{li} + \varepsilon_{i,t}, t = 1, \ldots, T, \mathrm{i} = 1, \ldots, \mathrm{N} \quad (2)$$

Equation 2 extends on the preceding equation by assuming that the errors $\varepsilon_{i,t} \sim N(0, \sigma^2)$ are assumed to be independent across the individuals. The Levin-Lin-Chu test assumes the null $H_0 : \rho_i = \rho = 0\ \forall_i$ against the alternative $H_1 : \rho_i < 0\ \forall_i$. In contrast to the LLC test, the Im-Pesaran and Shin test-IPS [55], in contrast to LLC test, admits the likelihood of changing autoregressive processes between individuals and is stated by the following equation:

$$\bar{t}NT = N^{-1} \sum_{i=1}^{N} t_{iT} \left(P_i, \phi_{i1}, \cdots, \phi_i P_i\right) \quad (3)$$

In this case, $t_{iT}\ (P_i, \phi_{i1}, \ldots, \phi_i P_i)$ is the t-statistic for determining the unit root in the ith individual process. P_i denotes the lag order, which is usually chosen based on some information criterion and $\bar{t}NT$ is used to test the null hypothesis $H_0 : \rho_i = \rho = 0\ \forall_i$, against the alternative $H_1 : \exists i \in \{1,\ldots,\mathrm{N}\}, \rho_i < 0$.

With regard to second-generation unit root tests, we conform to the cross-sectional Im-Pesaran-Shin test's premise (CIPS), proposed by Pesaran [56], which in addition to standard ADF, includes lagged cross-sectional averages of individuals $\bar{y}_t$ and is performed by running the following equation:

$$\Delta_{Yi,t} = \rho_i Y_{i,t-1} + \varphi_i \overline{Y}_{t-1} + \varphi i \Delta \overline{Y}_t \cdots + \gamma_{l_{i'}} D_{li} + \varepsilon_{\ i,t}, \ldots, T, i = 1, \ldots, N \quad (4)$$

The cross-sectional Im-Pesaran-Shin statistic is determined as group mean of t statistics derived from cross-sectional augmented Dickey-Fuller equations, as shown in Eq. 3.

Cointegration analysis—methodology

To explore the relationship between life expectancy, renewable energy consumption, and institutional quality in EU countries and to validate the presence of a long-term link between the variables, we follow the literature and conduct cointegration tests [56–64]. Compared to panel unit root tests, panel cointegration tests are more efficient and robust than standard time series cointegration tests. As a first step, we follow cointegration testing and Granger causality testing. Second, we develop a clear modelling strategy using Fully Modifies Least Square (FMOLS) estimation methods in the presence of cointegration [65, 66]. According to the literature, the Granger causality test is a valuable tool for discovering dynamic interrelationships between two groups of variables, being allowed for institutional-level estimation [67, 68].

The panel cointegration tests of Pedroni [69] are given by Eq. 3:

$$y_{i,t} = \beta_i' x_{i,t} + \gamma_{li}' D_{li} + \varepsilon_{i,t}, Where x_{i,t} = x_{i,t-1} + \varepsilon_{i,t} \quad (5)$$

Fully modified least square (FMOLS) —methodology

The fully modified least square (FMOLS) proposed by Pedroni [62] represents a measurement tool used to provide optimal estimates of cointegrating regressions, and it is indeed an appropriate instrument to explore the long-run relationship between life expectancy, renewable energy consumption, and institutional quality. FMOLS is superior to OLS (ordinary least squares), because it allows serial correlation, the existence of endogeneity, and cross-sectional heterogeneity. Moreover, the method takes care of small sample bias and endogeneity bias by taking the leads and lags of the first difference regressors. To account for the serial correlation effects and endogeneity that occur from the presence of a cointegrating link, the method modifies least squares [70]. The model has the following specifications:

$$\mathrm{X}_t = \hat{\Gamma}_{2'1} D_{1t} + \hat{\Gamma}_{2'1} D_{1t} + \hat{\varepsilon}_t \quad (6)$$

If we consider the implication of difference regression, the model can be described as follows:

$$\Delta \mathrm{X}_t = \hat{\Gamma}_{2'1} \Delta D_{1t} + \hat{\Gamma}_{2'1} \Delta D_{1t} + \hat{\upsilon}_t \quad (7)$$

