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Novel research methods to evaluate renewable energy investment and environment: evidence from global data

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ABSTRACT

The global economy is facing a severe threat of global warming and climate change, where the primary cause of these issues is regarded as the carbon dioxide emissions. To eradicate such issues, this study tends to explore the global energy use, economic growth, renewable electricity and carbon emission throughout 1990–2020. Using various time-series econometric specifications, this study validates the stationarity of all these variables for the long-run estimations. Besides, this study detects the issue of data non-normality, due to which this study opted the novel and efficient quantile-on-quantile regression. The estimated outcomes asserted that energy use and economic growth significantly and severely enhance global carbon emissions at higher quantiles, whereas the magnitude of the influence is found weaker in the lower and lower-middle quantiles, thus validating energy use and economic growth as the factors of increased environmental degradation. On the contrary, renewable electricity significantly reduces the carbon emissions level only in the lower as and middle quantile, while the influence non-negative at the higher quantiles. This study recommends the use of renewable energy, increase renewable's investment, research and development, adoption energy efficient approaches to reduce fossil energy.

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1. Introduction

Economic growth stability, environmental degradation, and energy use are among the top issue for all economies across the globe. The fifth report of the Intergovernmental Panel on Climate Change (IPCC) in 2013 stated that global climate change would have a strong and considerable influence on national economic and social development. Likewise, the report believed that carbon dioxide (CO_2) emissions via the combustion of fossil fuels were the primary driver of climate change and global warming. More than a hundred nations have signed the 'Kyoto Protocol' in 1997, which established the objectives of CO_2 emissions reduction for the major

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industrialised economies in order to preserve mankind from the global warming threat (Shahzad et al., 2021). Developing and/or emerging economies perceive carbon-intensive energy limits as harmful to their attempts to expand their economies, implying that industrial or developed economies should enhance funding for initiatives to counteract global warming caused mostly by their industrial processes (Shahbaz, Hye, et al., 2013; Wang et al., 2021). Since the world economy's growth and prosperity is becoming heavily dependent on carbon-intensive energy, limiting energy usage or a reduction in power supply has major implications for income.

Controlling CO_2 emissions in oil-producing emerging nations, where natural gas and petroleum consumption and production are the important driving force of economic development, maybe difficult since it may ultimately impede the growth of the economy (Shahbaz, Tiwari, et al., 2013). Additionally, exogenous shocks such as production quotas and oil prices cause structural changes in the production as well as utilisation of petroleum products, resulting in an uneven reaction of growth and related environmental degradation, the implications of which vary by country (Awodumi & Adewuyi, 2020). Still, the global economic growth is reported as 3.7% as of 2018 just before the Covid-19 pandemic (World Economic Outlook, 2020). Also, the International Energy Agency revealed that demand for energy raised by 2.3%, which is recorded as the fastest pace of the decade. This further pushes growth of energy-related carbon emissions by 1.7%, which harms the globe's environmental quality due to its contribution to global warming.

As a matter of fact, the literature widely emphasises on the adverse impact of increased economic growth on energy consumption enhancement, which leads to environmental degradation and climate change via enhancing CO_2 emissions.[1] Still, economies are hesitant to minimise pollution at the expense of higher income. In other terms, continued economic progress is dependent on greater energy consumption, which leads to higher CO_2 emissions. Based on such persistency of the environmental issue, this study observed the exploration of the stated problem for various time series (country level) and panel economies (Ghazouani et al., 2020; Shahzad, Ferraz, et al., 2022). However, very limited attention has been paid to the prevailing issue from a global perspective, which motivates this study to empirically examine the stated problem at a wider scale. Therefore, this study tends attract the scholars attention towards the hidden facts about the association of CO2, economic growth, and non-renewable energy consumption at a global level (Shahzad, Elheddad, et al., 2022).

Nonetheless, the scholars have identified economic expansion and energy utilisation as the primary drivers of increased CO_2 emissions level. Yet, the scholars and policy-makers believe that the use of renewable energy resources could overcome the issue of an increased level of CO_2 emission while rebalancing economic growth in the world (Balsalobre-Lorente, 2018; Gielen, 2019). To be more specific, renewable energy can be produced by utilising the renewable natural resources such as solar, hydro, geothermal, etc. where generally renewable electricity is produced. Further, this renewable energy could be used in various industrial and manufacturing sectors, which could fulfil the energy requirement and reduce the use of traditiona fossil fuel and natural resources extraction. Besides fulfilling the energy need, renewable energy also helps in reducing the emissions level (Gielen, 2019). As a result, the growth of renewable energy has caught the interest of many countries, particularly the developed countries. In particular, the climate and energy framework European Union established 2030s objectives for increasing renewable energy contribution (at least 32 percent) and encouraging energy efficiency (at least 32.5 percent) . Indeed, the growth of renewable energy is regarded as one sound solution for reducing CO_2 emissions and achieving sustainable development goals (Lee, 2019). Yet, the authors observed a wide gap in the scientific research regarding the global level research although various studies have attempted to provide empirical evidence for countries and groups of countries. However, this study feels that these results are insufficient for a global level policy implication and need further research for appropriate and timely implications for controlling such global level issues.

This study aims to analyse the global level environmental conditions in response to the total energy used. Since the existing studies in the literature have widely anticipated in the country level or a panel level analysis of the association. However, the primary aim of this study is to investigate the global level data, which is quite a novel research area and contribution to the existing studies by analysing the most updated available dataset. Another aim of this study is to examine the influence of global economic growth on the global CO_2 emissions. Since the global economy is rapidly increasing since the last few decades. However, along with the economic growth, it is observed that the increased economic growth is more diverted towards the development of industrial sectors across the globe, where the use of non-renewable energy is more common. On the other hand, some developed economies have initiated projects for curbing environmental degradation and promoting environmental quality. However, such use of renewable energy is yet to develop at a mega level. Therefore, this study also aims to analyse whether renewable electricity could influence the environmental quality of the globe. Following the said objective, it could be mentioned that this study is a novel contribution to the existing literature since it enables scholars and policy-makers to adopt and implement policies for global concern, rather than the country-level policies.

The remaining study is organised in four sections: where Section-2 provides review if relevant literature covering all the variables under consideration; Section-3 presents data and methodology used to obtain empirical results; the obtained results are presented and discussed in Section-4; Section-5 represents the conclusion and policy implications.

2. Literature review

This section deals with some shreds of literature review related to the research. For topic clarity, it comprises three parts to understand the association between carbon emissions and energy use, economic growth, and renewable electricity.

Saboori and Sulaiman (2013), in their research, states that there is bi-directional causality between carbon dioxide emissions and energy consumption in all five ASEAN economies. In the short run, energy consumption causes carbon emissions; increasing consumption levels lead to increased emissions. In the long run, it is the inverse that increasing carbon emissions lead to higher consumption levels

(Chontanawat, 2020). Zou and Zhang (2020), in their case study of the Chinese thirty regions, investigated the carbon emissions, energy consumption, and economic growth for the year 2000 to the year 2017. They determined that energy consumption and carbon emissions are interconnected, due to which there exists a negative spill-over effect on carbon emissions in the provinces of the country. Their empirical outcomes show a statistically positive impact on the emissions while negative spillover impacts the surroundings. They concluded that energy consumption is an important factor in determining the positive association. Another novel study of ten Central & Eastern European countries from the year 2000 to 2017 estimated the bi-directional causality among GDP growth and the variables of financial development. The authors stated that rising financial development leads to increasing Carbon emission discharge. There is a positive and significant impact on energy consumption in CO_2 emissions (Manta et al., 2020). Golove and Schipper (1997) analysed the historical trends for carbon emissions and energy consumption. They suggested that the high levels of economic activity led to increased emissions. Increasing urbanisation has created rising demand for energy. Several studies highlighted that energy consumption and emissions usually came from households. Due to this, household emissions, including carbon and GHG (Greenhouse Gas), have constantly increased. They concluded that carbon behaviour and socioeconomic conditions directly or indirectly impact household emissions (Rafique et al., 2022; Zhao et al., 2022). They emphasised that education and effective government policies can be effective in reducing those emissions in high-risk areas (Ye et al., 2017). Additionally, another statistical analysis of the next eleven economies depicted the causality between carbon emissions, energy consumption, and the economy's growth. In the case of the United States, the authors found a Granger cause of energy consumption on carbon emissions respectively (Shahbaz et al., 2016).

