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Dynamic prognostic interaction between social development and energy consumption optimization: Evidence from european union member countries

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A R T I C L E I N F O

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A B S T R A C T

Analyzing optimization of energy use becomes only possible when their interactions with the indicators of social development are properly estimated. The study employed the panel VAR and impulse response functions to investigate this causal interaction by analyzing panel data from 27 EU countries. The results reveal that a 1% increase in renewable energy consumption contributes to raising life expectancy, fertility and education by 2.20%, 1.27% and 2.11% respectively. However, a 1% surge in fossil fuel utilization contributes to lower life expectancy and fertility by 0.66% and 2.76% and gives rise to education by 0.33%. Reciprocally, fertility, education and research and development contribute to renewable energy utilization by 1.75%, 2.82% and 3.34% respectively whereas research and development contribute to decreasing fossil fuel combustion by 3.57%. Lastly, urbanization and internet subscriptions were found to have no statistically significant interaction with energy use, inferring that these social factors do not contribute to energy use. Therefore, this study urges policymakers to invest in the education sector and research and development to achieve sustainable socio-economic development by simultaneously optimizing energy consumption and increasing the overall share of renewable energy by diversifying its production from green energy sources (solar, wind and hydro) in the EU countries.

1. Introduction

Energy is considered a global commodity and a cornerstone of social and economic development but a statistically accurate projection is indispensable to maintain a balance between demand and supply of energy for achieving sustainable growth [1]. There lies a global consensus on diversification and the transition of energy systems related to the production and consumption of renewable and efficient energy fuels, as conventional energy sources, which are not replenishable, will deplete shortly [2]. Consequently, it will not be an option but an obligation for the following generations to use renewable energy. In this context, due to the EU's commitment to achieving sustainable socio-economic development and environmental quality, the union is putting in place the necessary regulatory frameworks to urge its members in achieving the Sustainable Development Goals (SDGs). For that reason, many European countries are guided to diversify their energy systems by increasing the share of renewable energy up to 20% by 2020 and 32% by 2030 [3]. In this context, the EU parliament has set up an '*Energy Transitions*' plan to strive for greater energy market integration and the adoption of ambitious, legally binding targets for renewable energy, energy efficiency, and greenhouse gas reductions. The EU's Clean Energy Package (presented by European Commission in 2016) convinced that it would make an essential contribution to sustainability and security of green energy supply and production and would prove to be necessary for attaining the EU's SDGs and climate goals for 2050 [4].

However, to have a better empirical understanding of patterns and optimization of energy use must be investigated and their pertinent socio-economic contributors must be identified by analyzing casual interaction between the indicators of social development and energy consumption (renewable and non-renewable separately). The empirical investigation of this reciprocal association can provide robust prognostic understanding of energy use and its production. This interaction, on one hand, can disclose how renewable and fossil fuel combustion affect

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Nomenclature

R&D	Research and development
ICT	Information communications technology
EU	European Union
DVD	Digital versatile disc
ASEAN	The Association of Southeast Asian Nations
BRICS	Brazil, Russia, India, China and South Asia
OECD	The Organization for Economic Cooperation and Development
WDI	World Development Indicators
HDI	Human Development Index
VAR	Vector autoregression
CD	Cross-sectional dependence
IRF	Inverse response function
UNPF	United Nations Population Fund
GHGs	Greenhouse gases
SDGs	Sustainable Development Goals

overall social development taking into consideration its pertinent indicators, such as health, education, information communication and technology (ICT), research and development (R&D), and urbanization. On the other hand, the existence of bidirectional causal association can also reveal how these social factors contribute to raising or lowering energy use, which can be helpful to have a better understanding of the optimization of energy having significant potential implications for energy policy design and projections, especially for the EU countries where susceptibility to social development generates relatively higher and better impacts.

2. Literature review

2.1. Energy consumption optimization

It has become a fact that households consume far more energy than those four or five decades ago. Daily showering with hot water, especially in urban localities is common rather than the restrictive periodic bathing practiced by populations of earlier periods, greatly increasing domestic energy consumption. The same generational changes have occurred with a wide range of domestic appliances [5]. Home heating and cooling systems have become common and also a plethora of kitchen appliances such as the electric toaster, mixers, juicers, sandwich makers, coffee makers, electric fry-pans, and a wide range of home entertainment facilities such as radios, DVDs, and CD players, televisions, computers and play stations, etc all of which have dramatically been taken up by households and substantially increased the 'operational energy consumption' [6].

The dwellings themselves have changed and are built using more materials, fixtures, and fittings manufactured or fabricated from elaborately transformed minerals that embody large amounts of energy [7]. As a result, households have been increasing their use of energy substantially and this growth in demand for energy is directly linked to increasing affluence. Therefore, access to renewable energy at the household and commercial/industrial levels has gotten serious attention and importance due to rampant energy demands with the growing population and production, deteriorating global environmental situation, negative implications of climate change, and detrimental health consequences of non-renewable energy consumption.

2.2. Urbanization and energy consumption

Several retrospective studies focused on a cause-and-effect association between energy consumption and urbanization. Urbanization was empirically reported to have a bidirectional causality with energy consumption in selected Asian countries [8,9]. Besides, a unidirectional relationship between urbanization and energy use was also empirically confirmed in ASEAN [10], different income level countries in the world [11], and China [12] meant urbanization accelerated residential energy demand and production of energy use in rural areas in the short run but not in the long run [13]. Whereas another study reported that urbanization reduced energy utilization in BRICS [14]. Statistical confirmation of a significant positive long-run relationship revealed that urban development accelerated energy consumption. However, to the best of our knowledge, no study focused on the empirical relationship between urbanization and renewable energy and fossil fuel combustion individually or separately.

2.3. Health and energy consumption

Moreover, only a couple of studies have empirically investigated the link between energy use and fertility rate so far. A zero-sum relationship was revealed between energy use and fertility rate [15] having $-1/3$ exponential scaling using allometric theory. This decline in fertility rate was explained by parental trade-offs-total children and energy investment in every child [16]. The second study statistically described a two-way positive causal relationship between renewable and non-renewable energy consumption and fertility rate in 16 selected EU countries [17]. The information on the varied fertility rates of the EU member countries was linked to the long-term fertility-ecological footprint nexus. The association concerning life expectancy, the studies indicated that renewable energy use contributed to increasing life expectancy in the short as well as in the long run targeting South and Southeast Asian economies. According to the study's conclusions, energy use contributes to lower life expectancy and increases new-born mortality rates. The study also discovered that high levels of environmental pollution due to energy use could contribute to an increase in the infant mortality rate and decrease the expected life span [18,19].