In addition, if we consider $\widehat{\Omega}$ and $\widehat{\Lambda}$ to be the long-run covariance matrices computed using the residuals $\hat{\upsilon}_t = \left(\hat{\upsilon}_{t1}, \hat{\upsilon}2_t\prime\right)\prime$, then the model can be described as follows:

$$y_t^* = y_t - \hat{\omega}_{12}\, \hat{\Omega}_{22}^{-1}\, \hat{\upsilon}_{\,2} \quad (8)$$

An estimated bias correction term:

$$\lambda_{12}^* = \lambda_{12} - \overline{\omega}_{12}\, \hat{\Omega}_{22}^{-1}\, \hat{\Lambda}_{\,22} \quad (9)$$

The FMOLS is described by the following equation:

$$\hat{\theta} = \begin{bmatrix} \hat{\beta} \\ \hat{\gamma}_1 \end{bmatrix} = (\sum\nolimits_{t=1}^{T} Z_t Z_t\prime)^{-1} (\sum\nolimits_{t=1}^{T} Z_t Y_t^* - 1 \begin{bmatrix} \hat{\hat{\gamma}}_{12}^{*\,\prime} \\ 0 \end{bmatrix}) \quad (10)$$

in which case $Z_t = (X_t\prime, D_t\prime)'$. In other words, the implication of FMOLS estimation is to construct long-run estimators$\overline{\Omega}$ and $\hat{\Lambda}$ The scalar estimator can be defined as: $\hat{\omega}_{\,1.2} = \hat{\omega}_{11} - \hat{\omega}_{12}\, \hat{\Omega}_{22}^{-1} \hat{\omega}_{21}$ which may be defined as the estimated long-run variance of υ_{1t} conditional on υ_{2t}.

Factor analysis-methodology

The institutional quality (IQINDEX) was calculated using factor analysis methods. Five elements comprise the overall Institutional Quality Index (IQINDEX), each of them representing the facets of institutional performance and governance: voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, and control of corruption. The method finds a few common factors (say, q of them) that linearly reconstruct the p original variables:

$$y_{ij} = Z_{i1} \mathrm{b}_{1j} + Z_{i2} \mathrm{b}_{2j} + Z_{i3} \mathrm{b}_{3j} + \ldots Z_{iq} \mathrm{b}_{qj} + e_{ij}, \quad (11)$$

where y_{ij} denotes the value of the ith observation of the jth variable, $\mathcal{Z}_{ik}$ reflects the i th observation on the k th common factor, b_{qj} represents the set of linear coefficients named the factor loading, and finally, e_{ij} indicates the j th variables unique factor.

Empirical results

Tables 2, 3, and 4 summarize the results of estimating the unit root test, a methodology that becomes primordial in achieving viable results and avoiding spurious results. According to some scholars, applying unit root tests and verifying the stationarity of data represents the first step in examining and revealing the long-run dynamics between the variables [71, 72]. Following Al-Mulali [59]'s point of view, when the ADF test is run, it is necessary to check both versions: intercept only and intercept and trend. Therefore, the benchmark results listed in Tables 3, 4, and 5 show the output estimation for unit root tests, applied in level and the first difference with intercept, in intercept and trend, or none of them independently included in the equation.

For statistical analysis, this work employs econometric tests, such as unit root tests (ADF, Levin, Lin & Chu, Im, Pesaran and Shin, PP-Fisher Chi-square) and the Pedroni test of panel cointegration. According to literature insights, when we apply the ADF test, it is necessary to check both ADF versions with intercept only and intercept and trend. Tables 3, 4, and 5 reveal the results of ADF, LLC, IPS, and CIPS panel unit root tests for life expectancy, renewable energy consumption, institutional

Table 2 Summary of data set employed in the regression analysis

Variable	Obs	Mean	Std. Dev	Min	Max
LIFEEXP	567	76.25847	3.272649	70.25854	83.48537
RNWENC	511	16.92711	11.77205	0.0872	52.8915
IQINDEX	567	0.0004885	1.002802	−2.010954	2.008531

Table 3 Unit root test of life expectancy variable (LIFEEXP)