Mardani et al. (2019), in their review study of 175 articles, applied the meta-analysis PRISMA method for analysing the association between carbon emissions and economic growth. It is a comprehensive overview of research articles that illustrates the bi-directional causality of economic growth trends and carbon dioxide emission from the year 1995 to the year 2017. They stated that causality exists when economic growth varies (increase or decrease), stimulating carbon emissions at high or low levels. However, a potential decrease in emissions might have opposed impact on the growth of the economy. Acaravci and Ozturk (2010), in their study, applied the autoregressive distributive lag (ARDL) approach to determine the casual association among carbon emissions, economic growth, and energy consumption. There is a positive association between GDP growth and carbon emissions in the long run and a negative association between carbon estimates and per capita GDP growth square. Further, the findings validate some countries' environmental Kuznets (EKC) hypothesis. In a time-series analysis of carbon emissions and economic growth of the next eleven countries for the period of 1972 to 2013. The paper emphasises that changes in economic growth policies and other advancements in the country cause changes among the variables (Shahbaz et al., 2016). In the case of India, a novel study from the period of 1971 to 2006, Ghosh (2010) investigated that there is only short-run causality (unidirectional) between economic growth to supply of energy to carbon emissions while there isn't any casualty between variables in the long-run analysis. Another research depicted that the economic growth of a country increases carbon emissions and there is an N-shaped EKC association between them (Balsalobre-Lorente, 2018). Antonakakis et al. (2017) examined the dynamic inter-association between carbon emissions, GDP, and energy consumption in 106 countries. They concluded that continuous growth of the economy escalates GHG emissions. Saboori and Sulaiman (2013) investigated the non-linear but significant effect of economic growth and carbon emissions in Thailand and Singapore, indicating that income contribution is less towards carbon emissions over time. The findings were mixed for different countries due to different levels of economic development. Further, they insisted that economic growth is not a solution to decrease carbon emissions in some countries. The Granger causality tests in ASEAN countries and unidirectional causality existed from emissions to economic growth in the long run (Lean & Smyth, 2010). Models were tested to analyse the environmental Kuznets hypothesis and authors recommended that economic growth does not reduce emissions or consumption of energy that causes environmental problems (Richmond & Kaufmann, 2006).

Since the issue of carbon emissions prevails in the last few decades, therefore, studies have suggested renewable energy as remedial measure for reduced emissions and environmental recovery (Cai et al., 2022; Luan et al., 2022; Qin, Hou, et al., 2021; Qin, Raheem, et al., 2021; Shahzad et al., 2021). The recent strand of literature extensively explores the role of renewable energy and renewable electricity in the environmental quality. Also, clean environment even helps in reducing the human health related issues in the pandemic period (Sharma, Tiwari, Jain, et al., 2021). For instance, the recent study of Sharma, Tiwari, Erkut, et al. (2021) explored that renewable energy although enhances environmental sustainability, still, development of renewable energy decline economic growth of the 27 European Union countries. Also, renewables help in reducing the harmful impact of pesticides, which is a major contributor of GHG emissions. Two-thirds of global energy demand can be supplied by renewable energy and can help in reducing GHG emissions (Gielen, 2019). Renewable electricity consumption, natural resources, and energy revolution enhance environmental conditions. There is a negative association between renewable electricity energy and carbon dioxide emissions. This stresses paying more attention to renewable energy consumption towards improving environmental quality. Germany, France, Italy, and United Kingdom has made significant improvement in this regard. Moreover, the econometric outcomes support the concept that natural resources and renewable energy reduce carbon emissions, depicting an inverse association between them (Balsalobre-Lorente, 2018). Gielen (2019) stated that transition towards renewable energy from conventional energy is necessary for socio-economic advantages and reduction of carbon and GHG emissions worldwide. Further, the increasing transmission towards renewable electricity will increase the supply of renewable resources to meet the global energy demand. Renewable energy is crucial for reducing carbon and GHG emissions. Robalino-López et al. (2014), in their study elaborated the model for carbon emissions from the year 1980 up to the year 2020. They suggested that carbon emissions can be controlled if there is enough increase in the Gross domestic product along with the renewable energy usage plus prolific fossil fuel technology. The study claimed that carbon is the crucial contributor to GHG emissions. In another notable research in the case of China, which is efficient in adopting renewable green energies and is becoming a world leader in deploying and investing in green energies in the future, Centre for strategic and international studies (CSIS). China has approved goals for renewable electricity development (Chiu, 2017). According to Qi et al. (2014), long-term emission targets prevent emission leakage in the country (China). They have an increasing contribution in non-fossil fuel energy for reducing carbon emissions. Furthermore, the authors investigated that carbon emissions and renewable energy has an inverse relationship. Every 1 percent increase in renewable energy leads to decreased carbon emissions (Zheng et al., 2021). They applied the quantile regression and the findings depicted that the direct effect of energy on emissions is less than the indirect effect that GDP influences the GHG emissions.

Following the above literature strand, this study noted that the available literature provides contradictory findings in terms of the nexus between carbon emissions and economic growth; where several studies claimed that positive association, while other argued the negative impact between them. Besides, all the studies are observed biased regarding the association between fossil fuel energy consumption and carbon emissions by utilising traditional approaches. Therefore, there is a need for exploring the said nexus via novel approach. Moreover there is limited literature available regarding renewable electricity, where the literature completely ignores the global case. In this context, the current study tends to explore the association between these variables at a global level.

3. Data and methodology

3.1. Theoretical framework and data

The global economy is rapidly expanding, and it is anticipated that this expansion will continue over time. Several economies throughout the world are dependent on agriculture, with agriculture being the primary dominating industry in these nations. However, owing to the recent resurgence of the industrial sector, agricultural land is diminishing. In addition, high population growth promotes deforestation. Increases in economic development and industrial sector energy use lead to environmental deterioration. The global economy is confronted with a tremendous energy demands, which is typically met via the utilisation of conventional energy sources. Such energy sources release CO2, which contributes to the degradation of the environment. Whereas environmental deterioration affects the global environment and human health, since it is an universal challenge. As a matter of fact, massive quantities of GHG emissions, such as CO2, methane, and nitrous oxide, are to blame for environmental damage. CO2 emissions are increased by the everyday usage of fossil fuels, enormous smoke releases from industries, and the utilisation of wood as a source of energy. Emissions of CO2 have consequences for the economy and other industries, like forestry and agriculture among others. On the other hand, renewable energy is regarded as a promising tool to recover from the increased pollution and CO_2 emissions level. For instance, the in the developed economies, the budget helps in financing the renewable energy sector, which is used to replace the traditional energy sector such as coal, oil, and natural gas. Specifically, the renewable energy sector help economies to accomplish their energy need from the renewable energy resources – generally known as renewable electricity. As a result, the pollution intensive industries are replaced by energy efficient, technologically advanced, and renewable energy resources. Consequently, the extraction of natural resources dropped down and so is the consumption of such resources. Thus, the level of CO_2 emissions, which is directly linked to the consumption non-renewable energy resources reduces and the economy tends to achieve environmental sustainability and carbon neutrality. Besides, the literature also provides evidence regarding the beneficial role of renewable energy on environmental quality and sustainability.

Based on the theoretical underpinning and objectives of the study, the current research used four variables, where the focus variable is the global environmental quality and captured by CO_2 emissions. The scholars and researchers are focussed on controlling CO2 emissions since it is considered the primary factor of climate change, global warming, and environmental degradation (Sarwar et al., 2019; Shahzad et al., 2021). The variable CO_2 is emissions due to the combustion of fossil fuel and is measured in kiloton (kt) The world economy is observed as rapidly increasing over time, which motivates the industrialists and investors to invest in the industrial sectors' expansion. Therefore, the industrial sector is more biased towards the use of non-renewable energy, which could enhance the global CO_2 emissions level. In this sense, current study uses economic growth – captured by gross domestic product (GDP) measured as constant US$2015 and energy use measured as kilowatt-hours (kWh). Moreover, the existing studies demonstrated that renewable energy could be used as a remedial measure to reduce environmental pollution (Balsalobre-Lorente, 2018; Gielen, 2019; Qi et al., 2014), where renewable electricity is a primary factor. Therefore, this study uses electricity from renewable energy ELREC, measured as a percentage of the total energy used. Data for all the variables are obtained from the World Development Indicators of World Bank (2022), covering the period from 1990 to 2020.

