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Research article

Modelling energy trilemma and economic growth on renewables in N11 economies: Do economic complexity matter?

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ABSTRACT

Utilizing renewable energy is a necessity for accomplishing global agendas, including combating climate change and promoting sustainable development programs. Although much literature has investigated the nexus between energy sources and their affected regressors during the last few years, no appreciable emphasis is available in the previous studies respecting the influence of the energy trilemma index and economic expansion on the influence of the energy trilemma index and economic the renewables in N11 economies. Therefore, the current study analyzes the crucial influencing factors, including the energy trilemma, economic growth, economic complexity, financial development, and urban population, as drivers of renewable energy in N11 economics from 1990 to 2021 by utilizing a panel quantile regression approach. The empirical outcomes certify that renewable energy is positively connected with the energy trilemma, economic growth, financial development, and urban population, but not with economic complexity, which has the inverse result. As a result, legislators responsible for monitoring the deployment of renewables should stimulate their attempts to consider the energy trilemma dimensions into account when determining energy structural policies, increase the use of greener energy subsidies, pose high-carbon taxes, promote green financial innovation, and improve energy efficiency.

1. Introduction

Both advanced and underdeveloped nations continue to promote economic growth since it could result in expanding global energy demand. Therefore, to maintain a balance between environmental protection and economic progress, national planning agendas have recently included the worldwide goal of limiting climate change by expanding the deployment of renewable energy (RE) [1]. Although most developing economies, including the Next 11 are on the track of transition to renewables, they still need to create significant efforts at eliminating challenges to this transformation. Therefore, investigating the challenges of the dissemination of renewable forms of energy, which can be categorized in a wide variety of contexts including political, financial, societal, environmental,

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governing, and technical is crucial. Energy trilemma (ET), economic growth (GDP), economic complexity (ECI), financial development (FD), and urban population (URB) are some of these challenges [2,3,4,5].

In this regard, the World Energy Council (WEC) contends that switching to efficient, safe, equitable, and renewable energy sources exposes a well-managed equilibrium dilemma among the three aspects of energy security, fairness, and sustainability. The ET index evaluates the system's performance of energy supply in each of the three dimensions; Energy security considers a country's ability to adapt to changing energy needs as well as the reliability of its power infrastructure. Energy equity evaluates a country's ability to deliver reliable, affordable, and plentiful energy for domestic and industrial use. Also, to combat climate change, a sustainable environment entails the conversion of power infrastructure to low- or indeed carbon. The regional assessment of the World Energy Trilemma reveals critical information about the ways to secure equitable energy systems. Therefore, the explanation for the energy trilemma is to accomplish a balanced renewable energy transition that addresses one component without damaging others. A complete depiction of the relative priority balance across different countries can be obtained through an analysis of regional performance [6,7].

Parallel to the ET index in driving renewables dissemination, one of the most one of the most significant issues that academics are taking more seriously is the structural transformation which the ECI index suggested by Ref. [8] can measure. Economic complexity is the term used to describe the national economy's structural changes, characteristics, technical expertise, and abilities that support the growth of industries based on a top-scale capacity performance. Moreover, the economic complexity index links structural changes with more specialized goods and services. As a result, it measures the productive structure while reflecting the degree of complexity and capturing differences in industrial structures [9]. Considering the entire number of abilities and expertise employed, a greater economic complexity index number suggests better manufacturing process capabilities and also reveals the degree of product variety and the pervasiveness of manufactured goods [10].

Additionally, the crucial driver of the deployment of renewable energies is financial development. A robust financial system contributes to environmental progress, and nations with healthy financial systems are more likely to favor utilizing sources of sustainable energy. In economies with a stable financial system, organizations that actively participate in environmentally friendly practices and help to utilize renewables are rewarded and encouraged [11].

Regarding urbanization, the latest research has demonstrated that the urban nature of cities, their planning, and the size of the population, as well as their manufacturing, agrarian, or commercial operations, may significantly contribute to environmental damage, making investments in the clean energy industry very sensitive to these factors. so noticeable attention should be given to the examination of links between urbanization and the deployment of renewables [12].

Using the debate just had, the foremost intention of this research is to explore if the ET index, GDP, ECI, FD, and URB push the expansion of RE in the N11 nations using yearly data from 1990 to 2021. To accomplish this, we use an estimation method based on a panel quantile approach with non-additive fixed effects, recently suggested by Ref. [13].

Four ways in which this study advances the literature are as follows: (i) For all we know, it analyzes N11 countries, whereas past research just analyzed a few individual nations. (ii) It's the first research that focuses on the relationships between renewable energies and the EI index among the N11 nations. (iii) Panel quantile regression is used in estimation which successfully addresses the statistical issues caused by the prevalence of outliers and a non-normal residual distribution in the panel dataset. (iv) The empirical outcomes may help decision-makers enact legislation that will accelerate the transition towards sustainable energy not only in N11 but also in various underdeveloped economies.

The study's organizational structure is illustrated in Fig. 1. Overviews of the literature review for the research include the factors impacting the utilization and dissemination of renewables. The methodology section includes the data and methods after the development of the hypotheses are highlighted. Then, the core of the discussion and empirical results are shown. The study's conclusion takes into account the consequences for policymakers in the N11 countries.

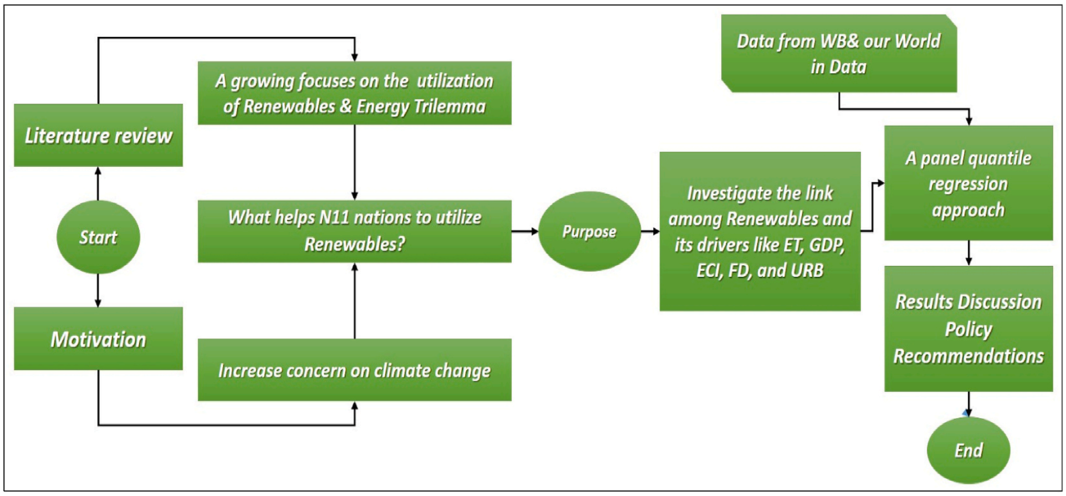

Fig. 1. Framework of this research.

2. Review of the literature and hypotheses construction

A growing number of academics are concentrating on investigating the crucial function that renewable energy deployment plays in enhancing the environment [14–17]. Because switching to alternative sources of energy has been considered to be a crucial issue for improving environmental quality, it is essential to investigate what influences these resources to assist the authorities in pinpointing the regressors that are going to drive their use and functioning to promote the transition. The literature review is divided into five subparts under the variables that influence the dissemination of RE and are pertinent to our empirical investigation; the RE-ET link is discussed in the first subpart; the GDP-RE link is discussed in the second subpart, and the RE-ECI link is investigated in the third subpart. While subparts 4 and 5, respectively, highlighted FD, URB, and their links to RE.

2.1. Energy trilemma & renewable energies link

Both advanced and underdeveloped nations have given the idea of halting climate change by curtailing emissions of greenhouse gases serious consideration. Although the energy sector is emitting the maximum emissions, it is shifting to low-carbon energy. Policymakers must take into account energy security, equity, and environmental concerns, which are each known as the ET index, due to the complexity of energy systems and the uncertainties surrounding the transition path.