2.4. Education and energy consumption

The different levels and quality of education play a vital role in the production, conservation, and use of energy [20] by provoking energy-efficient behaviour of the citizens [21–23]. Some empirical studies explored that secondary education significantly enhanced renewable [24] and overall energy consumption use in the short run [25–27] and primary education lessened renewable energy utilization in Saudi Arabia [28]. Also, higher education development considerably contributed to increased energy use in Turkish Cyprus [29]. Some findings showed a bidirectional relationship between education and renewable energy expenses [30] and fossil fuels as well. Moreover, the findings supported the empirical conclusion that ICT significantly contribute to energy consumption in the short run [31]. The rate of internet access enlarges energy utilization in the short run but not in the long run.

2.5. Social development and energy consumption: a mechanism at play

Energy consumption and social development in general have strong empirical interactions. The availability of modern, safe, and affordable energy services (both at residential as well as commercial or industrial levels) and appliances improves a population's living conditions and socioeconomic prospects. In rural areas, access to energy is fundamental to getting clean fresh water, sanitation, and healthcare. Apart from that, energy offers various other benefits, such as creating employment opportunities in agriculture and commercial (particularly industries of food processing) [32], and education (allows study after sunset that attracts teachers as well) sectors [33]. On the other hand, a lack of inadequate supplies and inefficient use of energy impede social development through stagnant and inadequate education, health care, transportation, and telecommunications systems [34]. Access to energy is important, but so are quality, security, contemporary fuels, appliances, and price [35]. Thus, the plethora of studies focused on the determinants and impacts of energy consumption considering its relation to socioeconomics, environmental, geographical, and institutional or political settings.

3. Research gap

However, a dynamic interplay between social development and energy utilization and its policy implications got negligible attention, especially impacts of non-renewable energy on social development. Besides, prognostic role of selected indicators of social development has not been empirically investigated so far. A couple of studies were found discussing the only causal relationship between renewable energy consumption and social development (used as an aggregate index) in Tunisia, Henan province of China, and the OECD countries [36–38]. The prime focus of the published studies was to analyse the purely economic, technological, and environmental aspects of energy consumption whether renewable or non-renewable, the individual prognostic role of indicators of social development was overlooked and neglected. Despite this, none of the studies looked at the dynamic causal relationship between fossil fuel consumption and social development and how renewable or non-renewable energy consumption separately affect social development. Besides, we hardly find any experimental study discussing the factual relationship between ICT and R&D and energy use, particularly non-renewable energy. Also, the direction of causality between tertiary education and energy use remained yet to be determined.

Therefore, this work fills a void in the literature, the prime objective of this study is to investigate a reciprocal causal relationship between energy use and the indicators of social development in EU member nations along with potential policy implications for the stakeholders. The aforementioned motivations compels the goal of empirically analyzing the dynamic interaction between energy consumption optimization and social development in EU member countries using the latest robust econometric methods. However, it is challenging to reach an agreement on the development of policy across different countries due to the complexity of these elements brought on by varying economic structures and environmental legislation in different countries. As a result, the empirical data offered in this study can be used to help formulate policies that will optimize energy use and production and promote sustainable social development.

4. Material and methods

4.1. Data

The study uses panel data from 27 European Union member states from 1990 to 2019 acquired from the World Development Indicators database of the World Bank for empirical cross-validation. The World Bank disseminates country-wise data on annual bases, therefore, this data can be freely obtained from its official online data repository [39]. The acquired data provides comprehensive and robust country-wise information concerning energy consumption, information and communication technology (ICT), health, demography, education, research and development (R&D), and technological innovations. This study obtained data on total renewable energy consumption and fossil fuel consumption for energy use estimation, tertiary schooling for education, fertility, and life expectancy for health, internet users for ICT, the number of researchers for R&D, and lastly, the urban population for urbanization: all of these are the prominent indicators of social development. Panel data as compared to cross-sectional, and time series has more benefits regarding statistical analysis. For instance, panel data is relatively more reliable in terms of estimating parameters. Similarly, it is more informative, and efficient than time-series and cross-sectional data in the sense that it observes more variability. Heterogeneity across the individual observations can be addressed, as it can model both individual or common behaviours of various groups. Lastly, biases of estimation are minimum in panel data [40].

Fig. 1 presents the percentage of renewable and fossil fuel energy consumption across the 27 European Union countries by 2021. The map shows that Austria, Sweden, Finland and Latvia are the leading states with the highest share of renewable energy use out of total energy utilization with 65.6%, 53.2%, 43.2% and 38.09% in 2021, respectively. On the contrary, the largest economies of the EU, such as Ireland, Poland, Germany, Italy, Spain, Netherlands, Belgium, Czech Republic, and Greece, are heavily dependent on fossil fuel consumption with 85.4%, 83.2%, 75%, 79%, 73%, 77.5%, 76%, 77.7%, and 82%, sequentially. Therefore, it is a dire need for an energy production transition from non-renewable to more renewable energy generation by tapping modern energy sources to achieve zero carbon emissions by 2050.

4.2. Causality model

As aforementioned, this study seeks an empirical investigation of the cause-and-effect link between social development and energy consumption in the long run. The variables of renewable and non-renewable energy are calculated by taking their share out of total energy consumption. Since social development depends on various multidimensional indicators related to demographic, educational, and health factors, among others, it provides more measuring challenges. For that, this study consulted the Human Development Index (HDI) of the United Nations to shortlist the number of these factors. Table 1 shows the pertinent definitions of these selected indicators to measure social development as the main explanatory variable and variables of energy consumption (taking renewable and non-renewable energy separately) are used as dependent variables in the causality model. It includes

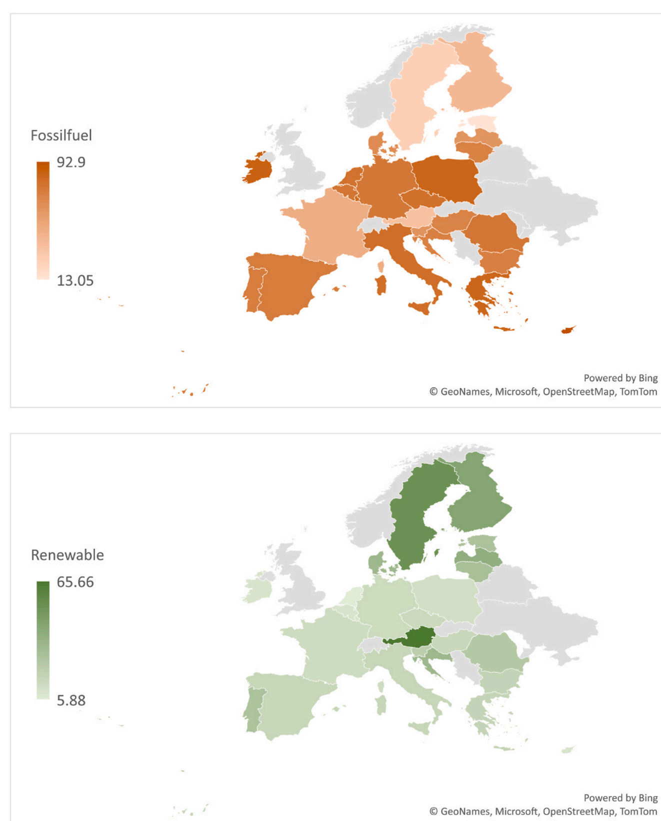

Fig. 1. Rate of renewable and non-renewable energy use in EU member states by 2021.