3.2. Data normality and descriptive statistics

In order to empirically analyse the time series data, we firstly provide the data in a summarised form. Specifically, the descriptive statistics for all the variables are calculated, including mean, median, and range (maximum and minimum) values. Besides, the deviation of observations from the mean values is also calculated – termed as standard deviation and indicates volatility in a variable throughout time. In addition, the data normality is also analysed, for which the skewness and Kurtosis are utilised. However, the comprehensive measure for data normality is the Jarque and Bera (1987) normality test, which undertakes both the skewness and excess Kurtosis to indicate whether the data is regular or irregular. The standard equation form of the said test is given as:

$$J.B = \frac{N}{6}\left(S^2 + \frac{(K-3)^2}{4}\right), \tag{1}$$

This test holds the null hypothesis that skewness and Kurtosis are equal to zero. However, the statistically significant estimate could lead to adopting an alternative hypothesis (non-normal distribution of the data.

3.2.1. Unit root testing

Stationarity in time series is a conventional issue in the econometric investigation. Before estimating the empirical model, it is important to analyse the stationarity or presence of unit root of the time series. In applied econometric analysis, conventional approaches are based on the normality proposition, indicating that the mean as well as variance are persistent across time (Khan et al., 2020). However, some numerous economic factors and indicators follows the property of non-normality or irregular distribution – referred to be the unit root component. However, in the non-stationary data, the conventional estimating approaches such as ordinary least square regression provides inaccurate and biased estimates. In this regard, the Dickey and Fuller (1979) proposed augmented Dickey-Fuller (ADF) unit root specifications, which is employed in this research work. This particular test is used to confirm the stationary property of all variables.

3.2.2. Quantile-on-quantile (QQ) regression

Current study employed QQ specification as per the suggestions and explanations of Sim and Zhou (2015). This technique is the generalisation of traditional quantile regression approach that analyzes the influence of one variable's quantiles over another variable's quantiles. The QQ approach further combines two techniques, firstly, quantile regression – analyse the influence of regressors on the response variable and secondly, non-parametric analysis. At first, the quantile regression is suggested by Koenker and Bassett (1978), which is an innovation to the conventional OLS regression models, where the averages of variables are compared. On the other hand, quantile regression may explain greater variance in quantiles, which allow economists to predict with lower margin of errors. Additionally, as discussed and presented by Stone (1977) and Cleveland (1979), classical regression reduces dimensionality to satisfy linear models, causing a loss in prediction ability. Conversely, the prediction power increases when the quantiles of regressors are contrasted to the focus variable's quantiles, as allowed by the QQ technique, since more variation is explained between the constructs (Shahzad et al., 2017). A standard equation for a non-parametric QQ regression model is as follows:

$$CO_{2,t} = \beta^{\theta}(\chi_t) + \mu_t^{\theta} \tag{2}$$

The prior equation depicts a framework where the CO_2 emissions are captures environmental degradation of the country in the available time period captured by t. Besides, χ_t is a vector that denotes a set of regressors separately, including GDP, EU, and ELREC across the selected time. Moreover, θ shows the θth quantile based on the standard conditional distribution, which is CO_2 emissions in this study. Besides, the component μ_t^{θ} indicates error term of the quantiles where the conditional θth is proposed equal to zero. Lastly, the $\beta^{\theta}(.)$ components of the equation are a unknown function due to lacking of information regarding the association between regressor(s) and dependent variable.

The QQ technique is related to the total behaviour of the constructions while examining the connection among multiple factors. In other words, whether positive or negative, all shocks to the χ have an identical influence on CO_2 emissions. The sort of disruptions in χ, for instance, may be negative or positive, and the CO_2 could react non-uniformly or uniformly.

In order to evaluate the effects of θth quantile of CO2 on the τth quantile of χ_t, the mentioned Eq. (2) is evaluated in conjunction with the χ_t applying regression analysis. In addition, because $\beta^{\theta}(\cdot)$ is undefined, the predicted first-order Taylor expansion function is shown below:

$$\beta^{\theta}(\chi_t) \approx \beta^{\theta}(\chi^{\tau}) + \beta^{\acute{\theta}}(\chi^{\tau})(\chi_t - \chi^{\tau}), \tag{3}$$

where $\beta^{\acute{\theta}}$ captures the partial derivatives of $\beta^{\theta}(X_t)$ for every single regressor – also known as the marginal or response effect. Further, the parameters are double indexed which as shown priorly in the Eq. (3): i.e., $\beta^{\theta}(\chi^{\tau})$ and $\beta^{\acute{\theta}}(\chi^{\tau})$ stands for θ and τ, respectively. Additionally, $\beta^{\theta}(\chi^{\tau})$ and $\beta^{\acute{\theta}}(\chi^{\tau})$ are the functions of χ^{τ}, which itself is a function of τ indicating that $\beta^{\theta}(.)$ and $\beta^{\acute{\theta}}(.)$ are the functions of θ and τ. Moreover, the function $\beta^{\theta}(X^{\tau})$ and $\beta^{\acute{\theta}}(X^{\tau})$ may be consequently transformed to $\beta_1(\theta,\ \tau)$ and $\beta_2(\theta,\ \tau)$. Thus, the transformed version of Eq. (3) could be presented below:

$$\beta^{\theta}(\chi^{\tau}) = \beta_1(\theta,\ \tau) + \beta_2(\theta,\ \tau)(\chi_t - \chi^{\tau}), \tag{4}$$

where the prior mentioned equation could adopt the following form after adjusting in the Eq. (2):

$$CO_{2,t} = \beta_1(\theta,\ \tau) + \beta_2(\theta,\ \tau)(\chi_t - \chi^{\tau}) + \mu_t^{\theta}, \tag{5}$$

(*)

where (*) below the prior equation indicates θth conditional quantile for CO_2 emissions. As mentioned earlier, the under discussion conditional quantile is different that the traditional conditioned quantiles due to double indexing: β_1 and β_2 in terms of θ and τ, that shows θth quantile of CO_2 emissions with the τth quantile of χ. The fluctuations may be present in the among the θth quantiles of CO_2 emissions and the τth quantile of χ, where no linear relation could be expected at a particular time between the variables. Hence, Eq. (5) examines the total interconnectedness using the distribution-based dependencies of the variables under consideration. Additionally, in the under-discussion equation, the parameters χ_t and χ^{τ} may be replaced with their predicted complements, i.e., $\hat{\chi}_t$ and $\hat{\chi}^{\tau}$, respectively. Thus, β_1 and β_2 are the predicted coefficients of the linear regression, which could be estimated via $b_1$and b_2 and can be analysed through the minimisation problem given as:

$$min_{b_1,\ b_2} \sum_{i=1}^{n} \rho_{\theta}\left[CO_{2,t} - b_1 - b_2(\hat{\chi}_t - \hat{\chi}^{\tau})\right] \times K\left(\frac{F_n(\chi_t) -\ \tau}{h}\right), \tag{6}$$

where $\rho_\theta(u)$ illustrates the quantile loss, which may be explained as $\rho_\theta(u) = u(\theta - I(u > 0))$, and '$I$' is the function represents unusual indicators. Moreover, K(*) reveals the kernel function where h captures the kernel bandwidth parameters.

In the current study, we utilised the Gaussian kernel to examine the weight of the χ^τ neighbourhood, which is a widely studied, popular and used kernel functions in the fields of economics as well as finance. Beside the benefit of being symmetric, this function has an advantage of simple to use and analyse, where lower weights are allotted to further observations. The mentioned distances and weights between the function's distribution of $\hat{\chi}_t$ is here negatively related, which is presented as $F_n(\hat{\chi}_t) = \frac{1}{n}\sum_{k=1}^{n} I(\hat{\chi}_k > \hat{\chi}_t)$, where the distribution function's value deals with the quantile of $\hat{\chi}^\tau$, captured by τ.

3.2.3. Frequency domain causality test

This study also aims to assess the causal effects of economic growth, energy use, and electricity from renewable energy on global CO_2 emissions at different frequencies. In this sense, the frequency domain causality test developed by Breitung and Candelon (2006) is used in this investigation. This test extends the earlier work of Geweke (1982) and Hosoya (1991). The key contrast here between frequency domain and time-domain techniques is that the 'time-domain' approach indicates whether a given fluctuation exists within a time-series, while the 'frequency-domain' method evaluates the degree of a specific variability in time-series (Gokmenoglu et al., 2019). As per Breitung and Candelon (2006; hereafter B.C), the frequency domain eliminates seasonality-based variations inside the small sample. Additionally, the B.C frequency domain testing may detect nonlinearities, causal cycles, and causalities among temporal components at both frequencies, i.e., low and high (Guan et al., 2020). In other terms, the B.C. frequency domain causation test distinguishes between long-run (permanent) and short-run (temporal) causality across time-series.