The availability of power generation, often known as energy security, has a serious influence on RE. To fulfill projected demands, sufficient energy sources must be secured because sustainable growth depends on the constant availability of energy. By emphasizing using renewables, enhancing the efficacy of their utilization, and continuing to expand their sources as far as potential, nations are working to develop domestic energy sources, lessen their reliance on imports, meet long-term energy needs, and maintain their financial and ecological resources by liberalizing electricity prices and removing obstructions to electrical generation. As a consequence, the dilemma between renewables and energy security has been challenged by economists and environmentalists, with differing results. According to some researchers, energy security limits renewable energy, which is negatively impacted by rising net energy imports such as [18,19], whereas others indicate a positive effect as mentioned in Refs. [20–23].

Additionally, concerns regarding the equity of electricity pricing have increased in regard to the rapid dissemination of renewables. Accordingly, numerous academics explored the relationship between energy equity and RE and argued that insufficient energy supplies affect investors and consumers by restricting their access to clean facilities and increasing their reliance on biomass energy sources in low-income areas [24–27]. As a result of the trend to the decarbonization era, researchers are also closely investigating the connection between renewable energy sources and ecological sustainability which contend that high emission levels could persuade governments to switch to renewable energy sources and diversify their energy supplies as for North African countries [18], for G7 Countries [28], for N11 economics [29], and for Thailand [30]. As a result, it is inappropriate to generalize the findings of earlier studies to the nations of N11, which also have sizable ET characteristics. Thus, investigating environmental sustainability, energy equity and energy security, strengthens the debate by considering how the N11 countries' renewable energy is affected by the ET index.

2.2. Economic growth & renewable energies link

One of the fundamental goals of economic policies has been to enhance economic growth, which is a sign of progression. However, over the recent decades, renewable energy utilization for economic expansion has become a matter of intense discussion in countries all over the world, including N11 economies. Indeed, economies must pursue economic progress if they intend to accomplish the long-term eradication of poverty and build up their infrastructure. So, greater energy use is crucial for greater economic activities leading to more robust growth. Growing reliance on fossil energies, rather than renewable energy sources, could not lead to a low-carbon energy transition age. As a consequence, the correlations between economic growth and renewables have been highlighted among both economists and environmentalists. Several studies concentrate on the relationship between economic growth and renewable energy parameters such as for leading producers of natural gas in Africa Continent [31], for Bangladesh [32], for North African countries [18], for EU and Ukraine [33], for India [34] and for the 10 economies with the highest Emissions of carbon dioxide [35]. These presumptions are crucial for N11 governments since they show that the study's goal is to fill in a knowledge gap. This is extremely important when considering how long-term economic growth will affect renewable energy.

2.3. Economic complexity & renewable energies link

The level of proficiency and understanding required to produce the exported items is indicated by the economic complexity index, which serves as an indicator of economic development. Therefore, exploring how economic and structural factors in both underdeveloped and emerging economies affect the utilization of RE was investigated by some researchers. A study for E7 countries [36] reveal how economic complexity negatively affects policy decisions about overall energy transformation and demand for greener forms of energy. Also, research for 29 Asia-Pacific countries [37] discloses that emissions of CO_2 have decreased in regions with less complicated economies by increasing the utilization of both solar power and power. Consequently, it will be useless to generalize the conclusions of earlier research to the economies of N11, where they have perceived notable monetary and economic growth. To highlight, the ECI is employed, which adds to the debate, to assess ECI in a more efficient and economical way.

2.4. Financial development & renewable energies link

Financial expansion is unquestionably crucial for economic progress since it enables capital formation owing to the accumulation and utilization of savings, the enhancement of important knowledge referring to investment operations, and the optimum use of capital. Likewise, the financial sector as well monitors thoroughly on energy emissions. To put it another way, financial development might have a propensity to initiate research schemes, draw in overseas investments, and then quicken economic activity to strength quality of the environment through investments in ecofriendly activities and improve the utilization of green energy sources. Thus, various investigators assess the association between FD and RE with conflicting results; some of them demonstrate the importance of FD in advancing the usage of RE such as for the European Union countries [38], for South Asia [39], for 34 upper middle income underdeveloped economies [40], and for Turkey [41]. Contrarily, by increasing its dependence on fossil energies, financial development may undermine environmental quality by increasing its business and industrial operations, and this is demonstrated by research as for China [42], for 32 high-income countries [43]. In terms of causality, a unidirectional feedback mechanism between financial growth and energy utilization as mentioned in Refs. [44–46] and one-way causality as conducted in Ref. [47]. Yet, when examining the linkage among renewables and financial development, there is a gap in the conclusions of recent work.

2.5. Urbanization & renewable energies link

The structure of communities, their population density, and their scale all might have a big impact on the environment. Despite mixed results, the link between urbanization and the utilization of fossil and renewable energy is a hot topic in academia. A few reviews of the literature looked at the association between URB and RE, but a greater understanding of this relationship is essential for future sustainable development on a global scale such as [48,49] found that there is a positive association between sustainable urbanization and RE demand.

2.6. Research gap

There are not enough studies in the literature that analyze how renewable energy sources affect developing countries. All of the already stated empirical research may suggest that there are no studies on N11 economics specifically, in addition to the fact that little research has been done on the drivers of RE. Considering this reason, given the prominence of dissemination of RE in these nations, and to support decision-makers in identifying the main drivers of these resources and adopting appropriate and acceptable policies to accomplish the goals of sustainable development, it seems crucial to consider the most significant drivers of RE.

3. Theoretical framework and hypotheses development

The correlation between renewable energy, the energy trilemma index, financial development, economic growth, and the economic complexity index has been a focus of numerous theories. Among the more popular theories are the ones listed below.

3.1. The significance of energy trilemma dimensions

The World Energy Council (WEC) indicates that the three dimensions of energy security, equity, and sustainability provide a well-managed equilibrium issue while moving to efficient, secure, equitable, and renewable energy sources. The theoretical framework of each dimension is as follows:

The theoretical classic analysis of energy security is evaluating the energy supplies' four main considerations: their availability, accessibility, affordability, and acceptability, of which availability and affordability seem to be more significant in terms of impact on other elements of energy security [49]. The foundation of the traditional energy security theories, including constructivism, neoliberalism, neorealism, and international political economy, is the assumption of a steady and ample supply of fossil energies at affordable rates. Fossil energies were thought to be the most dependable and desired energy sources, and centralized systems were thought to be the most common methods for generating energy and long-term energy infrastructure. The fundamentals of energy security should be reconsidered and questioned in light of the modern world's rapidly advancing renewable energy and smart grid technologies, decentralized energy systems, and emerging environmental and climate issues. Therefore, the following hypothesis is put out in light of theoretical and empirical data regarding the economic growth and energy security consequences of renewable energy consumption.

The concept of energy equity concerning inequality and spatial justice was initially introduced by Ref. [50]. Thus, energy equity is related to several governmental, environmental, and socioeconomic concerns. Lack of electricity could be considered a violation of equity in distribution. The matter of energy access is addressed off-grid by alternative energy sources like renewable energy and energy diversification, which also tackle the problem of spatial disparity in resource allocation [51]. proposes that energy inequality is influenced by household income, energy efficiency, and costs. Furthermore, measures for monitoring programs to reduce energy poverty levels or their causes have been developed, as have previous and ongoing attempts to quantify energy poverty [52].

The energy-environmental Kuznets curve (EEKC) hypothesis employs an energy viewpoint to evaluate the hypotheses in light of environmental concerns and energy use. Early on, the connection between per-capita income and ecologically friendly energy sources was the main focus. The logical argument for why investment in renewable energy schemes is underdeveloped in the early stages of economic expansion can corroborate our hypothesis. Yet over time, investments in renewable energy become more profitable thanks to government-funded R&D projects. The percentage of commitments to renewable energy is increasing as more and more renewable energy sources are being used. To provide the resources required to build a profitable and effective renewable energy industry, economic sustainability is essential [53].

According to WEC, Secure, equitable, and environmentally friendly fuel systems reveal a well-managed, balanced Trilemma among the three dimensions. Thus, the following hypothesis is put out in light of theoretical and combined empirical data regarding the energy trilemma index consequences of renewable energy consumption.