Table 1
Name and definition of the variables.

Social development		Variable	Definition
Indicators of social development	ICT	Internet	Individuals using the Internet (% of the population)
	Education	Tertiary	School enrolment, tertiary (gross), gender parity index
	Urbanization	Urban	Urban population (% of the total population)
	R&D	Researchers	Researchers in R&D (per million people)
	Health	Expectancy	Life expectancy at birth, total (years)
		Fertility	Adolescent fertility rate (births per 1000 women ages 15–19)
Energy use	Renewable energy use	Renewable	Share of total final energy consumption
	Non-renewable energy use	Fossil fuel	Fossil fuel energy consumption (% of total)

demographic (urbanization), health (life expectancy and fertility), education (tertiary), R&D (researchers), and ICT (internet users) indicators. All the variables chosen here are thus related to the outcomes of a social development process and considered good proxies of social development in the literature, following previous works that have calculated a similar index in different contexts.

The subpopulation that has access to urban amenities like general services, transportation, etc. Is defined by the urban population (as a percentage of the total population) [36,41]. Health status, nutrition, and income at birth strongly correlate with life expectancy, which is linked via employment and housing [38]. A low number typically indicates that a large portion of the population lives in poor living conditions and that the nation lacks adequate health services [42]. The inclusion of the fertility rate in the model was driven by the ongoing issue of reduced fertility rate in the EU [43] in order to investigate its cause and effects associated with energy use. Investigating this causal link was helpful because the majority of EU member countries are presently dealing with an aging population that may be brought on by low birth rates [44]. Although medical innovation and improved medicinal procedures and medications coupled with technological advancement have tremendously contributed to an upward trend in life expectancy [45], this study aims to ascertain the impacts of other factors (energy use with a macro approach) on life expectancy. The variable to measure education is also fundamentally a classical indicator of social development [46,47]. Additionally, we include in our index indicators that were not included in earlier works cited there, such as the percentage of the population that uses the internet and the number of researchers engaged in R&D per million people, both of which are excellent contemporary measures of social welfare [48]. Indeed, the Millennium Development Goal's aim of ensuring universal access to reproductive health was deemed to be a success indicator for the adolescent fertility rate. The risk of maternal mortality and impairment is increased for many young women when the adolescent fertility rate is high [49,50].

Thus, a causal relationship in logged form between the indicators of social development as the main explanatory variables, and renewable and non-renewable energy consumption as the dependent variables is calculated employing the following equations (1) and (2) of the constructed models.

$$LRenewable_{it} = \beta_0 + \beta_1 LInternet_{it} + \beta_2 LExpectancy_{it} + \beta_3 Urbanization_{it} + \beta_4 LResearchers_{it} + \beta_5 LTertiary_{it} + \beta_6 LFertility_{it} + \mu_{it} \quad (1)$$

$$LFossilfuel_{it} = \beta_0 + \beta_1 LInternet_{it} + \beta_2 LExpectancy_{it} + \beta_3 Urbanization_{it} + \beta_4 LResearchers_{it} + \beta_5 LTertiary_{it} + \beta_6 LFertility_{it} + \mu_{it} \quad (2)$$

Where, μ is the distributed error term. The study uses two models for both renewable and non-renewable energy consumption to examine the eventual long-run and short-run statistical causal relationship between the variables.

4.3. Panel VAR model

Finally, panel vector autoregression (VAR) is used as the main causality model to determine the course or direction of the dynamic causal interaction between social development and energy use. It is important to note that the panel VAR model treats all variables as endogenous and interdependent irrespective of their exogenous or endogenous configurations in both dynamic and static conditions. However, in some cases, exogenous configurations can be applied by including dummy variables; this approach is called the dummy approach [51]. Panel VAR is based on the pre-testing of integrated data and order p with the panel-specific fixed-effect. Thus, the typical panel VAR for Y_{it} can be estimated using Eq. (3).

$$Y_{it} = a_1 y_{i,t-1} + \ldots + a_p y_{i,t-p} + u_i + \varepsilon_{it} \quad (3)$$

Here Y_{it} means a vector of endogenous variables for each unit $i = 1,2,3,..N$ and $t = 1,2,3,..T$, I could generically indicate countries and t indicate the period, a_p is the lag operator, μ_i presents individual-specific unobserved fixed effects and ε_{it} is the vector error term.

5. Results

5.1. Descriptive statistics

Table 2 gives a summary of descriptive statistics of the explanatory variables. No considerable degree of difference was found between the mean and median of all input variables. The normal range for skewness is between +3 and −3 and for kurtosis is between +10 and −10. Values above these normal thresholds can be a problem, but a small deviation cannot be a violation of any assumption [52]. For our case, the values of skewness and kurtosis of the variables fell within the accepted thresholds indicating symmetry of data and lack of heaviness of distribution tail (outliers) by large, which revealed the standard normal distribution of data.

5.2. Cross-sectional dependence

When dealing with panel data, the economists suggest that there might be high cross-sectional dependence due to globalization, economic interdependence, and trade openness among the countries [53,54]. Thus, it is of paramount importance to test the existence of cross-sectional dependence before testing stationarity and performing advanced causality model analysis [55]. This study employs three tests of cross-sectional dependence [56–58]. Table 3 presents the outcomes of CD tests. The results show significance at $p < 0.01$ in all CD tests which means that the null hypothesis is rejected in both random effects (RE and fixed effects (FE) models indicating the presence of CD ratio in the panel dataset.

5.3. Panel unit root

If there is a presence of cross-sectional dependence in the panels, the application of just first-generation panel unit root tests will not be a reliable and effective approach. The second-generation panel unit root tests must be employed before further empirical examination of the model [59]. Therefore, this study used both the first and

Table 2
Statistical summary of the variables.