The econometric equation for the B.C frequency domain analysis is as follows: let $X_t = (H_t, C_t, D_t)$, where X t reflects the three-dimensional vector of endogenous and stationary observed variables at time ($t = 1, \ldots, T$). The proposition of this study is that X_t has a finite order VAR interpretation, which is described as below:

$$\theta(L).X_t = \varepsilon_t, \tag{7}$$

where $\theta(L)$ is a 3×3 lagged polynomial with p-order and presented as $\theta(L) = I - \theta_1 L^1 - \ldots - \theta_p L^p$, having $L^k X_t = X_{t-k}$. Further, the residual term is depicted with ε_t via following the white noise and expected as zero and $\varepsilon_t.\acute{\varepsilon}_t = \sum$. It is important to note that $\sum$ is symmetric as well as positive. Following the study of Breitung and Candelon (2006), there are no deterministic terms involved in the priorly mentioned equation.

Since $\sum$ is symmetric as well as positive, yet the Cholesky decomposition occurs $\acute{G}.G = \sum^{-1}$. Here, the lower triangular and the upper triangular matrix are depicted by the component G and $\acute{G}$, respectively. In this case, $E(\eta_t.\acute{\eta}_t) = I$, whereas $\eta_t = G.\varepsilon_t$. The MA representation after following Cholesky decomposition could be expressed as:

$$X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \theta(L).\varepsilon_t = \begin{bmatrix} \theta_{11}(L) & \theta_{12}(L) \\ \theta_{21}(L) & \theta_{22}(L) \\ \theta_{31}(L) & \theta_{32}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{bmatrix}, \tag{8}$$

$$X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \Psi(L).\eta_t = \begin{bmatrix} \Psi_{11}(L) & \Psi_{12}(L) \\ \Psi_{21}(L) & \Psi_{22}(L) \\ \Psi_{31}(L) & \Psi_{32}(L) \end{bmatrix} \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \\ \eta_{3t} \end{bmatrix}, \tag{9}$$

From the prior equations, $\phi(L) = \theta(L)^{-1}$ and $\Psi(L) = \phi(L)G^{-1}$. Using the representation, the spectral density of H_t may be presented as:

$$f_H(\omega) = \frac{1}{2\pi}\{\left|\Psi_{11}(e^{-i\omega})\right|^2 + \left|\Psi_{12}(e^{-i\omega})\right|^2 \tag{10}$$

where H_t could be depicted as the sum of two non-correlated processes of MA, as illustrated in Eqs. (8) and (9), the intrinsic component motivated by the prior implementation of H_t and the elements carrying the predictive capacity of the C_t and D_t factors. At every specific frequency ω, the ability of prediction of the C_t and D_t characteristics in relation to the forecasting component of the spectrum can be determined only using the fundamental component. The null hypothesis of no Granger causality is examined in the series. For instance, C_t does not Granger cause H_t at frequency if the predicting element of the H_t spectrum at frequency ω is zero. This improves Geweke (1982) and Hosoya (1991) causality tests for the 'x' and 'y' parameters, expressed as follows:

$$M_{x\to y}(\omega) = ln\left[\frac{2\pi f_y(\omega)}{\left|\Psi_{11}(e^{-i\omega})\right|^2}\right] \tag{11}$$

$$= ln\left[1 + \frac{\left|\Psi_{12}(e^{-i\omega})\right|^2}{\left|\Psi_{11}(e^{-i\omega})\right|^2}\right] \tag{12}$$

When $\left|\Psi_{12}(e^{-i\omega})\right|^2 = 0$, the prior equation associated to the measures of Geweke will be zero.

4. Results and discussion

The section of empirical results is initiated with descriptive statistics and the normality estimates as reported in Table 1. Specifically, the mean and median values for all the variables are found positive and have a small difference between the two. This indicates that all the variables are moving progressively. In their words, economic growth is in the increasing trend along with the increasing energy use, CO_2 emissions, and electricity from renewable energy globally. This statement is also noted from the range values of the variables, which are also found positive. Besides, the standard deviation of the variables is also provided that demonstrates volatility in a

Table 1. Descriptive statistics and normality test.

	GDP	CO_2	EU	ELREC
Mean	4.58E + 13	24405818	1630.424	2.087084
Median	4.10E + 13	22451917	1625.123	1.203530
Maximum	8.46E + 13	34041046	1919.992	6.765609
Minimum	1.80E + 13	15272289	1337.612	0.246678
Std. Dev.	2.04E + 13	5678957.0	197.3034	2.137490
Skewness	0.445902	0.450680	0.132168	1.136240
Kurtosis	1.925223	1.871232	1.580755	2.775172
Jarque-Bera	4.225996	4.520895	4.515617	11.29855
Probability	0.120875	0.104304	0.104579	0.003520

Source: author's own estimations on the data extracted from the given sources.

Table 2. Unit root test.

Augmented Dicky-Fuller unit root test		
Variables	I(0)	I(1)
CO_2	−1.902	−5.746***
GDP	−3.218*	–
EU	−2.676	−6.861***
ELREC	−2.506	−6.250***

Note: * is 10% significance level, ** is 5%, and *** is 1%. I(0) is level data and I(1) is for first difference.
Source: author's own estimations on the data extracted from the given sources.

particular variable or the deviation of observation from the mean value. In this sense, the standard deviation of the standard deviation for GDP ($2.04E^{13}$) is noted as the highest of all variables, followed by CO_2 emissions (5678957.0), energy use (197.3034) and the smallest deviation in electricity from renewable energy (2.137490). Besides, the parameters for indicating normality of the variables are also evaluated, where the statistics for skewness and Kurtosis are provided in the under-discussion table. However, this study employed the Jarque and Bera (1987) normality test that allows for skewness and excess Kurtosis at the same time. The empirical findings ofthe Jarque-Bera test reveals that the probability values for GDP, CO_2 emissions, and EU are insignificant, while significant only for ELREC, which rejects the null proposition of normal distribution of data. Hence, only ELREC is found irregularly distributed, whereas GDP, CO_2 emissions, and the EU are normally distributed.

In order to empirically analyse time series data, stationarity is a traditional issue to deal with. In this sense, current study utilised the Dickey and Fuller (1979) proposed ADF unit root testing specifications and the empirical results are provided in Table 2. The results indicate that only GDP is stationary at level [I(0)], while other variables are non-stationary at level. Therefore, this study tested the stationarity at first difference [I(1)], which leads to the rejection of null (presence of unit root). Hence, the significant estimates asserted that CO_2 emissions, EU, and ELREC is stationary. Thus, the stationary data allows the current study to analyse the association between the variables under-consideration empirically.

Since the Jarque and Bera (1987) estimates reveal that the variables follow a mixed path regarding distribution. Therefore, current study used the QQ regression that deals with the irregularity issue of time series. Figure 1 depicts a graphical representation of the relationship between EU and global CO2 emissions. According to Xu et al. (2021), the deeper blue colour represents a smaller coefficient value of impact,

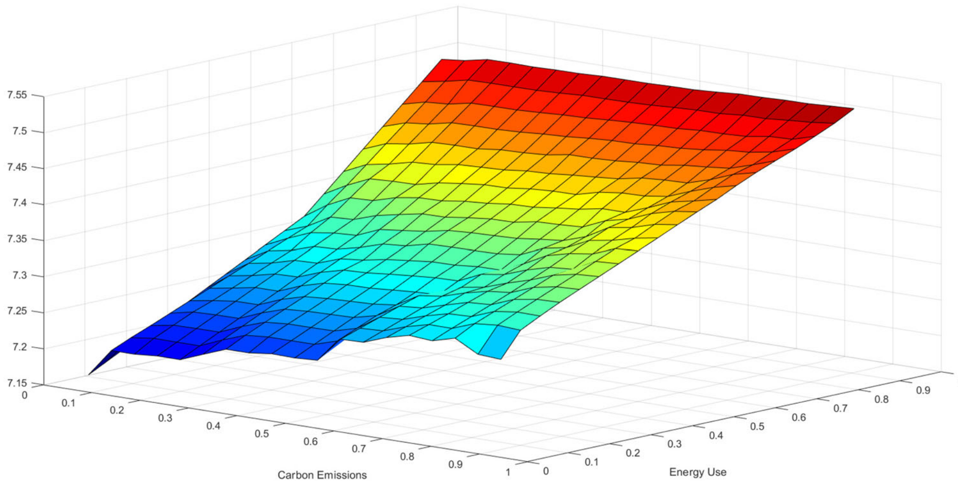

Figure 1. Quantile-on-quantile regression for CO_2 emissions and EU.
Note: The z-axis presents the coefficient values, the x-axis shows energy use, and the y-axis represents CO_2 emissions.
Source: author's own estimations on the data extracted from the given sources.