Hypothesis (1). The energy trilemma index increases renewable energy consumption

3.2. *The significance of economic growth*

The first investigation of the correlation between energy consumption and economic growth (Kraft and Kraft, 1978) has been expanded to include the consumption of renewable energy sources. Such a study is essential for determining whether conservation techniques can be implemented without impacting the rate of development. A neo-classical theory known as the "neutrality hypothesis" contends that no significant link between economic growth and energy consumption. Because of this, conservation policies can be put into effect to reduce carbon emissions (depending on renewable sources) while maintaining the rate of growth. This has been confirmed by several studies, including one by Ref. [54], which concluded that the hypothesis of neutrality is supported by the majority of developing countries, while the growth hypothesis is supported by just 32 lower-middle-income economies. Proponents of the "growth hypothesis" contend that energy is a component of production that advances economic development in addition to human and physical capital. As a result, the neo-classical "neutrality hypothesis"—which holds that environmental regulations could impede economic growth—is refuted. Therefore, the following hypothesis is put out in light of theoretical and empirical data regarding the economic growth consequences of renewable energy consumption.

Hypothesis (2). Economic growth increases renewable energy consumption.

3.3. *The significance of economic complexity*

Classical development theories correlate economic success to knowledge and technology advancements, structural changes, and the diversity and economic complexity of the ensuing products and services. Therefore, gaining the capacity to manufacture and sell increasingly complex products could be a reasonable explanation for the process of economic progress [55]. However, economic complexity results in it possible for useful goods, like renewable energy sources, to grow across a nation. Numerous primary knowledge-sensitive products are produced by knowledge management in large production networks. Economic complexity indicates a greater capacity for producing and exporting more complex, higher-value-added products. It explains why developed countries have comparative advantages in producing goods while requiring increased coordination in highly skilled human capital [10]. Thus, in light of theoretical and empirical evidence on the influence of economic complexity's environmental effects on renewable energy, the following hypothesis is proposed.

Hypothesis (3). Economic complexity index decreases renewable energy consumption.

3.4. *The significance of financial development*

This section presents a few theories of ecologically responsible funding; the sustainable finance resource theory, sustainable finance priority theory, and sustainable finance positive indicator theory are some of these theories. They can be summed up as follows [56, 57]. The sustainable finance priority theory states that economic agents in a country or region rank the sustainable finance agenda based on the rate at which they are attempting to achieve green finance goals. It highlights that investors have multiple important interests, among which may be the achievement of sustainable financial objectives. It also allows investors to communicate the importance or priority they attach to these objectives. Given the system disruption theory in sustainable finance and the possible disruption to the dominant conventional financial structure, economic actors may have to decide which measures to promote the shift to environmentally friendly finance. The theory holds that by giving economic actors all the information they need to understand how the shift to sustainable finance will play out and how it may affect them, we can reduce their skepticism and help them see why the move is so urgently needed. Thus, in light of theoretical and empirical evidence on the influence of financial development on renewable energy, the following hypothesis is proposed.

Hypothesis (4). financial development increases renewable energy consumption.

3.5. *The significance of urbanization*

Three theories can be used to describe the relationship between urbanization and carbon emissions: compact city theory, ecological modernization theory, and environmental transition theory. Urbanization increases consumption of energy, transportation activities, and infrastructure development, all of which contribute to environmental degradation, according to the environmental transition theory. Furthermore, the ecological modernization hypothesis states that early stages of urbanization see an increase in environmental degradation due to the rapidly growing needs for fuel, electricity, transportation, and building materials. But eventually, because of government policies, advanced energy systems, and technological developments, urbanization will tend to lower carbon emissions [58]. Furthermore, urban institutions utilize economies of scale for public infrastructure (including transportation, power, and schools) following the compact city idea, which is also known as the phenomenon of agglomeration [59]. Therefore, the following hypothesis is put out in light of theoretical and empirical data regarding the urbanization consequences of renewable energy consumption.

Hypothesis (5). Urbanization increases renewable energy consumption.

4. Methodology

4.1. Data source and description

Empirical investigation was carried out using yearly data from 1990 to 2021 for N11 countries. The chosen countries and time frame were based on the data's accessibility. In terms of data sources, the World Development Bank Database (2023) has been used to obtain data for all the variables being examined except for data for the economic complexity index are obtained from Our World in Data. For the energy trilemma as it is one of the main independent variables of the study, the research paper uses the principal component analysis (PCA) to combine the three dimensions of energy trilemma (energy equity, environmental sustainability, and energy security) into one index.

Omission of significant variables and prevent biased estimators.; namely, economic complexity index, financial development proxies by monetary sector credit to the private sector (% GDP), and urbanization represented by urban population (% of total population). For more details on the measurement, data source, and abbreviation, see Table 1.

Table 2 shows the descriptive statistics for the variables under investigation. The standard deviations of the variables are discernible when examining the minimum and maximum values of RE and the regressors. The sampled economies' standard deviation for RE is 26.28105. RE, which is a dependent variable, has a minimum and maximum value of 0.440000 and 88.68000, accordingly. Compared to the other regressors, the ECI variable has a low level of variability. Apart for URB, the remaining regressors in this study all exhibit just minor variation. This improves the study model's resilience and stability and solves the issue of unreliable and fluctuating data results. This gives robustness and stability to the study model and eliminates the problem of inconsistencies and variability in the data results. Furthermore, the initial variables that were selected and their plots, as well as the average growth rates, were shown in Figs. 3–7.

Fig. 2 depicts the usage of renewable energy as a percentage of total final energy consumption and its average growth rates. In general, there was a global steady trend within the last 30 years with high levels of consumption in Nigeria which might reach full capacity usage of renewables. Regards the average growth rate, South Korea is the only economy among N11 that recorded a positive average growth rate of renewables.

Excluding south Korea, there is a general negative average growth in the energy trilemma index for other investigated countries, as shown in Fig. 3.

Fig. 4 displays the GDP trend in constant 2015 dollars. Vietnam has a higher average growth rate than the other nations, with Bangladesh and South Korea coming in second and third.

Fig. 5 indicates that the Philippines recorded the highest levels of economic complexity index followed by Vietnam and Turkey among the N11 region.

The monetary sector credit to the private sector as a percentage of GDP is depicted in Fig. 6. Expanding the average growth of financial development was seen in N11 except for Indonesia and Pakistan which recorded a negative average growth rate of financial expansion. While these nations recorded an increasing trend in urban population and average growth rates as shown in Fig. 7.

4.2. Model specification

This study tries to examine the impact of energy trilemma and economic growth on the renewable energy of 11 countries, using ECI, URB and FD from 1990 to 2021 as control variables in reference to the studies of [60,61] and is represented as illustrated in equation (1).

Table 1
Variables descriptions.

Variables	Symbols	Measurements	Data Source
Dependent variables			
Renewable energy	*RE*	Renewable energy consumption (% of total final energy consumption)	WDI
Independent variables			
Energy Trilemma	*ET*		WDI
Energy Equity		Access to electricity (% of population)	WDI
Environmental sustainability		CO_2 emissions (Kt)	WDI
Energy security		Energy imports, net (% of energy use)	WDI
Gross domestic product	GDP	GDP (constant 2015 US$)	WDI
Control variables			
Economic complexity index	ECI	Economic complexity index	Our World in Data
Financial development	FD	Monetary sector credit to private sector (%GDP)	WDI
Urbanization	URB	Urban population (% of total population)	WDI

Table 2
Descriptive statistics.

	RE	ET	GDP	ECI	FD	URB
Mean	30.7893	3.72E-1	4.32E+1	−0.3019	38.6354	524392
Median	26.7100	0.0155	3.08E+1	−0.3678	27.8966	429374
Maximum	88.6800	2.5127	1.69E+1	2.3586	171.4942	1.58E+0
Minimum	0.4400	−2.4828	4.51E+1	−2.7642	0.0000	137725
Std. Dev.	26.2810	1.2693	3.59E+1	0.9433	31.1936	271586
Observations	352	352	352	352	352	352

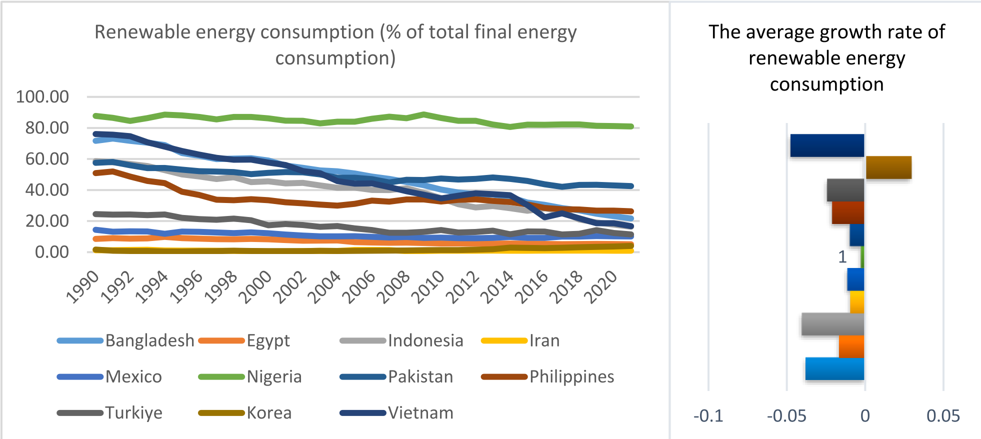

Fig. 2. Shows the usage of renewable energy and average growth rates.