	Renewable	Expectancy	Fertility	Fossil fuel	Internet	R&D	Tertiary	Urban
Mean	15.28	77.00	15.30	75.15	42.48	2809.75	1.15	71.95
Median	11.08	77.66	10.78	78.27	42.95	2457.10	1.17	70.98
Maximum	53.24	83.49	70.29	99.67	98.12	8002.60	1.47	98.04
Minimum	0.33	65.67	3.52	13.05	0.11	259.90	0.71	50.39
Std. Dev.	11.90	3.79	12.12	18.01	33.94	1654.09	0.14	11.55
Skewness	0.82	−0.52	1.70	−1.19	0.03	1.13	−0.50	0.12
Kurtosis	2.76	2.47	5.47	3.96	1.43	4.01	2.87	2.53

Table 3
Results of cross-sectional dependency tests.

CD Test	Pesaran	Frees	Friedman
Model 1 (Renewable)			
Random effects model	50.089* (0.0000)	5.636*** (0.0861)	317.572* (0.0000)
Fixed effects model	50.178* (0.0000)	5.671*** (0.0861)	318.887* (0.0000)
Model 2 (Fossil fuel)			
Random effects model	41.405* (0.0000)	7.675*** (0.0861)	329.803* (0.0000)
Fixed effects model	38.972* (0.0000)	7.583*** (0.0861)	310.273* (0.0000)

Note: *, ** and *** indicate significance at the levels 1%, 5%, and 10%, respectively.

second-generation panel unit root tests to check the stationarity of the panels at I(0) and I(1). The results of common and individual unit root tests are given in Table 4. The significance of t-statistics at a 1% level for both individual and common unit roots rejected the null hypothesis indicating that the data was stationary at I(0) and I(1).

5.4. Cointegration test

After confirming the stationarity, the succeeding step is to run a panel cointegration test to check the presence of a long-run causal relationship between the dynamic panels. This long-run association can be assessed by checking the integration of series with the identical rank in such a way that it cannot deviate from the equilibrium [60]. Thus, this study used the current Westerlund [61], which is an error correction cointegration test for panel data, and Johansen [62] and Pedroni [63] cointegration tests to empirically examine the long-run equilibrium procedure among the variables that allow the error of cross-sectional dependence. These tests are useful when analysing a large sample size because they will reduce uncertain results [64,65]. Evidence presented in Table 5 was sufficient to negate the null hypothesis stating that all panels were cointegrated for both models of renewable and non-renewable energy consumption. It is confirmed that the variables

Table 4
Results of panel unit root tests.

Method	Statistic	P. Value	Cross-sections
Stationarity at I(0)			
Null: Unit root (assumes common unit root process)			
Levin, Lin & Chu t*	−4.865	0.0000	8
Null: Unit root (assumes individual unit root process)			
IPS W-stat	−16.546	0.0000	8
ADF - Fisher Chi-square	320.120	0.0000	8
PP - Fisher Chi-square	435.294	0.0000	8
Stationarity at I(1)			
Null: Unit root (assumes common unit root process)			
Levin, Lin & Chu t*	−81.2665	0.0000	8
Null: Unit root (assumes individual unit root process)			
IPS W-stat	−70.8873	0.0000	8
ADF - Fisher Chi-square	1384.46	0.0000	8
PP - Fisher Chi-square	900.459	0.0000	8

Table 5
Results of panel cointegration tests.

Westerlund test		
	Model 1 (Renewable)	Model 2 (Fossil fuel)
Variance ratio	−2.710** (0.0034)	−2.886** (0.0019)
Johansen test		
Trace test	352.197* (0.0000)	371.733* (0.0000)
Max Eigen test	167.017* (0.0000)	155.216* (0.0000)
Pedroni test		
Modified Phillips-Perron t	3.602* (0.0002)	3.047** (0.0012)
Phillips-Perron t	−5.381* (0.0000)	−8.461* (0.0000)
Augmented Dickey-Fuller t	−4.936* (0.0000)	−6.332* (0.0000)

Note: *, ** and *** indicate significance at the levels 1%, 5%, and 10%, respectively.

are indeed cointegrated in the same order. Also, this validates the presence of stable long-run equilibrium among the independent and dependent variables of the study.

5.5. Panel VAR results

Finally, this study employed a panel VAR model to determine the direction of causality among the variables. The optimum lag length criteria k for intervals was selected 2 to meet the essential assumption according to the AIC, HQ, SC, LR, and FPE. T-statistic was used to test the significance of the hypothesis. The results concerning the course of causality are depicted in Table 6 using the panel vector autoregression technique as the primary model of this study. The results revealed a bidirectional causal interaction between renewable energy use and fertility and tertiary education. Additionally, a unidirectional causality runs from renewable energy to life expectancy and R&D to renewable energy use.

Furthermore, it also showed two-way causality between fossil fuel combustion and tertiary education. However, one-way causality was evident running from fossil fuels to life expectancy and fertility rate and R&D and ICT to fossil fuel consumption. Further, urbanization had statistically insignificant causal interaction with energy use whether renewable or non-renewable. Interestingly, findings revealed that renewable energy contributes to increasing life expectancy, adult fertility rate, and tertiary education, and oppositely, fossil fuel utilization reduced life expectancy and fertility rate. Besides, the results suggest that the growth in fertility rate, R&D, and higher education contributes to increasing renewable energy utilization whereas R&D inhibits non-renewable energy utilization.

This infers the development of the education, health, and R&D sectors in EU member states to promote renewable energy utilization; therefore, stakeholders must prioritize financing the aforementioned sectors to optimize renewable energy, which will ultimately lead to the transformation and simultaneous sustainable growth of these sectors resulting in technological innovations, increasing overall literacy rate and the prosperity of involved business operations both public and private.

Table 6
Panel VAR results.

D. Variables	Source of causation							
	Ren	FF	Exp	Fer	Urban	Int	R&D	Ter
Renewable	–	–	1.93^c (0.20)	1.92^c (0.27)	−1.49 (−0.04)	0.89 (0.03)	−0.70 (−0.01)	3.65^a (2.11)
Fossil fuel	–	–	−2.12^b (−0.66)	−2.34^b (−2.76)	0.38 (0.13)	1.49 (0.04)	−0.43 (−0.05)	3.89^a (0.33)
Expectancy	0.64 (0.03)	−0.37 (−1.48)	–	0.90 (0.01)	−0.02 (−2.82)	0.04 (0.06)	−1.69^c (−4.23)	−0.80 (−0.83)
Fertility	2.98^b (1.75)	−1.44 (−1.31)	−2.13^b (−0.95)	–	−1.89^c (−0.10)	−1.04 (−0.47)	−2.58^b (−1.81)	−0.37 (−2.56)
Urban	−1.30 (−0.07)	0.20 (0.06)	−1.39 (−0.07)	1.93^c (0.94)	–	−1.23 (−0.03)	0.63 (36.54)	0.01 (2.76)
Internet	−0.40 (1.22)	1.68 (0.16)	−1.12 (−0.01)	1.97^c (0.02)	0.36 (0.01)	–	1.82^c (11.45)	−2.08^b (−0.01)
R&D	3.00^a (2.82)	−3.74^a (−3.57)	1.00 (1.15)	−1.95^c (−0.01)	0.90 (0.95)	1.59 (0.76)	–	0.04 (0.06)
Tertiary	2.59^a (1.34)	2.69^a (4.39)	0.15 (2.52)	−0.20 (−0.02)	0.50 (0.68)	1.43 (0.01)	−1.10 (−7.00)	–
C	0.35 (0.49)	1.27 (3.69)	1.98^b (0.01)	0.24 (2.79)	0.82 (2.51)	−0.10 (−14.25)	1.97^b (1.75)	2.24^b (1.34)

Note: Coefficients are given in a, b and c indicate significance at the levels 1%, 5%, and 10%, respectively.