while the heavier red colour represents a greater magnitude value of regressor on the focus variable. The results of the said figure demonstrate a positive association between EU and CO_2 emissions across the quantiles. However, the magnitude value is different throughout different quantiles. However, the magnitude value of EU is positive in lower, medium and higher quantiles. Whereas the lower quantiles asserted that lower energy use is related to lower CO_2 emissions, the higher quantile asserted that, the higher use of energy leads to higher emissions of CO_2 globally. Such findings are consistent to the earlier study of Golove and Schipper (1997) as well as the recent studies of Chontanawat (2020), Zou and Zhang (2020), and Manta et al. (2020) for various developed and developing regions. The primary contributor to urban air pollution is the release of air contaminants from the burning of fossil fuels. The biggest cause of greenhouse gas emissions is also the combustion of fossil fuels. There is a fixed chance that oil will leak during any petroleum handling activity, either on land or in water, causing water pollution. Additionally, mining can contaminate water, which is an additional form of pollution to the environment. Modifications in groundwater flow brought on by mining activities frequently expose previously unpolluted streams to specific mineral substances that drain from the soil and result in acid mine drainage. Another by-product of several kinds of energy use is solid waste. Apart from the soil and water, the combustion of fossil fuel is regarded as the driver of CO_2 emissions in the atmosphere. It is well known that the industrial sector in emerging as well as developed economies are run by the traditional non-renewable energy, which is harmful in terms of increasing the pollution level and contributes to the formation of GHGs. In this case, the primary reason for the positive association of energy use and CO_2 emissions is that most countries across the globe are more attributed to economic growth maintenance and sustainability, where the industrial sector plays a substantial role in this regard. However, to run the industrial sector, these economies heavily depend upon traditional fossil fuel consumption, which is easy to use and produce. On the other hand, using such fossil fuel energy

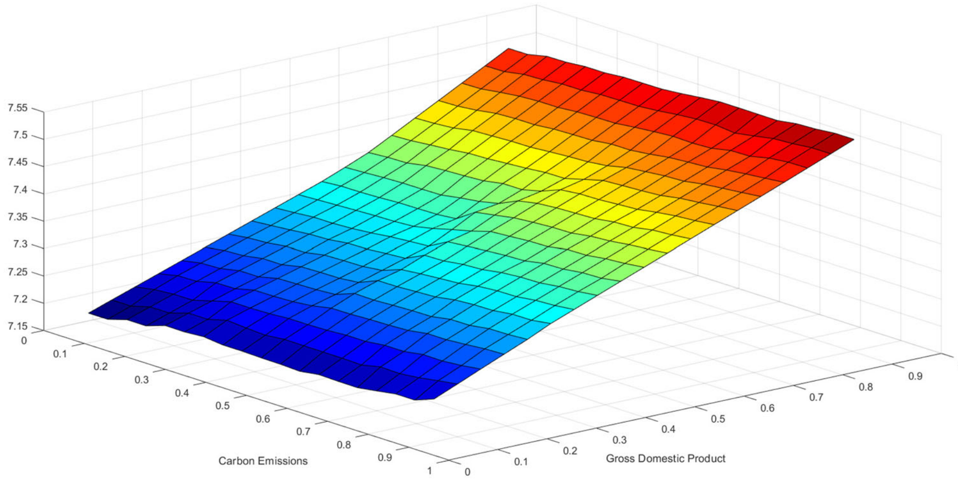

Figure 2. Quantile-on-quantile regression for CO_2 emissions and GDP.
Note: The z-axis presents the coefficient values, the x-axis shows gross domestic product, and the y-axis represents CO_2 emissions.
Source: author's own estimations on the data extracted from the given sources.

sources significantly and adversely affects the global environmental quality via increased CO_2 emissions. However, the increased production level and industrial expansion significantly promote non-renewable energy, which further fuel the CO2 emissions and leads to global level issues such as climate change, global warming, and environmental degradation.

Figure 2 indicates QQ results for the association between global economic growth and global CO_2 emissions throughout the study time period. The findings demonstrate a positive association between economic growth and CO_2 emissions. Nonetheless, the impact of economic growth is found heterogeneous across quantiles. The findings asserted that the lower quantile of GDP exhibit lower impact on the CO_2 emissions. However, economic growth enhancement is positively associated with the increased global CO_2 emissions between 1990 and 2020. However, the higher quantiles $(0.7 - 1)$ reported that economic growth enhancement significantly promotes economic growth by 7.35–7.55%. These results are consistent with the existing studies of Shahbaz et al. (2016) and Antonakakis et al. (2017) in a global sample of 106 economies. Enhanced economic growth significantly enhances the per capita income level of all the countries across the globe. However, the enhanced income level further increases the savings and investment at individual and aggregate levels. Whereas an increase in the investment level is mostly devoted to the increase of production level and the expansion of the industrial sector, which uses higher non-renewable energy use to fulfil the energy requirements. Whereas such energy consumption is a significant factor of CO_2 emissions globally. Environmental degradation is correlated with increased economic growth. When industrial activities rise in less developed nations, more energy-intensive goods are produced and more pollutants are emitted (Jiang et al., 2020). Losses from air pollution are mostly concentrated in a limited number of industry sectors: the top four sectors (agricultural, utilities, production, and transport) are responsible for even more than 75% of all air pollution-

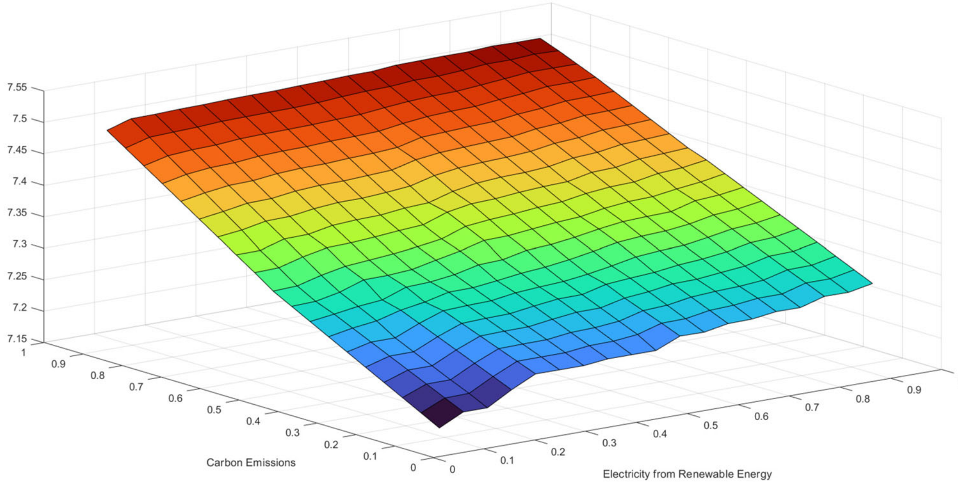

Figure 3. Quantile-on-quantile regression for CO_2 emissions and ELREC.
Note: The z-axis presents the coefficient values, the x-axis shows electricity from renewable energy, and the y-axis represents CO_2 emissions.
Source: author's own estimations on the data extracted from the given sources.

related harm but only contributes slightly more than 20 percent of GDP.[2] Thus, it is concluded that enhancement in economic growth is a prominent factor of increased environmental degradation. As per Saboori and Sulaiman (2013), economic growth is the leading source of increased pollution levels, and it cannot be a solution for curbing the emissions level.