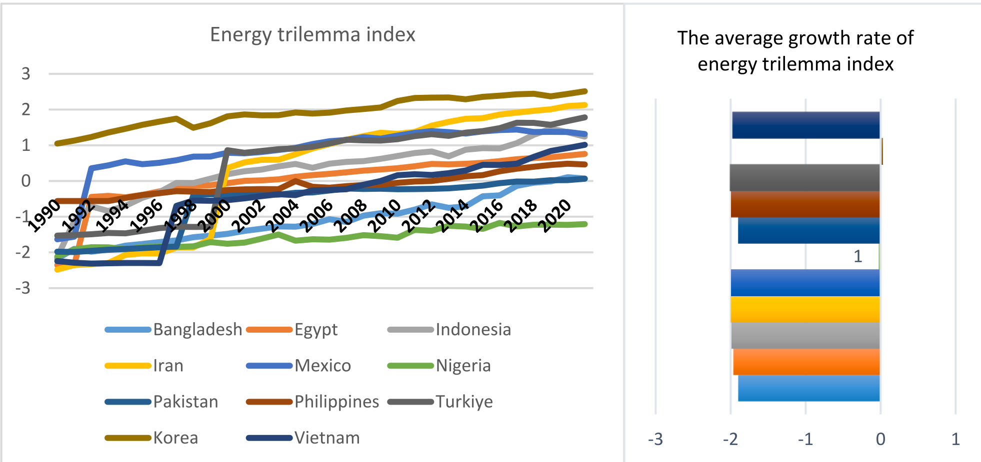

Fig. 3. Shows energy trilemma index and average growth rates.

$$LRE_{kp} = \delta_0 + \delta_1 LET_{kp} + \delta_2 LGDP_{kp} + \delta_3 LECI_{kp} + \delta_4 LFD_{kp} + \delta_5 LURB_{kp} + \xi_{kp} \tag{1}$$

Where, the subscript K = 1, …, N for each nation and P = 1, …, T denotes the study's timeframe from 1990 to 2021, LRE denotes the renewable energy, LET stands for the energy trilemma, LGDP denotes the gross domestic product, LECI represents the economic complexity index, LFD stands for the financial development and LURB presents the urban population growth. Using the renewable energy as the dependent variable, while the energy trilemma and GDP (constant 2015 US$) are the independent variables. δ_0 represent the intercept and $\delta_1 - \delta_5$ denotes the coefficients of the explanatory and control variables (energy trilemma, gross domestic product, economic complexity index, financial development and urban population growth), respectively and ξ is the error term.

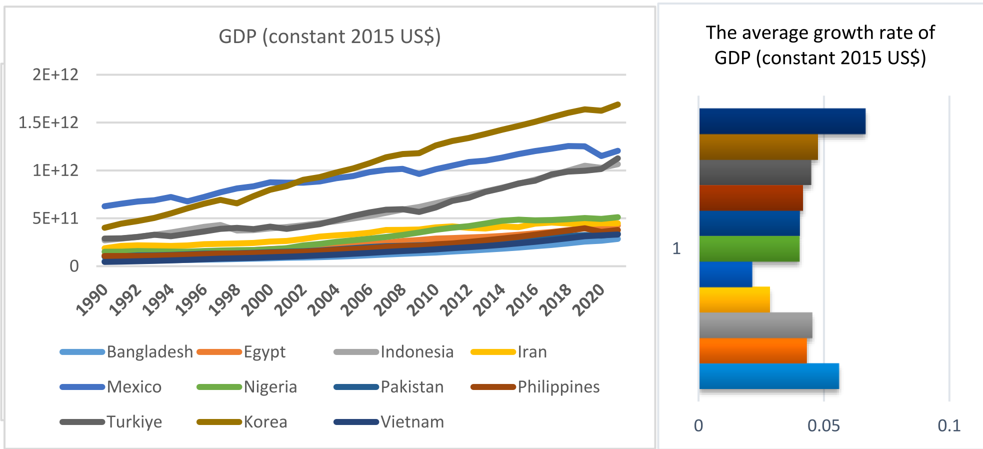

Fig. 4. Shows GDP (constant 2015$) and average growth rates.

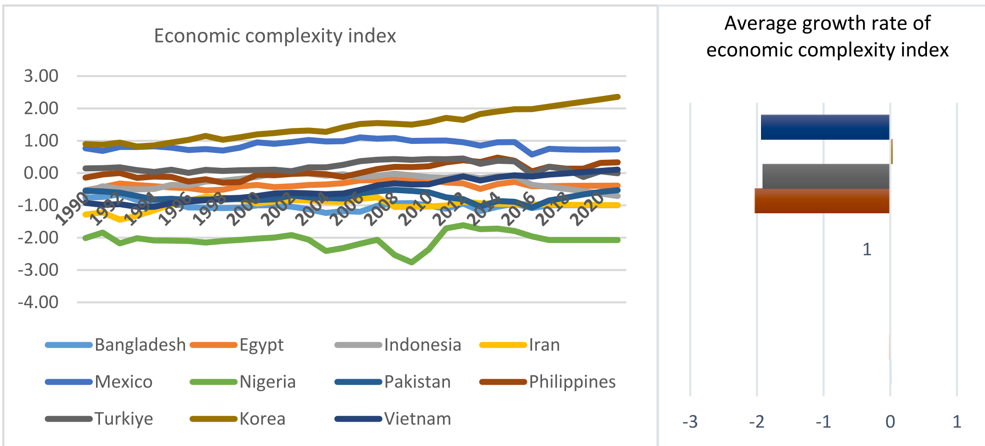

Fig. 5. Shows economic complexity index and average growth rates.

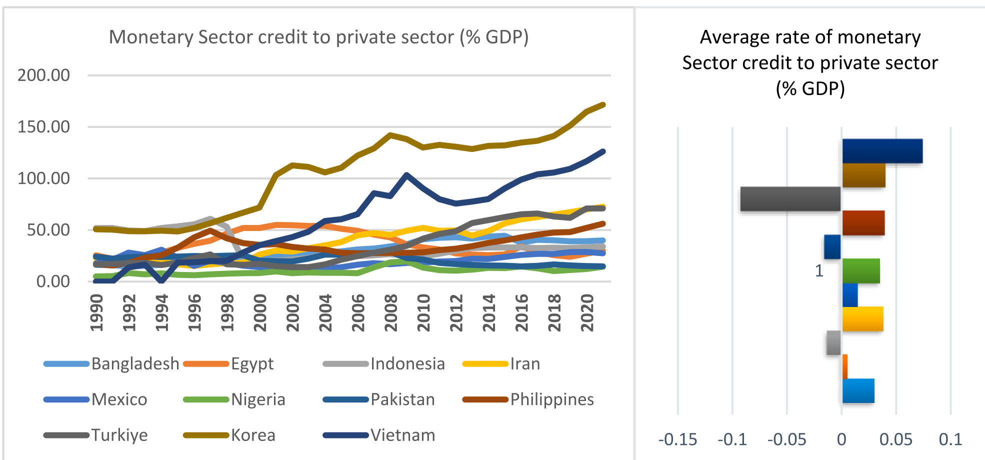

Fig. 6. Shows financial development and average growth rates.