	Level			1st difference		
	Intercept	**Intercept & Trend**	**None**	**Intercept**	**Intercept & Trend**	**None**
Levin, Lin & Chu	−7.18728 (0.0000)	6.41880 (1.0000)	14.8604 (1.0000)	−4.10875 (0.0000)	−4.72873 (0.0001)	−6.57573 (0.0000)
Im, Pesaran and Shin	−3.26936 (0.0005)	7.11702 (1.0000)	–	−7.94200 (0.0000)	−7.93466 0.0000	–
ADF-Fisher Chi-square	92.5528 (0.0003)	12.4977 (1.0000)	12.1345 (1.0000)	186.706 (0.0000)	174.520 (0.0000)	140.484 (0.0000)
PP-Fisher Chi-square	85.3337 (0.0042)	95.7927 (0.0004)	1.77869 (1.0000)	471.306 (0.0000)	366.952 (0.0000)	320.388 (0.0000)

Null hypothesis: unit root (individual unit root process). Probabilities are given between parentheses

Table 4 Unit root test of renewable energy consumption (RNWENC)

	Level			1st difference		
	Intercept	**Intercept & Trend**	**None**	**Intercept**	**Intercept & Trend**	**None**
Levin, Lin & Chu	−3.97396 (0.0000)	6.52399 (1.0000)	4.93215 (1.0000)	−11.9829 (0.0000)	−8.78965 (0.0000)	−15.4088 (0.0000)
Im, Pesaran and Shin	4.84243 (1.0000)	−1.91503 (0.0257)	–	−7.27298 (0.0000)	−3.30316 0.0005	–
ADF-Fisher Chi-square	35.7684 (0.9736)	69.1038 (0.0809)	10.6706 (1.0000)	254.131 (0.0000)	173.380 (0.0000)	270.602 (0.0000)
PP-Fisher Chi-square	16.5088 (1.0000)	49.5391 (0.6469)	6.78244 (1.0000)	281.480 (0.0000)	208.357(0.0000)	320.137 (0.0000)

Null hypothesis: unit root (individual unit root process). Probabilities are given between parentheses

Table 5 Unit root test of institutional quality index (INQINDEX)

	Level			1st difference		
	Intercept	**Intercept & Trend**	**None**	**Intercept**	**Intercept & Trend**	**None**
Levin, Lin & Chu	−4.90948 (0.0000)	9.17857 (1.0000)	−3.12968 (0.0009)	−26.9062 (0.0000)	−4.26704 (0.0000)	−38.1514 (0.0000)
Im, Pesaran and Shin	−5.36226 (0.0000)	−3.32981 (0.0004)	–	−23.2717 (0.0000)	−15.1943 0.0000	-
ADF-Fisher Chi-square	268.629 (0.0000)	94.0393 (0.0006)	79.1620 (0.0145)	841.040 (0.0000)	239.261 (0.0000)	450.206(0.0000)
PP-Fisher Chi-square	361.007 (0.0000)	253.278 (0.0000)	77.0331 (0.0215)	834.862 (0.0000)	279.435 (0.0000)	480.344 (0.0000)

Null hypothesis: unit root (individual unit root process). Probabilities are given between parentheses

quality levels, and first differences, considering both versions of ADF specification. The empirical analysis suggests the retrospective of mixed results at the level order, but when we apply the first differences, the panels are stationary. The unit root test of the life expectancy variable (LIFEEXP) reveals that at the first level, we have mixed results, but when we apply the first difference, the null hypothesis could be rejected. The results indicate that all the panels are stationary. For renewable energy consumption (RNWENC) and institutional quality index (INQINDEX), the results are similar, Levin, Lin & Chu t, Im, Pesaran and Shin, ADF-Fisher Chi-square and PP-Fisher Chi-square revealing some implication of non-stationarity in levels and stationarity in 1st difference. The literature points out that it can be possible for some variables to be non-stationary at level but become stationary in the first difference [73–75]. After determining that the variables are stationary, we perform panel cointegration tests and focus on empirical analysis of the relationship between life expectancy, renewable energy consumption, and institutional quality. Table 6 reports the results of panel cointegration tests.