A general perception is regarding the association of renewable energy consumption and carbon emissions is that renewable energy and renewable electricity are the promising factors of reduced CO_2 and GHG emissions in the countries (Balsalobre-Lorente, 2018; Gielen, 2019; Robalino-López et al., 2014). The reduction of CO_2 emissions and GHG emissions could significantly lead to the sustainability of environmental quality. However, the findings this study is contradictory in this sense. The empirical outcomes for the association between electricity from renewable energy and CO_2 emissions are provided in Figure 3. The results suggested that enhancement in the electricity from renewable energy does not significantly reduce CO_2 emissions, instead increases emissions. The primary reason for the positive association between the two is that most of the global sample countries are developing and emerging economies, where the ratio of renewable energy is much lower, relatively to a few developed economies such as the USA and Japan. Therefore, renewable electricity does not lower the global level CO_2 emissions. Besides, the literature also shows a lower direct effect of energy consumption on CO_2 emissions than the indirect effect of economic growth on the emissions level (Zheng et al., 2021). Further, the study noted that at the lower and middle quantiles, renewable electricity is negatively related to the CO_2 emissions. In other words, renewable electricity generation significantly reduces the pollution level in the initial stages. However, this significant impact becomes insignificant and even transformed into positive association by preferring higher economic growth over the environmental sustainability. The negative association between the renewables and emissions is consistent to the existing literature of

Table 3. Frequency domain causality test (2006).

Causality	Long run (ω = 0.05)(*p*-value)	Medium Run (ω = 1.50)(*p*-value)	Short run ($\omega = 2.50$) (*p*-value)
EU → CO_2	5.0825 (0.0788)*	5.3017 (0.0164)**	5.5718 (0.0617)*
GDP → CO_2	6.4245 (0.0403)**	4.8706 (0.0876)*	5.0328 (0.0808)*
ELREC → CO_2	4.6108 (0.0997)*	18.6961 (0.0001)***	17.7353 (0.0001)***

Note: *, ** and *** indicates 10%, 5%, and 1% significance level.
Source: author's own estimations on the data extracted from the given sources.

Cai et al. (2022), Sharma, Tiwari, Erkut, et al. (2021), Gielen (2019), and Qi et al. (2014). Thus, it is concluded that renewable energy could have a role in the reduction of emissions level. Yet, the increased economic growth motivates the countries as well as industries to expand and increase the production level via utilising the non-renewable energy sources, which is a primary source of increased pollution of the globe.

Since the QQ regression lacks the property of depicting the causal association between the variables under study. Therefore, the current study employed the frequency domain causality test suggested by Breitung and Candelon (2006). This test captures the long-run, medium-run, and short-run causal impact of EU, GDP, and ELREC on the global CO_2 emissions. The estimated results obtained are reported in Table 3. The empirical findings reveal that EU, GDP, and ELREC are significantly causes CO_2 emissions in all the runs (i.e., long-run, medium-run and long-run). However, the significance level is heterogeneous across different runs. Specifically, EU is noted to cause CO_2 emissions in the long-run ($\omega = 0.05$) at 10% level of significance, in the medium-run ($\omega = 1.50$) at 5% level, and in the short-run ($\omega = 2.50$) at 10% level, which is also presented in Figure 4. These findings are consistent to the findings of Saboori and Sulaiman (2013) and Manta et al. (2020) reveals energy use significantly causes pollution emissions in the country. Therefore, it is now validated that one of the primary reasons of increased CO_2 emissions is the non-renewable energy use. Besides, the causal impact of GDP on CO_2 emissions is more significant in the long-run than the medium-run and short-run. Therefore, the impact of economic growth could be seen as more substantial and adverse in the long-run, regarding environmental quality as depicted in Figure 5. Such findings are consistent with the study of Mardani et al. (2019) and Ghosh (2010) that validate the short-run causality from economic growth to CO_2 emissions. Lastly, the ELREC is also found a significant factor in CO_2 emissions from a global perspective. Whereas the causal influence is highly significant in the medium- and short-run, but less significant in the long-run, as shown in Figure 6. This demonstrates that the short-run ELREC significantly promotes emissions due to the lower level of renewable energy technologies and higher use of non-renewable energy. While in the long-run, the significance level is reducing for increased CO_2 emissions due to the consistent development in technology, research and development, and renewable energy use. Therefore, the CO_2 emissions could be controlled by enhancing the use of renewable energy.

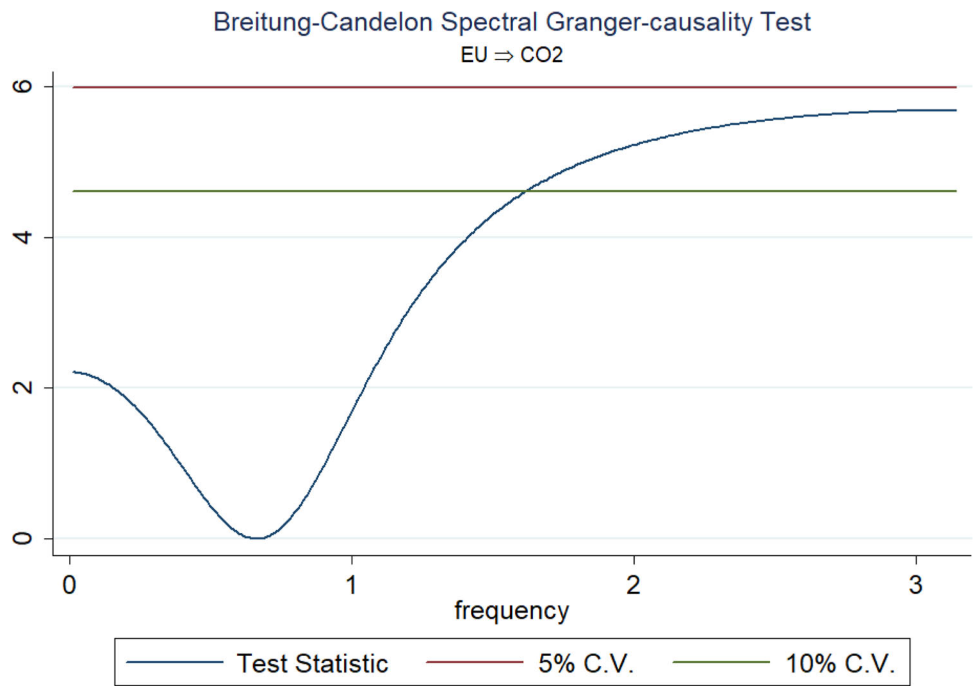

Figure 4. Frequency domain causality for EU and CO_2 emissions.
Source: author's own estimations on the data extracted from the given sources.

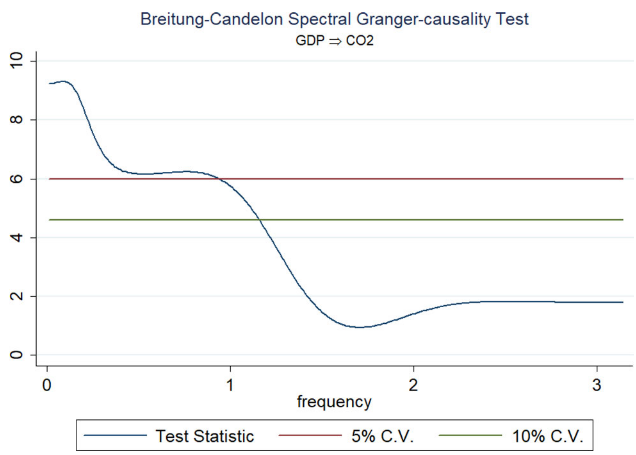

Figure 5. Frequency domain causality for GDP and CO_2 emissions.
Source: author's own estimations on the data extracted from the given sources.