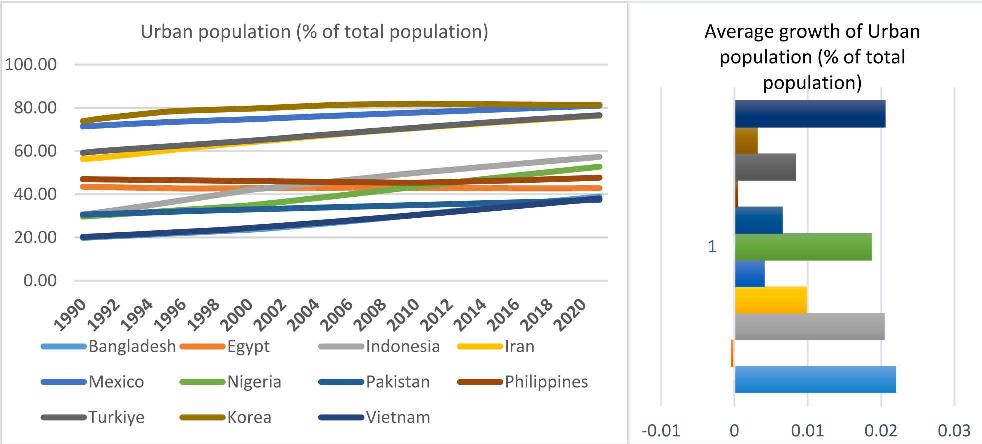

Fig. 7. Shows urban population (% of total population) and average growth rates.

4.3. Estimation method

In this research, we designed a panel quantile regression approach to investigate the relationship between the RE and ET in chosen nations. First, the pre-eliminatory investigation of the variables under study using descriptive statistics comes first before the estimating analysis. Then, for examining the most appropriate unit root and co-integration tests for the estimated model, the study employs five well-known tests, including second-generation unit root tests, namely Levin-Lin-Chu (LLC) [62], Im-Pesaran-Shin (IPS) [63], ADF Fisher χ^2, Phillips-Perron (PP) Fisher χ^2 [64,65] and the Cross-sectional augmented IPS (CIPS)(Im-Pesaran-Shin) [63,66]. As it known that the unit root tests used to check the stationarity of the variables under study, which also play a foundational role in time series and panel data analysis by guiding model specification, preventing spurious results, facilitating cointegration analysis, and contributing to accurate forecasting. Recent econometrics literature has developed the second unit root generation tests to address the problem of cross-sectional dependence across the panel units. Next, to determine whether the series are co-integrated, the study uses the Pedroni [67,68] and Kao co-integration tests [69]. Cointegration tests hold paramount importance in time series and panel data analysis by detecting and validating long-term relationships among variables. These tests serve as a crucial safeguard against spurious regression, ensuring that observed relationships are not merely a result of random fluctuations in non-stationary time series.

In ad€dition, to verify the existence of the cross-sectional dependency, the study uses four different tests to ensure the accuracy of the results, comprising [68,70–72] with the null hypothesis of cross-sectional independence. In panel data analysis, cross-section dependence tests are essential for evaluating the validity of empirical results. Ignoring cross-section dependence can lead to biased estimates and compromised statistical inferences. These assessments act as diagnostic tools, assisting researchers in choosing models and guaranteeing the validity of their findings. Cross-section dependence tests improve the precision and generalizability of empirical findings by addressing the assumption of independence across cross-sectional units. Before going to the quantile estimation, the study uses two forms of panel data regression: the fixed effect (FEM) and random effect (REM) model, then applying the Hausman test to decide on the ideal model. Next, for the diagnostic and robustness check the study applied different tests, including serial correlation LM test to check the absence of serial correlation. The null hypothesis illustrates that the error term has no serial autocorrelation, against serial correlation as an alternative. Modified Wald test to verify the absence of the heteroscedasticity. The null hypothesis affirms that the error term has constant variance (homoskedasticity), against non-constant variance (heteroscedasticity) as an alternative. the Variance Inflation Factor "VIF" as a test for check multicollinearity problem. VIF values range from one to ten. VIF is a numerical value that indicates how much the variance or squared standard error is inflated for each coefficient, if VIF = 1 indicates no correlation, range between 1 and 5 indicate weak correlation, range between 5 and 9 indicate moderate correlation while more than 10 indicates high correlation and is cause for concern. At the end, estimating the non-additive fixed effect panel quantile approach which is one of the innovative approaches developed recently by Ref. [73].

The use of this new method for estimating in panel quantile regressions resolves the endogeneity problem related to the fixed effects factor. The original concept of quantile regression, introduced by Ref. [74], aimed to extend the concept of univariate quantile estimation to evaluate conditional quantile functions. These functions represent the quantiles of the dependent variable's conditional distribution, expressed as functions of the observed regressors. This approach is beneficial for studying the asymmetric characteristics of the outcome variable distributions. Quantile regression is more resilient to outliers than the Ordinary Least Squares (OLS) method and allows for investigation into the factors of RE across the conditional distribution. Unlike OLS regression, which is sensitive to outliers and focuses on the mean effect, quantile regression can handle the impact of outliers and provides a detailed understanding of the distribution. According to Ref. [75], the mean effect obtained from OLS regression may not be reliable when explaining the estimated coefficients in models with heterogeneous responses. This means that quantile regression is appropriate for exploring the influence of different factors on RE at various points of the conditional distribution of the dependent variable. Recently, there has been increased attention on using panel data to combine quantile regression models, as noted by Ref. [76]. Regarding regression models, fixed effects can be included in panel data to account for within-group variation. However, the addition of these fixed effects can change the original model. Powell has proposed a new method that is specifically developed to enable robust inferences regarding the long-run coverage for broad persistence patterns. Powell recently developed a new method that aims to provide reliable statistical conclusions about the ability to cover long-term persistence patterns. This technique is suitable for estimating quantiles that have a fixed effect (γ_k) depends on the assessment of the distribution of y_{kp}/x_{kp} instead of $y_{kp} - \gamma_k/x_{kp}$.

Powell asserts that the latter estimate lacks consistency in numerous empirical situations. Powell's key defense is that the additive fixed effects models are unable to produce data on the elements that influence the result distribution caused by policy due to the likelihood that the values at the top of $y_{kp} - \gamma_k$ distribution probably be at the bottom of y_{kp}. As a result, the method suggested by Ref. [77] provides point estimates that we can rationalize in a manner analogous to that of those produced by cross-sectional regression models.

The underlying model of this study is represented following Powell's methodology as mentioned in equation (2).

$$y_{kp} = \sum_j x'_{kp}\delta_j(\xi_{*kp}), \xi_{*kp} \sim \xi(0,1) \tag{2}$$

Where y_{kp} is renewable energy consumption, x'_{kp} denotes the regressors, δ_j represents the parameters, and ε_{*it} stands for the error terms. This model's coefficients are supposed to be linear. and $x'_{kp}\delta_j$ (θ) raises accurately in θ. Commonly, for the θ^{th} quantile of y_{kp}, the quantile model counts on this conditional restriction which is represented as follows:

$$\mathrm{P}\left(y_{kp} \le x'_{kp}\delta_j(\theta) \,/\, x_{kp}\right) = \theta, \theta \in [0,1] \tag{3}$$

In equation (3), the likelihood of the latent result component is less than that of the quantile function, the same as all x_{kp} ; and the same as. θ. This probability may vary both by unit and within the unit according to Ref. [77] quantile regression estimator for panel data, provided that the variation is orthogonal to the instrument. In light of conditional and unconditional constraint, the Powell's estimator is thus expressed as follows:

$$\mathrm{P}\left(y_{kp} \le x'_{it}\delta_j(\theta) \,/\, x_{kp}\right) = \mathrm{P}\left(y_{ks} \le x'_{ks}\delta_j(\theta) \,/\, x_{kp}\right), x_k = (x_{k1}, \ldots, x_{kp})$$

The process of estimating the quantile regression model involves using numerical optimization through adaptive Markov Chain Monte Carlo sampling (MCMC). A multivariate normal distribution provided by Ref. [78] is used to carry out the MCMC optimization.

Table 3
Unit root.