For panel cointegration tests within-dimension and between-dimension, when an intercept is included, the results presented in Table 5 reveal that five statistics significantly reject the null hypothesis of no cointegration, except panel rho-Statistic. We obtain similar results for panel cointegration tests within-dimension and between-dimension when intercept and trend are included, except for Panel ADF-Statistic. Overall, most of the statistical tests reveal that the null hypothesis of no cointegration is rejected, and a cointegration relationship between life expectancy, renewable energy consumption, and institutional quality is empirically proved. The analyzed variables move together in the long run so that we can state a long-run relationship between life expectancy, renewable energy consumption, and institutional quality for all EU countries. Renewable energy sources overcome the

Table 6 Panel cointegration tests

Dimension	Test Statistics	Intercept		Intercept and trend	
		Statistic	Prob	Statistic	Prob
Within-dimension	Panel v-Statistic	2.6498	0.0040	14.3174	0.0000
	Panel rho-Statistic	−1.1245	0.1304	−0.0107	0.4957
	Panel PP-Statistic	−3.8996	0.0000	−3.0364	0.0012
	Panel ADF-Statistic	−3.9659	0.0000	−3.0376	0.0012
Between-dimension	Panel rho-Statistic	0.2796	0.6101	1.8575	0.9684
	Panel PP-Statistic	−4.7094	0.0000	−4.9573	0.0000
	Panel ADF-Statistic	−4.8185	0.0000	−1.2693	0.1022
Kao residual cointegration test					
ADF	t-Statistic		Prob		
	−1.6126		0.0053		

Null hypothesis: no cointegration. Trend assumption: no deterministic trend and Deterministic intercept and trend. Probabilities are given *between* parentheses

Table 7 Estimation of cointegrating relationship

Variable	Estimation Method	FMOLS			
		Pooled		Grouped	
		Coefficient	Prob	Coefficient	Prob
RNWENC	Long-run coefficient	0.2957	0.0000	0.3310	0.0000
INQINDEX		0.2330	0.0750	0.3160	0.0086
	No. of observations	486			
	R-squared adj	0.9061			

Dynamic FMOLS; panel fully modified least squares

pressure on the environment and contribute to environmental sustainability. At the same time, producing electricity or thermal energy does not release greenhouse gases, which contribute to global warming. In this way, natural resources are used in a way that does not affect the planet and public health. Energy vulnerability and the specifics of climate change also depend on the awareness of a future based on energy from renewable sources, and the abandonment of fossil fuels also depends on the institutional specifics that, through promoted policies, can accelerate the transition to green energy and sustainable development. In addition, adequate institutional configuration and solid strategies related to increased energy independence and lower carbon emissions help human health and increase life expectancy. Table 7 reveals the estimation of the cointegrating relationship between life expectancy, renewable energy consumption, and institutional quality.

The estimation results of a positive relationship between life expectancy, renewable energy consumption, and institutional quality are given in Table 7. Using the FMOLS estimator, we test the consistency of the results and validate that both renewable energy consumption and institutional quality can improve life expectancy in EU countries. The results suggest that, on average, a 1% change in renewable energy consumption leads to a 0.331 shift in life expectancy, and a 1% change in institutional quality leads to a 0.316 shift in life expectancy.

Discussion

In the face of accelerating climate change and mounting concerns over air pollution, the global imperative to transition towards renewable energy sources has never been more urgent. While this transition's primary focus is often on mitigating greenhouse gas emissions, it is imperative to recognize the broader spectrum of benefits that such a shift entails. Beyond combating climate change, the transition to renewable energy holds the potential to significantly reduce pollutants emitted from fossil fuels, thereby improving public health and extending life expectancy. Using renewable energy sources ensures access to health and economic development and impacts life expectancy. As a result, policymakers should support the use of green energy not only as a pillar of climate goals but also as an engine for health growth. The existence of a long-term relationship between life expectancy, renewable energy consumption, and institutional quality reveals the necessity to approach public reforms and develop policy mechanisms capable of improving the quality of institutions and increasing renewable energy consumption in EU countries. Our results are consistent with the results obtained by Ullah et al. [22, 23], which reveal that renewable energy consumption positively affects the environment and human health, but also with those obtained by Liu and Zhong [24], that indicates that to achieve the goals of sustainable development and improve human well-being, the government should support the consumption and production of renewable energy. Previous research supports the evidence that renewable energy offers a paradigm shift in global energy production, providing not only environmental sustainability but also significant health advantages that may improve life [13–15].