5. Conclusion and policy implications

This study investigates the association of global energy use and environmental degradation over the period of 1990–2020. This study also examines global economic growth and global electricity from renewable energy to global environmental quality captured by CO_2 emissions. In this regard, time series approaches are used, where the variables followed mixed order of integration regarding stationarity. Besides, the Jarque-Bera normality test illustrates that some variables follow the normal

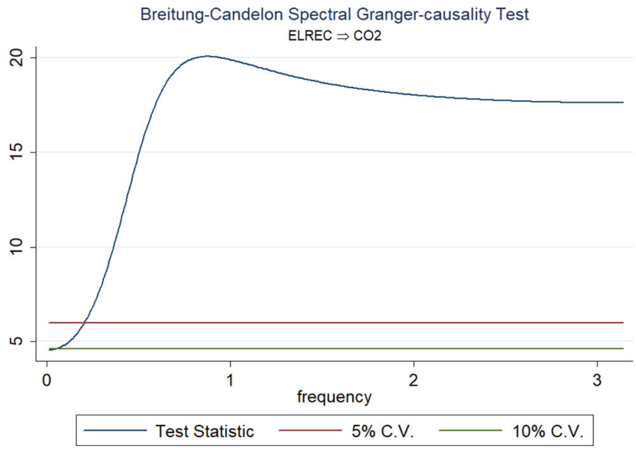

Figure 6. Frequency domain causality for ELREC and CO_2 emissions.
Source: author's own estimations on the data extracted from the given sources.

distribution property while others follow the abnormal distribution. This motivates to utilise QQ regression to analyse the said nexus at various quantiles empirically. The estimated results asserted that renewable energy's economic growth, energy use, and electricity significantly enhances global CO_2 emission levels throughout the selected quantiles. Interestingly, the estimates reveal that the magnitude of the influence is stronger in the upper quantiles of the explanatory variables. Besides, this study also utilised the time-frequency domain causality test, which validates a significant causal impact from economic growth, energy use and electricity from renewable energy to CO_2 emissions. In other words, economic growth enhances the purchasing power of consumers, per capita income, savings and investment level, which increases the production level and industrial expansion. This process requires a high level of energy to fulfil the requirements of production and industrial expansion requirements. Whereas most of the global energy demand is fulfilled via non-renewable energy sources, which produces pollution (CO_2, GHG, and other emissions) and leads to global climate change, global warming and environmental degradation. Moreover, there are fewer economies in the world utilising renewable energy while most of the regions are fossil fuel energy intensive and dependent economies. As a matter of fact, the influence of renewable energy electricity on CO2 emissions is positive, which is alarming from a global perspective and needs immediate environmental recovery policies.

Based on the empirical findings, this study suggests policies that could be advantageous for global environmental sustainability. Firstly, policies are required that could restrict dependency on pollution-intensive energy use. Instead, economies should adopt energy-saving and energy-efficient approaches to reduce fossil fuel energy consumption, which will help reduce carbon emissions in the region and promote environmental quality. Secondly, economic growth should be used as a factor of environmental sustainability. Generally, the increased income level is dedicated to increased production and industrial sector expansion, where traditional non-renewable energy is utilised to fulfil energy requirements. Therefore, policies are required to promote investment in environmentally friendly energy resources and technologies to enhance global environmental quality. Lastly, the use of renewable energy electricity shall be promoted to help reduce the global emission level. Specifically, policies should adopt structural transformation of the industrial sector, where renewable energy and renewable electricity shall be used to reduce fossil fuel dependency and consumption and promote global environmental quality and sustainability.

Disclosure statement

No potential conflict of interest was reported by the author.

Notes

1. See for instance Saboori and Sulaiman (2013), Antonakakis et al. (2017), Chontanawat (2020), Zou and Zhang (2020).
2. Visit https://earth.stanford.edu/news/how-much-does-air-pollution-cost-us#gs.9unreu

References

Acaravci, A., & Ozturk, I. (2010). On the relationship between energy consumption, CO2 emissions and economic growth in Europe. *Energy*, *35*(12), 5412–5420. https://doi.org/10.1016/j.energy.2010.07.009

Antonakakis, N., Chatziantoniou, I., & Filis, G. (2017). Energy consumption, CO2 emissions, and economic growth: An ethical dilemma. *Renewable and Sustainable Energy Reviews*, *68*, 808–824. https://doi.org/10.1016/j.rser.2016.09.105

Awodumi, O. B., & Adewuyi, A. O. (2020). The role of non-renewable energy consumption in economic growth and carbon emission: Evidence from oil producing economies in Africa. *Energy Strategy Reviews*, *27*, 100434. https://doi.org/10.1016/j.esr.2019.100434

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., & Farhani, S. (2018). How economic growth, renewable electricity and natural resources contribute to CO2 emissions? *Energy Policy*, *113*, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Breitung, J., & Candelon, B. (2006). Testing for short-and long-run causality: A frequency-domain approach. *Journal of Econometrics*, *132*(2), 363–378. https://doi.org/10.1016/j.jeconom.2005.02.004

Cai, X., Wang, W., Rao, A., Rahim, S., & Zhao, X. (2022). Regional sustainable development and spatial effects from the perspective of renewable energy. *Frontiers in Environmental Science*, *10* https://doi.org/10.3389/fenvs.2022.859523

Chiu, D. (2017). The East is green: China's global leadership in renewable energy. *New Perspectives in Foreign Policy*, *13*, 3–12.

Chontanawat, J. (2020). Relationship between energy consumption, CO2 emission and economic growth in ASEAN: Cointegration and causality model. *Energy Reports*, *6*, 660–665. https://doi.org/10.1016/j.egyr.2019.09.046

Cleveland, W. S. (1979). Robust locally weighted regression and smoothing scatterplots. *Journal of the American Statistical Association*, *74*(368), 829–836. https://doi.org/10.1080/01621459.1979.10481038

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, *74*(366a), 427–431. https://doi.org/10.1080/01621459.1979.10482531

Geweke, J. (1982). Measurement of linear dependence and feedback between multiple time series. *Journal of the American Statistical Association*, *77*(378), 304–313. https://doi.org/10.1080/01621459.1982.10477803

Ghazouani, A., Xia, W., Ben Jebli, M., & Shahzad, U. (2020). Exploring the role of carbon taxation policies on CO2 emissions: Contextual evidence from tax implementation and non-implementation European countries. *Sustainability*, *12*(8680), 1–16. https://doi.org/10.3390/su12208680

Ghosh, S. (2010). Examining carbon emissions economic growth nexus for India: A multivariate cointegration approach. *Energy Policy*, *38*(6), 3008–3014. https://doi.org/10.1016/j.enpol.2010.01.040

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*, 38–50. https://doi.org/10.1016/j.esr.2019.01.006

Gokmenoglu, K., Kirikkaleli, D., & Eren, B. M. (2019). Time and frequency domain causality testing: The causal linkage between FDI and economic risk for the case of Turkey. *Journal of International Trade & Economic Development*, *28*(6), 649–667. https://doi.org/10.1080/09638199.2018.1561745

Golove, W. H., & Schipper, L. J. (1997). Restraining carbon emissions: measuring energy use and efficiency in the USA. *Energy Policy*, *25*(7–9), 803–812. https://doi.org/10.1016/S0301-4215(97)00070-0

Guan, J., Kirikkaleli, D., Bibi, A., & Zhang, W. (2020). Natural resources rents nexus with financial development in the presence of globalization: is the "resource curse" exist or myth? *Resources Policy*, *66*, 101641. https://doi.org/10.1016/j.resourpol.2020.101641

Hosoya, Y. (1991). The decomposition and measurement of the interdependency between second-order stationary processes. *Probability Theory and Related Fields*, *88*(4), 429–444. https://doi.org/10.1007/BF01192551

Jarque, C. M., & Bera, A. K. (1987). A test for normality of observations and regression residuals. *International Statistical Review/Revue Internationale de Statistique*, *55*(2), 163–172. https://doi.org/10.2307/1403192

Jiang, M., Kim, E., & Woo, Y. (2020). The relationship between economic growth and air pollution—A regional comparison between China and South Korea. *International Journal of Environmental Research and Public Health*, *17*(8), 2761. https://doi.org/10.3390/ijerph17082761

Khan, M. K., Khan, M. I., & Rehan, M. (2020). The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. *Financial Innovation*, *6*(1), 1–13. https://doi.org/10.1186/s40854-019-0162-0

Koenker, R., & Bassett, G., Jr. (1978). Regression quantiles. *Econometrica*, *46*(1), 33–50. https://doi.org/10.2307/1913643

Lean, H. H., & Smyth, R. (2010). CO2 emissions, electricity consumption and output in ASEAN. *Applied Energy*, *87*(6), 1858–1864. https://doi.org/10.1016/j.apenergy.2010.02.003

Lee, J. W. (2019). Long-run dynamics of renewable energy consumption on carbon emissions and economic growth in the European Union. *International Journal of Sustainable Development & World Ecology*, *26*(1), 69–78. https://doi.org/10.1080/13504509.2018.1492998