Variables	Test	Level	First difference
RE	LLC	−1.0416	−5.5088[a]
	IPS	1.2037	−9.9939[a]
	Fisher-ADF	22.2731	135.253[a]
	Fisher-PP	15.4335	245.135[a]
	CIPS	−2.4143**	−3.3959[a]
ET	LLC	−3.0560[a]	−66.7484[a]
	IPS	−2.4942[a]	−34.7034[a]
	Fisher-ADF	67.9333[a]	173.717[a]
	Fisher-PP	65.3747[a]	254.607[a]
	CIPS	−1.9953	−3.0067[a]
GDP	LLC	6.0707	−2.8601[a]
	IPS	9.8851	−4.4649[a]
	Fisher-ADF	1.1781	67.0373[a]
	Fisher-PP	1.4705	131.966[a]
	CIPS	−1.4349	−3.1581[a]
ECI	LLC	0.9911	−10.1737[a]
	IPS	0.1411	−11.3566[a]
	Fisher-ADF	28.3351	156.899[a]
	Fisher-PP	26.0149	263.002[a]
	CIPS	−1.7459	−3.3312[a]
FD	LLC	−0.0372	−5.7568[a]
	IPS	1.1246	−6.8738[a]
	Fisher-ADF	14.8174	91.5787[a]
	Fisher-PP	10.0088	162.787[a]
	CIPS	−2.0874	−3.0531[a]
URB	LLC	2.4245**	−0.2461
	IPS	6.3744	1.2446
	Fisher-ADF	7.6648	19.0716
	Fisher-PP	23.2140	10.1374
	CIPS	−2.3361**	−1.8718

[a] Denotes 0.01 significance level.

Furthermore, we can state that the Powell non-additive fixed effect panel quantile method is frequently chosen since it can overcome the drawbacks of other quantile regression techniques as well as traditional fixed effects models. When dealing with data sets that show significant heterogeneity and when it is thought to be implausible to assume constant effects across quantiles, researchers opt for this approach. Non-additive fixed effects are permitted under Powell's approach, which recognizes that the influence of variables may differ among various portions of the conditional distribution. This flexibility is especially important when researching economic phenomena that exhibit heterogeneous responses across entities or at different places in the outcome distribution to explanatory variables. Powell's method offers a more realistic representation of complicated interactions by allowing for non-additive fixed effects. This gives researchers a valuable tool to investigate subtle patterns within panel data. The method is preferred in empirical research seeking a thorough and accurate study of panel data dynamics due to its superiority in capturing distributional variability, particularly in scenarios where traditional fixed effects models may be inadequate. Powell's approach is valued by researchers because it can accommodate the complexities of real-world data while also improving the depth of findings.

In addition, the study used the symmetric quantiles test, and the quantile slope equality test are statistical tests that are often employed in the context of quantile regression. Both tests are designed to assess whether the conditional quantile functions of two or more groups are equal across various quantiles. First, the null hypothesis for the symmetric quantiles test is that the conditional quantile functions of two or more groups are symmetric around a specified quantile. Second, the null hypothesis for the quantile slope equality test is that the quantile slopes (coefficients) of the explanatory variables are equal across different quantiles and groups. In both cases, rejection of the null hypothesis indicates evidence against the equality of conditional quantile functions or quantile slopes across groups. These tests are valuable in exploring heterogeneity in the effects of variables across different parts of the conditional distribution and are particularly useful when analyzing data with asymmetric or non-constant effects [61].

Finally, for robustness check the study uses the Feasible Generalized Least Squares (FGLS) method, which is very important, particularly when working with data that deviates from the traditional assumptions of serial independence and homoscedasticity. Because FGLS is built to handle autocorrelation and heteroscedasticity, it offers more accurate parameter estimates than Ordinary Least Squares (OLS) when these violations occur. These problems are common in time series and panel data analysis, where this strategy is especially helpful. Researchers can improve the precision of statistical inferences and the general reliability of empirical findings by using FGLS to provide more objective and precise estimations. The use of FGLS in econometric modeling is essential because it allows researchers to acquire reliable estimates even when faced with imperfect data, improving the accuracy and integrity of econometric analysis [79].

5. Empirical findings

Table 3 represents the results of the unit root tests, which illustrate the rejection of the null hypothesis at 1 % significant level for all the variables after accounting for the first difference, with the exception of URB which is stationary at level. Then, the results of the four different cross-section dependence tests are shown at Table 4, which indicate that based on the various tests we will statistically reject the null hypothesis of cross-sectional independence at the 1 % significant level, so the data suffer from cross-section dependence problem. Therefore, the study employs the CIPS second-generation unit root test not only the first-generation unit root tests.

Based on the outcomes of the unit root tests, we can go to examine the presence of the long-run relationship across the variables using the Pedroni [67,68] panel co-integration test. The results of co-integrations test displayed in Table 5 the rejection of the null hypothesis no co-integration, so the long run relationship between the series is supported by the Pedroni test. To select the most appropriate econometric specifications, the study uses the fixed effect and random effect estimation. According to Ref. [80] results which is depicted in Table 6, the fixed effects model is better in our analysis. Next, the results of the diagnostics and robustness check of the model are represented in Table 7, which indicate that the model doesn't suffer from any diagnostic problem, and this indicates that the long-term estimation of this model is reliable. The model represents no heteroscedasticity effects, no evidence of serial correlation in the residual terms and no multi-collinearity problem.

Table 8 represents the quantile regression model's findings for five distinct percentiles of the distribution of RE consumption. Fig. 8 demonstrates the associated Powell's panel quantile regression graphs. Accordingly, RE consumption presents our response variable and ET, GDP and additional control variables are the regressors of our model.

The symmetric test quantiles and the slope equality test quantiles estimated coefficients are both contrasted by the Wald's test statistic, are represented in Tables 9 and 10, respectively. First, Table 9 shows that the Wald test statistic value is around 431.17.and statistically significant at 0.01 level of significance, which indicates that the conditional quantile is not constant and that the coefficients are heterogeneous, varying across quantile levels. second, Table 10 shows that Wald test statistic, which is around 138, is statistically significant at the 0.01 level of significance, demonstrating signs of asymmetry across all of the quantiles being considered.

Table 4
Cross-section dependence tests.

Test	RE	ET	GDP	ECI	FD	URB
Breusch-Pagan LM	982.4259[a]	1322.918[a]	1670.576[a]	274.7004[a]	553.5887[a]	1717.620[a]
Pesaran scaled LM	88.42659[a]	120.8912[a]	154.0391[a]	20.94761[a]	47.53857[a]	158.5246[a]
Bias-corrected scaled LM	88.24917[a]	120.7138[a]	153.8617[a]	20.77019[a]	47.36115[a]	158.3472[a]
Pesaran CD	19.44643[a]	36.25070[a]	40.86468[a]	6.014286[a]	5.531707[a]	41.43454[a]

[a] Denotes 0.01, significance level.

Table 5
Panel co-integration test.

Within-dim.				Between-dim.		
	Test	Stat.	Prob.	Test	Stat.	Prob.
Pedroni (1999)	Panel v-Stat	1.0675	0.1429	Group rho-Stat	1.5423	0.9385
	Panel rho-Stat	1.1518	0.8753	Group PP-Stat	−3.6708	0.0001***
	Panel PP-Stat	−2.5655	0.0052***	Group ADF-Stat	−1.9897	0.0233**
	Panel ADF-Stat	−2.5896	0.0048***			
Pedroni (2004)	Panel v-Stat	−1.0076	0.8432			
	Panel rho-Stat	1.2143	0.8877			
	Panel PP-Stat	−2.3073	0.0105**			
	Panel ADF-Stat	−2.2486	0.0123**			

***, ** denote 0.01 and 0.05 significance level accordingly.

Table 6
Estimation results of Fixed and Random Effect Model.

	Fixed Effect Model	Random Effect Model
ET	1.0951** (0.4949)	−1.6035*** (0.4909)
GDP	2.55E-1*** (2.87E-1)	2.36E-1*** (2.83E-1)
ECI	−3.8465** (1.5601)	−6.8321*** (1.4323)
FD	0.2021*** (0.0220)	−0.1747*** (0.0215)
URB	−4.71E-0*** (3.33E-0)	−4.27E-0*** (3.26E-0)
C	51.0292*** (1.8062)	47.5494*** (3.1107)
Hausman	82.5411***	
R-Sq.	0.9601	0.5522

***, ** denote 0.01 and 0.05 significance level accordingly.

Table 7
Diagnostics check results.