5.6. Model stability and IRF

Moving forward, to check the robustness, stability, and normality of the model, this study consulted inverse roots with polynomial characteristics, residual diagnostic tests, such as serial autocorrelation and heteroskedasticity, and impulse response function. Fig. 2 shows that no companion matrix value lies outside the unit circle demonstrating that VAR satisfies the stability condition. It is worth noting that the findings of an unstable model lose significant policy implications in long-run panel dynamics. The results of all residual diagnostic tests are depicted in Table 7, which gives the outcomes in favour of acceptance of the alternative hypothesis indicating that the model is devoid of autocorrelation and heteroskedasticity. Therefore, it is confirmed that the performed model is stable and results are reliable enough to be accepted for policy inference.

A graphical representation of impulse response with Cholesky-dof adjustment is given in Fig. 3. The Monte Carlo simulation method was selected to check response standard error with 1000 replications showing a 95% confidence interval. The results of the impulse response function visualize that fertility rate, research and development, tertiary education, and urbanization significantly impact renewable energy consumption or vice versa. Besides, expectancy, fertility, R&D, and tertiary education do have a statistically significant effect on fossil fuel combustion and otherwise as well. One standard deviation shock given to the main explanatory variables will positively or negatively impact energy consumption. For example, one standard deviation shock given to renewable energy consumption will give rise to expectancy, fertility, and tertiary education and also stabilize research and development, ICT, and urbanization; however, one standard impulse to non-renewable energy use will result in a decline in R&D, urbanization and adult fertility rate.

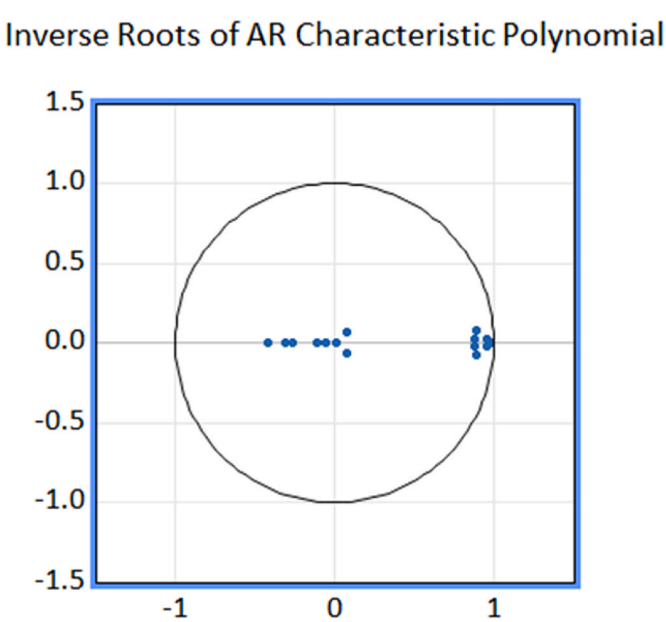

Fig. 2. Residual diagnostic test with inverse roots of AR characteristics polynomial.

Table 7
Residual diagnostic tests.

Test	Statistics
Autocorrelation LM test	1.18 (0.1557)
Heteroskedasticity	1.05 (0.3324)

The forecast outputs of the Cholesky decomposition analysis for 10 years are given in Table 8 for renewable and for fossil fuels in Table 9. The standard error was calculated with a Monte Carlo simulation set to 100 repetitions. In period 1, 100% forecast error variance in renewable and fossil fuels is explained themselves, other variables do not have a strong influence. From the second period onwards, research and development, higher education, and expectancy strongly influence renewable and non-renewable energy consumption. The variance contribution of renewable energy itself is about 71% and the variance contributions of fossil fuel consumption.

6. Discussion and policy implications

The results have provided concrete evidence that energy consumption and social development, in general, have strong empirical interactions that are discussed separately below.

6.1. Fertility rate and life expectancy

The results disclose that a 1% increase in the utilization of renewable energy contributes to raising fertility and life expectancy rates by 1.27% and 2.20% whereas fossil fuel contributes to reducing fertility and life expectancy by 2.75 and 0.66%. In return, life expectancy has no causal effect on fossil fuel and renewable energy consumption; however, growth in the fertility rate will contribute to an increase only in renewable energy by 1.75% in EU member countries. It is surmised that a rampant fertility rate augments population growth and growth in population contributes to raising more energy needs. This relationship is entirely different from the previous study in that there is a trade-off relationship between per capita energy consumption and fertility-a decline in fertility gives rise to energy consumption having 1/3 exponential scaling using allometric theory [16]. Surprisingly, despite claims to the contrary, there has been considerable evidence of a drop in the fertility rate of most EU member states (from 1.75 in 2001 to 1.50 in 2021) [66,67]. For example, as revealed by Ref. [43] Portugal, Greece, Italy, Spain, and Poland (South-eastern Europe) have low fertility rates whereas Sweden, France, Denmark, Norway, Holland, and the UK