Luan, S., Hussain, M., Ali, S., & Rahim, S. (2022). China's investment in energy industry to neutralize carbon emissions: evidence from provincial data. *Environmental Science and Pollution Research International*, *29*(26), 39375–39383. https://doi.org/10.1007/s11356-021-18141-7

Manta, A. G., Florea, N. M., Bădîrcea, R. M., Popescu, J., Cîrciumaru, D., & Doran, M. D. (2020). The nexus between carbon emissions, energy use, economic growth and financial development: evidence from central and eastern European countries. *Sustainability*, *12*(18), 7747. https://doi.org/10.3390/su12187747

Mardani, A., Streimikiene, D., Cavallaro, F., Loganathan, N., & Khoshnoudi, M. (2019). Carbon dioxide (CO2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. *Science of the Total Environment*, *649*, 31–49. https://doi.org/10.1016/j.scitotenv.2018.08.229

Qi, T., Zhang, X., & Karplus, V. J. (2014). The energy and CO2 emissions impact of renewable energy development in China. *Energy Policy*, *68*, 60–69. https://doi.org/10.1016/j.enpol.2013.12.035

Qin, L., Hou, Y., Miao, X., Zhang, X., Rahim, S., & Kirikkaleli, D. (2021). Revisiting financial development and renewable energy electricity role in attaining China's carbon neutrality target. *Journal of Environmental Management*, *297*, 113335. https://doi.org/10.1016/j.jenvman.2021.113335

Qin, L., Raheem, S., Murshed, M., Miao, X., Khan, Z., & Kirikkaleli, D. (2021). Does financial inclusion limit carbon dioxide emissions? Analyzing the role of globalization and renewable electricity output. *Sustainable Development*, *29*(6), 1138–1154. https://doi.org/10.1002/sd.2208

Rafique, M. Z., Nadeem, A. M., Xia, W., Ikram, M., Shoaib, H. M., & Shahzad, U. (2022). Does economic complexity matter for environmental sustainability ? Using ecological footprint as an indicator. *Environment, Development and Sustainability*, *24*(4), 4623–4640. https://doi.org/10.1007/s10668-021-01625-4

Richmond, A. K., & Kaufmann, R. K. (2006). Energy prices and turning points: The relationship between income and energy use/carbon emissions. *Energy Journal*, *27*(4) https://doi.org/10.5547/ISSN0195-6574-EJ-Vol27-No4-7

Robalino-López, A., Mena-Nieto, A., & García-Ramos, J. E. (2014). System dynamics modeling for renewable energy and CO2 emissions: A case study of Ecuador. *Energy for Sustainable Development*, *20*, 11–20. https://doi.org/10.1016/j.esd.2014.02.001

Saboori, B., & Sulaiman, J. (2013). CO2 emissions, energy consumption and economic growth in Association of Southeast Asian Nations (ASEAN) countries: A cointegration approach. *Energy*, *55*, 813–822. https://doi.org/10.1016/j.energy.2013.04.038

Sarwar, S., Shahzad, U., Chang, D., & Tang, B. (2019). Economic and non-economic sector reforms in carbon mitigation: Empirical evidence from Chinese provinces. *Structural Change and Economic Dynamics*, *49*, 146–154. https://doi.org/10.1016/j.strueco.2019.01.003

Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., & Leitão, N. C. (2013). Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. *Renewable and Sustainable Energy Reviews*, *25*, 109–121. https://doi.org/10.1016/j.rser.2013.04.009

Shahbaz, M., Mahalik, M. K., Shah, S. H., & Sato, J. R. (2016). Time-varying analysis of CO2 emissions, energy consumption, and economic growth nexus: Statistical experience in next 11 countries. *Energy Policy*, *98*, 33–48. https://doi.org/10.1016/j.enpol.2016.08.011

Shahbaz, M., Tiwari, A. K., & Nasir, M. (2013). The effects of financial development, economic growth, coal consumption and trade openness on CO2 emissions in South Africa. *Energy Policy*, *61*, 1452–1459. https://doi.org/10.1016/j.enpol.2013.07.006

Shahzad, S. J. H., Shahbaz, M., Ferrer, R., & Kumar, R. R. (2017). Tourism-led growth hypothesis in the top ten tourist destinations: New evidence using the quantile-on-quantile approach. *Tourism Management*, *60*, 223–232. https://doi.org/10.1016/j.tourman.2016.12.006

Shahzad, U., Radulescu, M., Rahim, S., Isik, C., Yousaf, Z., & Ionescu, S. A. (2021). Do environment-related policy instruments and technologies facilitate renewable energy generation? Exploring the contextual evidence from developed economies. *Energies*, *14*(3), 690. https://doi.org/10.3390/en14030690

Shahzad, U., Elheddad, M., Swart, J., Ghosh, S., & Dogan, B. (2022). The role of biomass energy consumption and economic complexity on environmental sustainability in G7 economies. *Business Strategy and the Environment*, *1*(February), 1–21. https://doi.org/10.1002/bse.3175

Shahzad, U., Ferraz, D., Nguyen, H.-H., & Cui, L. (2022). Investigating the spill overs and connectedness between financial globalization, high-tech industries and environmental footprints: Fresh evidence in context of China. *Technological Forecasting and Social Change*, *174*(2), 121205. https://doi.org/10.1016/j.techfore.2021.121205

Sharma, G. D., Tiwari, A. K., Erkut, B., & Mundi, H. S. (2021). Exploring the nexus between non-renewable and renewable energy consumptions and economic development: Evidence from panel estimations. *Renewable and Sustainable Energy Reviews*, *146*, 111152. https://doi.org/10.1016/j.rser.2021.111152

Sharma, G. D., Tiwari, A. K., Jain, M., Yadav, A., & Srivastava, M. (2021). COVID-19 and environmental concerns: A rapid review. *Renewable & Sustainable Energy Reviews*, *148*, 111239. https://doi.org/10.1016/j.rser.2021.111239

Sim, N., & Zhou, H. (2015). Oil prices, US stock return, and the dependence between their quantiles. *Journal of Banking & Finance*, *55*, 1–8. https://doi.org/10.1016/j.jbankfin.2015.01.013

Stone, C. J. (1977). Consistent nonparametric regression. *Annals of Statistics*, *5*(4), 595–620. https://doi.org/10.1214/aos/1176343886

Wang, Z., Ben Jebli, M., Madaleno, M., Doğan, B., & Shahzad, U. (2021). Does export product quality and renewable energy induce carbon dioxide emissions: Evidence from leading complex and renewable energy economies. *Renewable Energy*. *171*, 360–370. https://doi.org/10.1016/j.renene.2021.02.066

World Bank. (2022). *World development indicators*. https://databank.worldbank.org/source/world-development-indicators

World Economic Outlook. (2020). *International monetary fund*. https://www.imf.org/en/Publications/WEO#:~:text=Description%3A%20Global%20growth%20is%20projected%20at%20%E2%80%934.9%20percent%20in%202020,Economic%20Outlook%20(WEO)%20forecast.

Xu, B., Sharif, A., Shahbaz, M., & Dong, K. (2021). Have electric vehicles effectively addressed CO2 emissions? Analysis of eight leading countries using quantile-on-quantile regression approach. *Sustainable Production and Consumption*, *27*, 1205–1214. https://doi.org/10.1016/j.spc.2021.03.002

Ye, H., Ren, Q., Hu, X., Lin, T., Xu, L., Li, X., Zhang, G., Shi, L., & Pan, B. (2017). Low-carbon behavior approaches for reducing direct carbon emissions: Household energy use in a coastal city. *Journal of Cleaner Production*, *141*, 128–136. https://doi.org/10.1016/j.jclepro.2016.09.063

Zhao, X., Ma, X., Shang, Y., Yang, Z., & Shahzad, U. (2022). Green economic growth and its inherent driving factors in Chinese cities: Based on the metafrontier-global-SBM super-efficiency DEA model. *Gondwana Research*, *106*, 315–328. https://doi.org/10.1016/j.gr.2022.01.013

Zheng, H., Song, M., & Shen, Z. (2021). The evolution of renewable energy and its impact on carbon reduction in China. *Energy*, *237*, 121639. https://doi.org/10.1016/j.energy.2021.121639

Zou, S., & Zhang, T. (2020). CO2 emissions, energy consumption, and economic growth nexus: Evidence from 30 provinces in China. *Mathematical Problems in Engineering*, *2020*, 1–10. https://doi.org/10.1155/2020/8842770