LM Serial Correlation test	Modified Wald test	Variables	VIF
155.675 (0.2754)	1.9423 (0.0720)	ET	3.58
		GDP	3.43
		ECI	3.20
		FD	2.53
		URB	1.80

Table 8
Estimation results of panel quantile regression.

	Q1	Q2	Q3	Q4	Q5
ET	2.7751** (1.1469)	14.7356*** (3.6485)	18.5616*** (2.3016)	19.3023*** (2.7851)	21.0310*** (3.3346)
GDP	3.82E-1*** (1.13E-1)	2.20E-1 (1.69E-1)	1.13E-1** (4.61E-1)	1.43E-1*** (3.41E-1)	1.39E-1*** (2.83E-1)
ECI	9.4911*** (3.1401)	−1.5095 (5.1201)	−8.8522*** (2.4206)	−9.5529*** (2.6564)	−8.0177*** (3.3998)
FD	0.1025*** (0.0380)	0.2062*** (0.0323)	0.1448*** (0.0325)	0.1282*** (0.0301)	0.1308*** (0.0418)
URB	4.36E-0*** (7.38E-0)	3.12E-0*** (1.05E-0)	1.39E-0** (5.65E-0)	1.10E-0*** (3.73E-0)	1.41E-0*** (2.94E-0)
C	−0.6059 (3.0688)	−3.4195 (3.9803)	14.6278*** (3.4633)	21.9619 *** (2.3113)	23.9367*** (2.1452)
Sparsity Quasi-LR statistic Prob (Quasi-LR statistic)	51.1601 55.8184 0.0000**	39.8669 165.4950 0.0000***	30.4174 490.8092 0.0000***	26.3959 804.6050 0.0000***	32.3691 873.6786 0.0000***

***, ** denote 0.01 and 0.05 significance level accordingly.

The results of these two tests support the decision to employ quantile modelling.

The parameter values for these models in Table 6 can be seen as long-run coefficients for the factors influencing the use of RE in the N11 countries. The fact that almost all of the model's variables are statistically significant can be noticed.

For the robustness check, Table 11 represents the estimation results of the FGLS method. The results indicate that ET, GDP, and FD

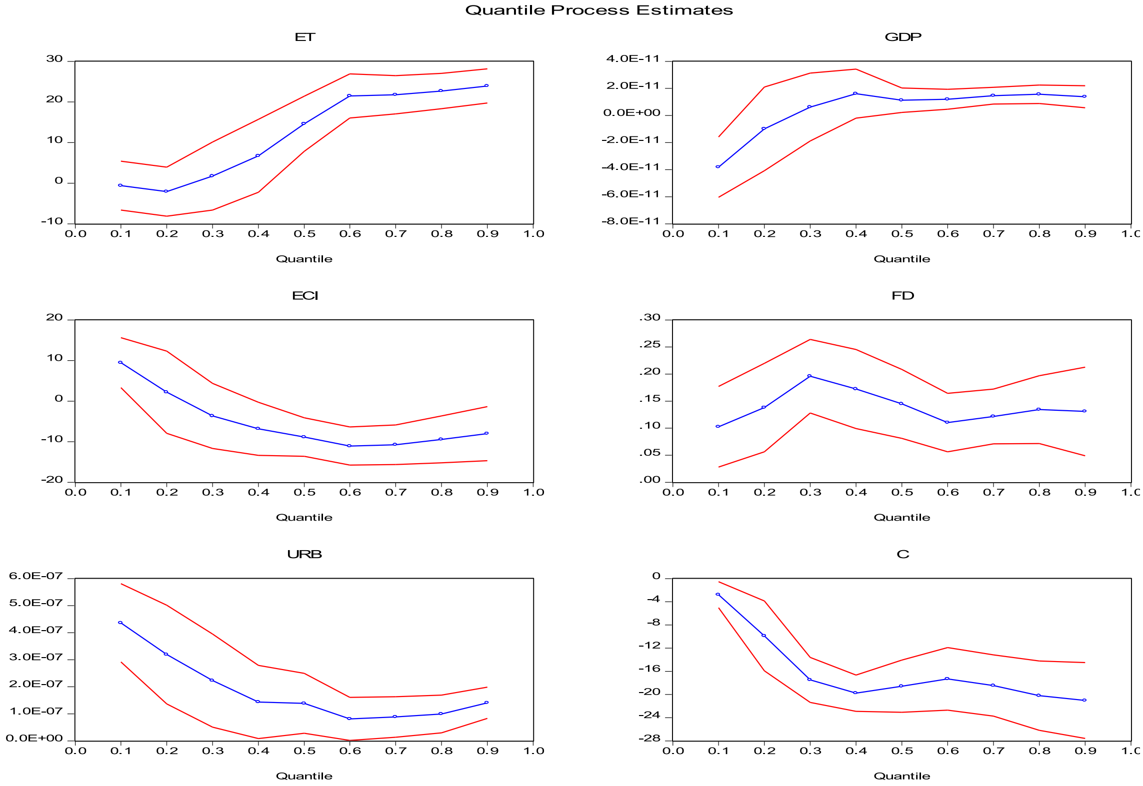

Fig. 8. 95 % Confidence intervals for Quantiles Process Powell (2016).

Table 9
Quantile wald slope equality test.

Test Summary		Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Wald Test		431.1718	20	0.0000
Restriction Detail: b(tau_h) - b(tau_k) = 0				
Quantiles	**Variable**	**Restr. Value**	**Std. Error**	**Prob.**
0.1, 0.25	ET	11.9604	3.2060	0.0002
	GDP	−3.59E-1	1.53E-1	0.0191
	ECI	11.0006	4.3957	0.0123
	FD	−0.1036	0.0341	0.0024
	URB	1.25E-0	9.65E-0	0.1959
0.25, 0.5	ET	3.8260	3.7179	0.3035
	GDP	−1.35E-1	1.51E-1	0.3738
	ECI	7.3426	4.8950	0.1336
	FD	0.0613	0.0310	0.0480
	URB	1.73E-0	9.43E-0	0.0668
0.5, 0.75	ET	0.7406	2.4180	0.7594
	GDP	−3.05E-1	4.28E-1	0.4756
	ECI	0.7007	2.5240	0.7813
	FD	0.0166	0.0330	0.6144
	URB	2.88E-0	4.74E-0	0.5437
0.75, 0.9	ET	1.7286	2.8693	0.5469
	GDP	4.31E-1	3.63E-1	0.9056
	ECI	−1.5351	2.8786	0.5938
	FD	−0.0026	0.0359	0.9411
	URB	−3.09E-0	3.16E-0	0.3286

Table 10
Symmetric wald quantiles test.

Test Summary		Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Wald Test		138.6995	12	0.0000
Restriction Detail: b(tau) + b(1-tau) - 2*b(0.5) = 0				
Quantiles	**Variable**	**Restr. Value**	**Std. Error**	**Prob.**
0.1, 0.9	C	−5.9250	6.6335	0.3718
	ET	13.3177	4.6907	0.0045
	GDP	−4.68E-1	1.24E-1	0.0002
	ECI	19.1778	5.4315	0.0004
	FD	−0.0563	0.0723	0.4362
	URB	3.00E-0	1.13E-0	0.0082
0.25, 0.75	C	−10.7137	5.4945	0.0512
	ET	3.0853	4.6567	0.5076
	GDP	−1.04E-1	1.48E-1	0.4817
	ECI	6.6419	5.3670	0.2159
	FD	0.0447	0.0521	0.3914
	URB	1.44E-0	1.07E-0	0.1771

Table 11
Estimation results of FGLS.

	Coefficients
ET	7.4462*** (1.0050)
GDP	4.81e-1*** (3.76e-1)
ECI	−10.1435*** (1.19660)
FD	0.0722** (0.0306)
URB	−1.0079*** (0.0698)
C	60.486*** (3.7232)

have a statistically significant positive effect on renewable energy, while ECI and URB have a statistically significant negative effect on renewable energy. In this way we can say that the robustness check results fortify the robustness and credibility of our findings, aligning seamlessly with the outcomes derived from the quantile estimations. This consistency across different methodological approaches enhances the internal validity of our study, affirming the reliability of the observed relationships.