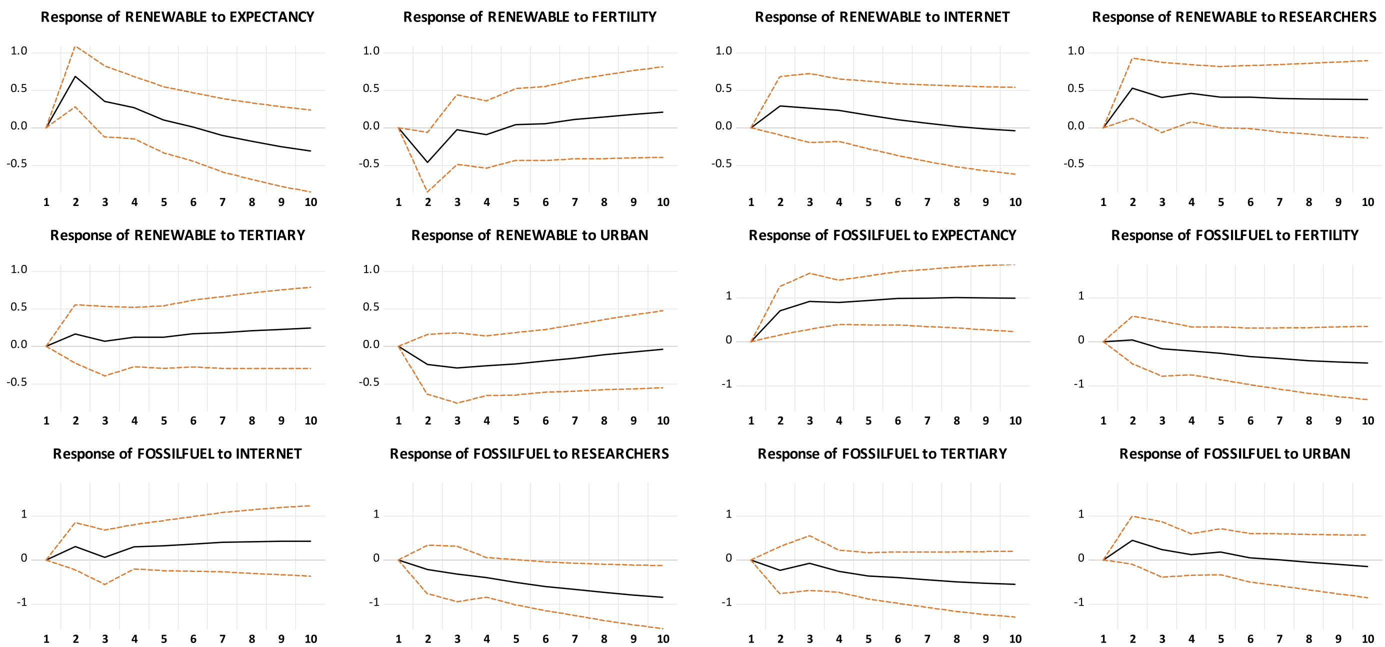

Fig. 3. Graphical representation of impulse response to Cholesky One S.D. innovations.

Table 8
Variance decomposition of renewable using Cholesky (d. f. adjusted) factors.

Period	Renewable	Fossil fuel	Expectancy	Urban	Internet	R&D	Tertiary	Fertility
P2	79.08	0.35	0.72	0.05	0.25	17.82	0.10	0.62
P3	74.92	0.67	0.73	0.08	0.33	21.58	0.32	0.51
P4	73.95	1.35	0.74	0.13	0.59	22.54	0.61	0.48
P5	73.31	1.65	0.76	0.21	0.66	24.21	0.95	0.43
P6	72.51	1.88	0.80	0.24	0.90	23.17	1.33	0.39
P7	72.30	2.37	0.97	0.27	0.98	22.38	1.70	0.36
P8	72.08	3.01	1.22	0.29	1.06	21.66	2.07	0.35
P9	71.96	3.59	1.48	0.32	1.18	20.91	2.43	0.35
P10	71.66	4.16	1.66	0.35	1.29	20.39	2.76	0.36

Table 9
Variance decomposition of fossil fuel.

Period	Renewable	Fossil fuel	Expectancy	Urban	Internet	R&D	Tertiary	Fertility
P2	4.72	79.82	1.35	0.17	0.18	11.61	2.55	0.46
P3	3.98	77.48	1.67	0.14	0.14	14.23	2.75	0.39
P4	3.33	76.05	2.13	0.14	0.12	15.04	2.80	0.40
P5	3.42	70.75	1.95	0.12	1.32	15.10	2.80	0.37
P6	7.60	62.58	2.43	0.11	1.88	18.41	2.86	0.67
P7	11.80	57.57	2.66	0.10	2.60	19.84	2.84	0.79
P8	13.65	53.62	2.64	0.10	4.20	20.81	2.92	0.86
P9	14.88	51.25	2.66	0.10	5.46	21.22	2.97	1.14
P10	15.76	49.20	2.55	0.12	6.86	21.20	2.97	1.36

research and development, tertiary education, expectancy, and internet are almost 4.16%, 20.39%, 2.76%, 1.66%, and 1.29% over the period, respectively. Similarly, renewable energy, research and development, internet use, life expectancy, and tertiary education have a greater impact on fossil fuels utilization with a variance contribution of 15.76%, 21.20%, 6.86%, 2.55%, and 2.97% over the period.

(North-western Europe) are associated with extremely low fertility rates. However, it is still empirically uncertain if the trend of fertility and birth drop remains desirable when considering the trilemma of lowering the demand of the continent's ecological footprints, avoiding the ageing population conundrum, and achieving sustainable development.

The association concerning life expectancy, on one hand, this empirical study reveals that renewable energy contributes to increased life expectancy. The plausible reason is that it does not have detrimental impacts on human health. Undeniably, advanced medication coupled with industrial prosperity also contributed to relatively higher life expectancy in EU countries: nearly 35 years on average compared to last century's figures and almost 10% (3.5 years) was due to safe, affordable, and adequate energy transmissions [68]. On the other hand, it provided additional pieces of evidence that fossil fuel consumption reduced the life expectancy rate, indicating that more use of fossil fuels emits more CO_2 (carbon dioxides), NOx, (nitrogen oxide), and particulate matters having a diameter of less than 2.5 μm ($PM_{2.5}$) into the atmosphere (macro level approach) causing severe air pollution. Several empirical findings showed that nitrogen oxide, particulate matters, and ground-level ozone are three of the most harmful pollutants in Europe affecting human well-being. The rampant emissions of these pollutants and CO_2 emissions negatively affect life expectancy, fertility, and infant mortality [19,45]. Almost 90% of the European population is exposed to contaminated air because of these pollutants and long-term exposure can shorten lives [69]. It was empirically studied that a 1% increase in nitrogen oxide, particulate matters, and smallest particles lowered life by 6.7, 2.68, and 4.5 months on average respectively [70]. The household or commercial combustion (micro level) of inefficient and contaminated solid fuels harmfully affects overall human health and especially for women, pregnancy and its related issues (fertility, miscarriages, or sterilization at an early age) can be evident because of long-standing direct or indirect exposure to non-renewable energy fuels [71,72] in contrast to renewable energy utilization.