EU actions in the energy and climate change field focus on the need for interstate collaboration and identifying alternatives to replace energy sources based on fossil fuels. The concept of sustainability is based on three pillars: economic, social, and environmental. Therefore, increasing the use of energy from renewable sources is crucial to lowering the EU's greenhouse gas emissions as well as its reliance on fossil fuels and energy imports. This will improve the EU's energy security while strengthening sustainability. In addition, a strategy that aims to increase the share of renewable energy in the final gross energy consumption will facilitate the sustainable development of the energy sector and the national economy, all for the benefit of the final consumer. Undoubtedly, the transition to sustainable economic growth and renewable energy involves the direct support of governments through policies and regulations, but also research and development activities to reduce the costs of new green energy sources, such as clean hydrogen, and all three pillars of sustainability are intercorrelated with the environmental life cycle cost [76]. Societies may improve the health and well-being of the present population while simultaneously protecting the earth for future generations by adopting renewable energy sources and moving away from fossil fuels. It is critical that we give policies and investments top priority as we get closer to a future powered entirely by renewable energy sources to optimize these co-benefits and guarantee a fair transition for all.

Conclusions

Renewable energy plays a critical role in reducing greenhouse gas emissions and addressing climate change. Achieving this requires a robust and politically responsible institutional framework to ensure energy security and long-term sustainability. The functionality of government institutions and the management of public powers are pivotal in shaping sustainable development and the successful implementation of environmental policies, particularly those related to renewable energy. Therefore, prioritizing institutional quality is essential for sustaining longevity as a new government strategy. Strong institutions have the power to influence the status of renewable energy and foster long-term sustainability goals. In this paper, we assess the implication of renewable energy and institutional quality on life expectancy at birth in the EU countries. To this end, panel data from 27 European countries for the periods 2000 and 2020 is used. The methodological background includes quantitative approaches, such as panel fully modified least squares (FMOLS), unit root tests, and cointegration procedures, as well as qualitative sequential methodology, such as empiric analysis, thus assuring coherence and feasibility for our work. We find compelling evidence that the use of renewable energy, institutional quality, and life expectancy at birth are all positively correlated among the EU countries.

The results for unit root tests (ADF, Levin, Lin & Chu, Im, Pesaran and Shin, PP-Fisher Chi-square) and the Pedroni test of panel cointegration reveal that the panels are stationary. In addition, the panel cointegration tests reveal that the null hypothesis of no cointegration is rejected, and a cointegration relationship between life expectancy, renewable energy consumption, and institutional quality is empirically proved. The analyzed variables move together in the long run, so we may conclude that there is a long-run relationship between life expectancy, renewable energy consumption, and institutional quality in EU countries. The findings regarding the FMOLS estimator validate the consistency of the results and prove that both renewable energy consumption and institutional quality can improve life expectancy in EU countries. We found that, on average, a 1% change in renewable energy consumption leads to a 0.331 shift in life expectancy, and a 1% change in institutional quality leads to a 0.316 shift in life expectancy.

Our findings bear important policy implications regarding sustaining longevity as new government strategies and exploring the scale of the target to increase healthy life expectancy. The entire EU health policy and the government's recommitment to narrowing the gap in healthy life expectancy should be focused on improving institutional quality and reducing carbon emissions through promoting projects capable of increasing renewable energy consumption. In addition, the empirical analysis shows that governments should raise public awareness about the essential transition to renewable-energy economies and develop public strategies capable of promoting the transition process to develop knowledge and attitudes toward the dynamic process of climate change and sustainable development. Promoting sustainability through renewable energy innovation in Europe is imperative. This encompasses incentivizing renewable energy adoption, financing research into renewable energy, and providing subsidies or implementing taxes to support eco-friendly modes of living. This effort also involves backing initiatives on government system efficiency, alternative fuels, and green energy. Furthermore, innovating and expanding renewable energy sources can drive better human health. Similar to any research, this study possesses certain limitations. Conclusions derived from this investigation should not be extrapolated to apply universally to countries in diverse regions. Therefore, it is possible to expand the analysis to explore the impact of renewable energy consumption on human life expectancy, along with investigating how institutional quality and investment in renewable energy projects could enhance health outcomes in different countries. In addition, the timeframe of the analysis should be prolonged to encompass additional economic and social factors that influence life expectancy, including economic growth status and public investment in health. Increasing the usage of renewable energy reduces greenhouse gas emissions and successfully fights global warming. However, often overlooked, the move to renewable energy also reduces the number of toxic pollutants released by burning fossil fuels, improving public health, and prolonging life expectancy. Hence, forthcoming research should concentrate on assessing the status of air pollutants and renewable energy consumption within both developing and developed countries' contexts.

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Declarations

Competing interests
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