6. Discussions

The summation of a panel quantile regression model findings depiction of the research explanatory variables is provided in Table (8) and Figure (9). According to the regression coefficients, all regressors in the N11 economies are significantly and positively related to renewable energy, excluding those associated with the economic complexity index which is significant and negative. According to the results, we accept all hypotheses that are formulated depending on related theories. Moreover, ET, URB, and FD are significant in Q1, Q2, Q3, Q4, and Q5, and the same for GDP and ECI except that they are insignificant in Q2.

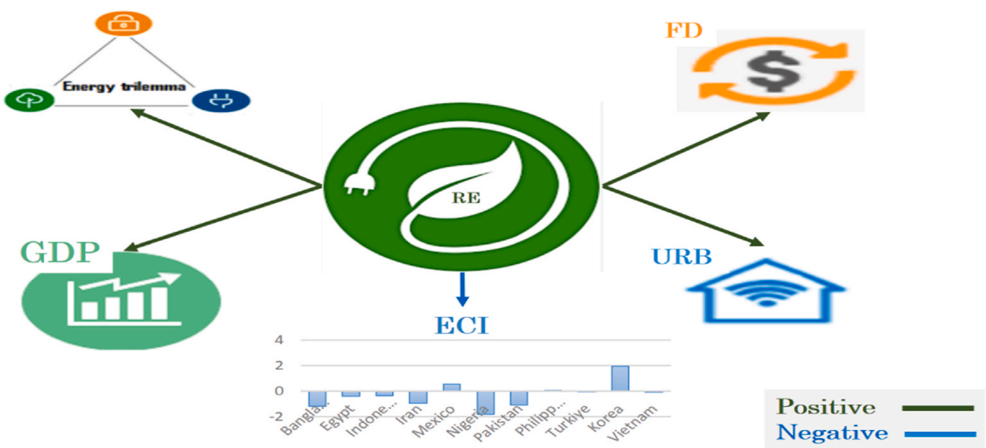

Fig. 9. A panel quantile regression model findings depiction for the study regressors.

The positive correlation between the energy trilemma index and renewable fuels means that N11 governments try to get a high score in the energy trilemma index of national energy system performances by utilizing renewable sources. In other words, environmental sustainability promotes the deployment of renewable fuels which play a significant role in mitigating carbon emissions and global warming [3,29,[81][82]83–88]. Renewables are a crucial aspect of environmental sustainability, which N11 seeks to protect the ecosystem and preserve upcoming generations, the abundance of renewable energy resources, such as Egypt, a sunbelt country with significant potential to increase its energy capacity, particularly for wind and solar power [89,90] and China which leads the world in terms of production statistics, is regarded as the leading producers of wind and solar power, as well as the top local and foreign investor in renewable energy [91,92].

Besides, achieving efficient and cost-effective energy can promote renewable energy technologies that provide a reliable and affordable source of fuels for N11 countries. Fundamental elements of social sustainability, such as promoting economic development and alleviating energy poverty, can be achieved through clean sources. Promoting renewable energy sources is a potential way to achieve energy security, which is essential in terms of sustainability. In comparison to petroleum and coal, which are readily accessible in particular places and have unpredictable cost fluctuations, renewable energy sources are generally available and have relatively stable costs. We can improve our energy security and economic resilience by diversifying our energy mix and minimizing our reliance on imported non-renewables [7,93].

The panel quantile regression projections in this analysis reveal that the positive influence of GDP is sufficient to validate the first hypothesis of this research which is a significant motivator of renewable energy generation in N11 nations. Given that higher income levels place a greater demand on the energy necessary for economic activity, this finding is in line with the anticipated effects of GDP. This demonstrates how policies must be designed to intensify spending on RE sources to keep up with demand [[94]95–97].

Furthermore, the results indicate that financial development also can trigger a rise of the adoption of renewable power, which might be attributed to the investment activity of private funders in the green industrial sector, that is considered one of the key drivers of ecological quality and this finding is parallel with many studies such as [98–100]. Furthermore, increased urbanization enhances the acceleration of renewable energy adaptation, resulting in a sustainable ecology. This significant positive nexus refers to the rapid increase in green urbanization resulting in the trend to planned urbanization, and greater dependence on renewables, especially biomass energy [101–104].

Contrariwise, the negative sign of renewables and ECI correspond to the conducted outcomes given the complexities in many N11 economies as developing nations, it is pivotal to reassess the environmental issues of this influencer in the renewable energies framework [37,105–107].

7. Conclusion and recommendations

The impact of the energy trilemma index, economic progress, economic complexity index, financial development, and urbanization on the renewables in N11 economies is investigated in this research using the panel quantile regression technique from 1990 to 2021. The key results of the panel quantile approach reveal that excluding the ECI, all variables promote renewable energy utilization. So, politicians can supervise the impact of these variables when developing procedures aimed at triggering the transition to sustainable renewable energies.

Numerous developing nations, especially the N11 nations, have set environmental objectives for 2050 that call for zero carbon emissions. Consequently, to consider the Paris Agreement into account and enhance the effectiveness of their efforts to combat global warming, renewable energy administrators should be dedicated to it. In light of this, our research recommends revisiting the ET dimensions of energy equity, security, and environmental sustainability as a stage of transition to the post-carbon era and other associated challenges that rely on the ET index to assist N11 countries.

Policymakers who are engaged in deciding about energy security should concentrate on meeting demand by diversifying the energy mix to include cost-competitive renewables, even though energy security is closely linked to all aspects of society, including the health and education systems and the environment. And this can be done in a variety of ways, including assisting investors in switching to green investments and recycling projects, offering lenient loan terms, lowering taxes, especially early on in the life cycles of these environmentally friendly projects, or offering technical training courses to raise the knowledge and awareness of employees. Furthermore, because it impacts the whole world, energy cooperation among regions is necessary. This offers a framework for power exchanges between energy-poor and energy-rich countries. For sustainability, various technologies and fuels are projected to be required, including renewables and green hydrogen generation.

The N11 states ought to render their economic institutions less complex in light of the empirical findings. In these nations, where authorities can assist this process and create incentives to entice high-tech multinational companies, the stimulation of energy innovation processes will minimize fossil energy reliance and environmental pressure. This negative association between the complexity index and renewables should serve as a catalyst for economic and environmental regulation, resulting in more energy-efficient structures and a greener energy mix that is employed to meet an economy's overall energy needs.

The study also found a correlation between financial development and renewables. To improve governance quality by strengthening legal or institutional systems, implementing standards, and empowering supervisory organizations, as well as creating an efficacious regulatory environment to enhance financial inclusion, policymakers should strengthen governance organizations and then empower them to operate effectively to promote renewables. The productive procedure of these organizations would enable appropriate legislation, property rights, and anti-corruption measures, which, if regularly checked, would cut emissions and enhance renewables. Notwithstanding that power is essentially accessible in all metropolitan areas in the N11 nations, eco-friendly urbanism improvement for sustainable energy is a significant aspect that decision-makers must carry out to implement the provision of minimal energy as well as energy conservation. It could be executed by putting more reliance on RE sources, for instance by supporting solar energy generation on building rooftops and luring investors with accessible loans with reasonable rates of interest, particularly because most of the N11 countries, like Egypt, China, and South Korea, are regarded as Sun Belt nations.

Due to various environmental concerns, we focused on renewable energy in our analysis; nevertheless, for forthcoming research, we recommend extending the study's focus by analyzing hydrogen capabilities. To limit the adverse and unanticipated consequences of the pertinent concerns associated to the intermittent nature of renewables, additional research can improve the existing literature by analyzing the technology transfer aspect and energy breakthroughs in the N11 economy's green sector.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Data availability

Data is available at World Bank and the link is https://databank.worldbank.org/source/world-development-indicators. and at Our World in data and the link is: https://ourworldindata.org/

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CRediT authorship contribution statement

Dalia M. Ibrahiem: Writing – original draft, Methodology, Investigation, Conceptualization. **Nourhane Houssam:** Writing – review & editing, Methodology, Investigation. **Rehab R. Esily:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Narayan Sethi:** Writing – review & editing, Methodology, Conceptualization. **Hanaa Fouad:** Writing – review & editing, Writing – original draft, Methodology, Investigation.

Declaration of competing interest

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

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