According to the study's findings, investing in a renewable energy sector can produce favourable health outcomes, such as extending life expectancy because investment in renewable energy sectors can extend life expectancy by 12 months on average in Europe [70]. The policy ramifications of these findings are pertinent for environmental and health initiatives. In this regard, the EU has implemented legislative measures to promote the development of renewable energy, thereby helping to lessen reliance on foreign energy supplies and the long-term environmental effects of emissions from more polluting fuels. Even though the UNPF [43] cited the low fertility rates and high life expectancy, in the developed nations, which can be associated with sustainable development; however, the agency cautioned that the age structure of the populations is actually constrained. Aging and low fertility are major problems in EU member states, hence sufficient research should be done to explain and narrow the gap between those nations with extremely low fertility and those with fertility levels that are close to replacement [73]. By including more demographic elements, such as household and gender classifications, in an experimental model, this study could be furthered in the future.

6.2. Education and R&D

Also, a bidirectional causal link with tertiary education suggests that, on one hand, a 1% surge in energy consumption (whether renewable or non-renewable) contributes to fostering education by 2.11% (renewable energy) and 0.33% (fossil fuel) and, on the other hand, education will give rise to energy use by 3.34% (renewable energy) and 2.39% (fossil fuel). In modern times, it is hard to imagine getting an education in classrooms devoid of proper energy facilities in urban as well as rural areas and hot and cold places, such as lighting, multimedia projectors, electric fans, central heating system, and air conditioners. Thus, a safe and sufficient energy supply is essential to boost the education sector. It has been scientifically proven that education is one of the fundamental determinants of economic growth [74] and economic growth had contributed to extending energy use [75]. Therefore, it can be argued that if education promotes economic growth and economic growth gives rise to energy use, then education is also a determinant of energy use employing economic growth as its tool. Energy use and structure are influenced by education in a variety of ways, including productivity expansion, consumer buying behaviour, technological development, awareness about fuel efficiency, adjustment, and fuel replacement [76].

Additionally, higher educational attainment can also positively affects renewable energy utilization via the supply and demand channels, such as economic growth, human capital, research and development, innovation, and technological advancement, which are also significant determinants of renewable energy consumption [23,77,78]. On the supply side, human capital, technological progress, and financing levels are key components for the production of renewable energy and advances in these areas can support the production of renewable energy. Awareness concerning the environment and human capital, which is heavily dependent on educational attainment, are demand-side drivers of renewable energy use [79,80].

Moreover, the outcomes of this study also show that a 1% rise in research and development contributes to increasing renewable energy by 2.82% and lowering fossil fuel by 3.57%. This trade-off relationship between R&D and fossil fuels, and a significant positive association with renewable energy suggests stimulating investment in R&D overall share of renewable energy by simultaneously shrinking the proportion of fossil fuel consumption. It can be argued that the levels and quality of educational attainment play a vital role in the production, conservation, and efficient use of renewable energy [20] by provoking energy-efficient behaviour of the citizens by discouraging solid fuel combustion at the residential level [21,22].

Practically, large upfront investments and highly qualified personnel are needed to develop and complete the centralized energy systems (such as large-scale electricity generating from upstream and downstream oil and gas production), but the operation is less labour-intensive and does not demand a high level of ability [30]. However, in addition to considerable investment and R&D expertise, the new and decentralized renewable energy systems (such as wind, hydro, PV, biomass, and energy efficiency) need additional highly skilled and educated staff for operation and maintenance [81]. Education has also been seen as one of the available tools that governments can utilise to promote energy literacy among businesses and consumers as well as the production and usage of renewable energy. Therefore, the development of education and training systems speeds up the confluence of cutting-edge technology and the demand for skilled labour in the renewable energy sector. Also, because of the size of the expenditures involved and the multiplicative effects, R&D has a considerable impact on the production of renewable energy as well [25,82].

6.3. Urbanization and ICT

Lastly, the results suggested that growth in the urban population and ICT did not contribute to energy use and vice versa in EU member states because of insignificant statistical interaction between the explanatory variables and energy consumption. The possible reason for these outcomes can be growing life expectancy and low fertility rate across the European Union nations as mentioned above, which projects population decline. Statistical data reveals projected population growth of about 4% from 2000 to 2025 [83]. This infers an elastic statistical relationship between urbanization and energy use in EU member countries because decreasing fertility rate reduces population growth, which in turn reduces energy use; however, low births also increase the proportion of the elderly population, which mounts energy use. One study was found indicating a positive link between urban population growth and energy use (a 1% increase in urban population raised energy use by 2%) but the data used for analysis was outdated (1960–2000) [84], which lacked fresh evidence concerning urban population growth and trends of energy utilization in EU countries.

Lastly, the results disclosed that growth in internet access escalates energy consumption (non-renewable) in Europe. Investment in the ICT sector direct or indirectly affects patterns of energy use especially electrification, which spurs electricity demands. One study disclosed that ICT accounts for almost 7% of total energy use in Germany and it exceeds 45% when includes charging the handsets. Also, the service and manufacturing of ICT raised electricity demands in South Korea [85] and Iran [86] as well whereas a slight trade-off relationship was revealed in Japan. Besides, the use of the internet fostered electricity consumption in Australia according to a study conducted in 2012 [87]. Overall, the population and economic growth foster demands for information and telecommunication technology access-expand infrastructure and production of concerned devices (smartphones, laptops, or computers), which in return surges energy use, especially electricity consumption. For example, India and China are among the top consumers of ICT devices in the world. China experienced rapid growth of internet users from 1990 to 2015 from 1% to 50% and India experienced 26% increase [88] and so did their energy thirst.

7. Energy policy review of EU countries

The holistic findings of this study imply that the growth of renewable energy use contributes to social development; therefore, the renewable energy portfolio must be optimized from production to consumption with a diversification approach. For instance, Sweden has emerged as a global leader in building a decarbonized economy with the lowest share of fossil fuels and the lowest carbon-emission-intensive economy. With Energy Agreement and Climate Framework in 2017, the country took practical actions to transform primary energy supply and generation to achieve the long-term goal of net zero emissions by 2040. As of now, renewable energy share (nuclear, hydro, biofuels, and waste) accounts for almost 50% of the total energy use of the country one of the highest in the world [89]. Through investments in nuclear power, hydropower, and most recently, other renewables, Sweden has substantially reduced the carbon footprint of its electricity production. This is a significant accomplishment that must be maintained [90]. Similarly, Austria, Finland, and Denmark plan to phase out all oil and coal-fired heating systems by 2035 and complete decarbonized economy by 2040. Austria has already achieved 77% of electricity generation from renewable sources (Hydro, biofuels and waste, wind, and solar) in 2018 which be 100% by 2030. Renewables accounted for 29% of the total primary energy supply in 2018 with bioenergy and hydropower accounting for the largest share. Finally, due to feed-in tariffs and decreasing implementation costs, both wind and solar PV deployment have surged. Austria is on track to fulfil its EU target of 34% renewables (already achieved in 2020) in gross final energy consumption and 10% renewables in transport because of this significant deployment of renewables [91].

However, as of now, most European countries, such as Ireland, Poland, Germany, Italy, Spain, Netherlands, Belgium, Hungary, Czech Republic, Cyprus, and Greece are still heavily dependent on non-renewable energy except for Sweden, Austria, Finland, Latvia, Denmark, and Lithuania as depicted in Fig. 1. Among them, Germany [56.2 billion cubic meters (bcm)], Italy (29.2 bcm), Netherlands (13.2 bcm), France (11.2 bcm), Poland (10.5 bcm), Hungary (7.1 bcm), Spain (3.3 bcm), and Belgium (1.4 bcm) have been the largest importers of Russian fossil fuels by August 2022 [92]. Reducing reliance on Russian conventional energy fuels has been a major challenge for many European countries, as the continent gets the majority of its energy fuels through pipelines connected to Russia. Moreover, these are the countries with rapid urbanization growth as compared to Sweden, Finland, or Austria, which consumes more renewable energy as compared to non-renewable [93] and also have relatively high life expectancy rates (82.0 $\leq$ 83.0) [94], fertility rates ($\geq$1.67) [95], and literacy rates (100%), etc. Currently, the aggregate share of renewable energy in gross total energy use of EU countries is 22.1% (exceeding its target by 2.1%), which was 16.7% in 2015 and 9.6% in 2004. Thereafter, dependency on solid fuel consumption was significantly reduced by 18.4% in 2020 compared with 2019, and greenhouse gas emissions decreased by 23% since 1990 [96]. This will play a significant role in the energy mix and the transition of the energy sector in Europe and subsequently, with this positive development, the continent is going to be the first climate-neutral region by 2050.

These countries must boost the rolling out of renewables to achieve diversification of energy systems individually and collectively by achieving their renewable energy targets set by the EU Parliament. For example, Germany's '*Energiewende*' has been defining a policy to diversify and transform energy generation and distribution by completely phasing out fossil fuel dependence and increasing renewable share by cutting 40% of GHG emissions by 2020, 55% by 2030, 70% by 2040, and 80–95% by 2050 [97,98]. Similarly, France set its target to achieve zero emissions by 2050 with the implementation of the '*National Low-Carbon Strategy*' and '*10-Year Energy Plan*' announced in 2019. However, the energy transitional plan despite many reforms has faced significant delay due to challenging implementation but the new EU Climate Goals can compel France to upgrade their targets and track the progress more stringently. The existing renewable energy share of the country comes from mainly indigenous nuclear power plants and both countries are one of the largest importers of Russian fossil fuels [99].

Italy opted for the National Energy Strategy in 2017 for the promotion of renewable energy sources up to 55% in electricity, 34% in heating, and 22% in transport sectors coupled with maximization of sustainability through energy efficiency by 2030 and decommissioning of all coal-fired power plants by 2025 [100]. The Netherlands is also going through a rapid energy transition to attain decarbonized economic growth. To accomplish this ambitious task, the government is focusing on energy and climate policy under the Climate Agreement of 2019 to lower GHG emissions by 49% in 2030 and 95% in 2050 in collaboration with involved parties. In this context, the Dutch government successfully doubled its energy share from renewable sources from 2008 to 2019. However, the country remained heavily dependent on traditional energy sources so far, which will make it hard for the emission-intensive industrial sector to decarbonize [101].

The same is the case with Poland and Hungary, Poland is set to achieve a carbon-neutral energy supply by increasing its renewable share by supporting nuclear energy and electrifying transportation. Reduced reliance on coal, particularly for electricity generation and building heating, is a key component of Poland's energy policy. Interestingly, Poland has made considerable progress in transforming energy generation and distribution. It has become one of the rapidly growing markets of photovoltaic modules across Europe, taking strong initiatives for the offshore deployment of wind turbines, and diversifying away fossil fuels imports from Russia [102]. Besides, Hungary adopted a long-term aspiring plan, National Clean Development Strategy (2017), to generate 90% clean electricity by 2030. Because the fastest growing solar energy modules and lifetime restoration of extension of nuclear reactors can be fruitful to diversifying energy generation systems [103]. Summing up, the EU countries should also reduce their reliance on Russian fossil fuels and support investment in clean energy technologies. In this respect, a diversified portfolio of renewable energy sources and increased power system flexibility for the integration of significant proportions of solar PVs is essential in addition to nuclear energy [104].

8. Conclusion

This research aimed to investigate a causal relationship between energy consumption considering renewable energy and fossil fuels combustion and indicators of social development including health, education, ICT, urbanization, and R&D. This study reveals that a 1% increase in renewable energy consumption contributes to raising life expectancy, fertility and education by 2.20%, 1.27% and 2.11% respectively. However, a 1% surge in fossil fuel utilization contributes to lower life expectancy and fertility by 0.66% and 2.76% and gives rise to education by 0.33%. Reciprocally, fertility, education and research and development contribute to renewable energy utilization by 1.75%, 2.82% and 3.34% respectively whereas research and development contribute to decreasing fossil fuel combustion by 3.57%. Lastly, urbanization and internet subscriptions were found to have no statistically significant interaction with energy use, inferring that these social factors do not contribute to energy use.

These robust findings imply significant policy guidelines for the involved stakeholders and policymakers. It suggests that expanding the share of renewable energy will contribute to sustainable social development. For that reason, policymakers and stakeholders must invest in energy transitions, by diversifying domestic or regional renewable energy sources (solar, wind and hydro) and gradually expanding the share of green energy. Many pragmatic studies focused on the hydro and wind potential of EU countries that seeks energy cooperation to increase and secure the green energy supply of the region [105–107]. The EU parliament has announced obligatory '*Energy Transition*' and '*EU Climate Goals*' plans to search for greater energy market integration and targets for renewable energy utilization and greenhouse gas reductions that would make an essential contribution to sustainability and security of energy supply and would prove to be necessary for achieving SDGs and climate goals of 2030 and 2050 [4].

Lastly, the study used the empirical data of the EU countries; therefore, the policy implications based on robust findings are primarily applicable and admissible for the EU member states only. This prognostic causal interaction between social development and energy use should be further investigated in other regions or countries of the world, especially the developing world.

Credit author statement

Khizar Abbas: Conceptualization, Writing—original draft, Methodology, Software, Visualization, Formal analysis, Investigation, **Deyi Xu**: Resources, Data curation, Writing—review & editing, Validation, Supervision, Project administration, Funding acquisition, **Khalid Manzoor Butt; Khan Baz; M. Sheraz; Sanwal Hussain Kharl**: Investigation, Validation, Supervision, Project administration.

Declaration of competing interest

We declare that none of the authors have competing financial or non-financial interests.

Data availability

I have upload a file of the data

Acknowledgment

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.energy.2023.127791.

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