

Moving Towards Energy Transition: What Role Do Green Financing, Green Technology and Environmental Sustainability Play?

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Abstract

Green finance strategies have been established to direct funding towards green energy initiatives and promote the advancement of green technology for ecological sustainability. Moreover, the progress in green technology has played a significant role in the growth of green energy infrastructure in China. Nevertheless, there have been no prior investigations undertaken in China that specifically examine the impact of green financing and green technology on green energy within an asymmetric quantile framework. Thus, in the current study, a multivariate quantile-on-quantile regression (m-QQR) methodology is used to experimentally examine the link between green energy usage and green financing in China controlling the environmental sustainability index, green technology and economic progress utilizing data from 2000 to 2022. Results of this study confirm that China benefits in terms of rising green energy consumption only at the mid-levels of green investment projects, if more high-cost projects are added beyond this mid-level,

the potential of the active projects diminishes and consumption of green energy declines. This study confirms the conservation hypothesis. A reverse relationship emerges between the consumption of green energy and environmental sustainability. Finally, green technology innovation is coupled with green financing for green energy transition. This study posits that the Chinese economy has the potential to experience significant benefits from the adoption of green energy, mostly driven by breakthroughs and the integration of green technology.

Keywords: Renewable energy consumption, green financing, environmental sustainability, green technology, quantile-on-quantile regression

JEL Classification: C32, Q42, Q55, Q56

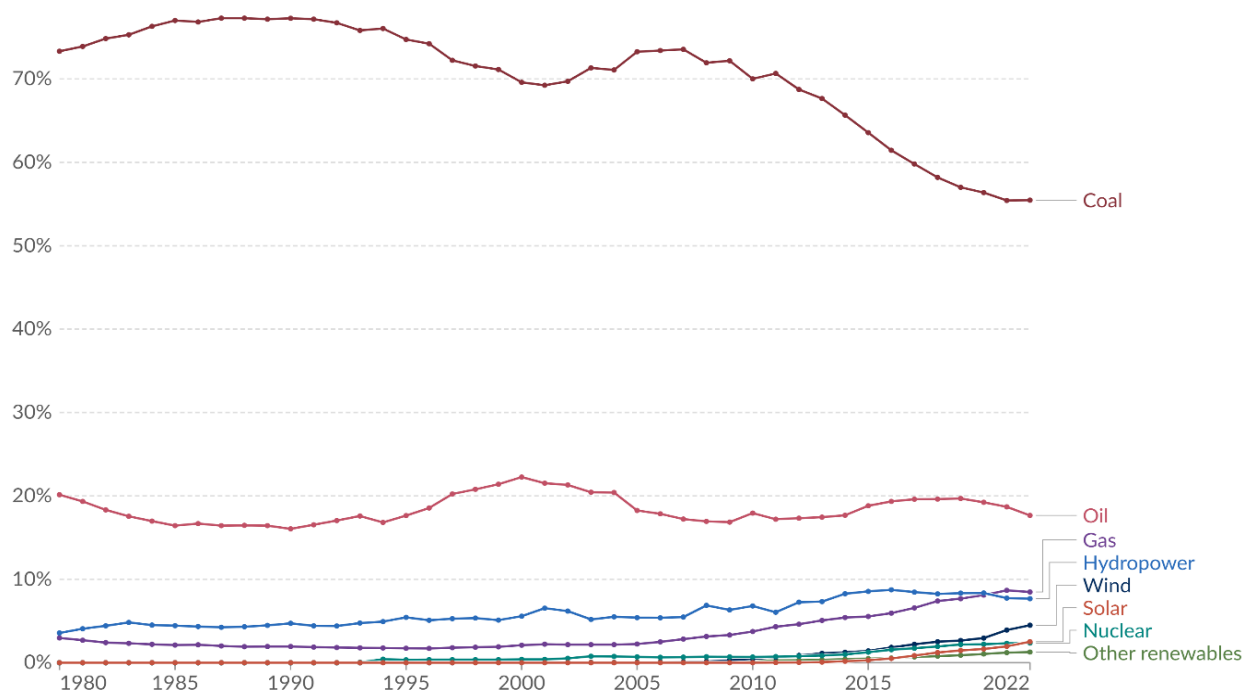
1. Introduction

The term "green economy" is newer than the term sustainable development. A green economy improves human well-being and social fairness while considerably lowering environmental challenges and ecological scarcities (UNEP, 2011). The importance of environmental sustainability in promoting the adoption of clean energy sources has gained increasing attention in recent years (Baek and Pride, 2014), potentially leading to the advancement of the green economy. Hence, it is imperative to integrate the application of green energy sources into the broader framework of an environmentally friendly economy to achieve sustainable development, combat climate change and provide a resilient and prosperous future for generations to come. In addition, the Sustainable Development Goals (SDG-7) also prioritize the availability of inexpensive and clean energy sources, as highlighted in many global agreements at the Conference of Parties (COP). Global attention from practitioners, researchers and politicians is required to comprehensively understand the integration of green energy into the economy, while simultaneously reducing dependence on fossil fuel sources. The main motivation of this study is that it explores factors that contribute to renewable energy use.

In line with this motivation, our research aims to determine the potential influence of integrating green finance (*GRFin*) and green technology (*GTECH*) with the environmental sustainability index (*ESI*) and economic growth (*PCGDP*) on the adoption of renewable energy (*RECON*) within the dataset of the Chinese economy. Green energy, alternatively referred to as renewable energy or clean energy, pertains to energy obtained from ecologically sustainable sources that possess little ecological consequences and generate negligible levels of emissions (Inuwa *et al.*, 2024). China, being the leading global consumer of renewable energy, has made significant investments in various forms of sustainable energy. China's investments are motivated by its goals to reduce carbon emissions and promote sustainable development. In 2022, China's utilization of green energy exceeded that of any other country worldwide, reaching 13.3 exajoules (Statista,

2023). Nevertheless, fossil sources have continued to dominate the energy basket over the years (Figure 1), indicating the necessity for governmental measures to prioritize the increase in green energy consumption. China has achieved significant progress in the implementation of renewable energy; however, it still has challenges in terms of grid integration, limitations on green energy production and the need for energy storage solutions (IEA, 2021).

Figure 1: Energy use share by source in China



Source: Energy Institute (2023)

On the other hand, green financing (*GRFin*) refers to environmental investment projects such as climate change mitigation, resource efficiency, biological diversity preservation, environmental protection, pollution prevention and so on. *GRFin* also includes investments in new green technology (*GTECH*) in a variety of industries, including green energy, energy efficiency, organic agriculture, sustainable forest management, water supply and sanitation and waste management. The multidisciplinary nature of *GRFin* is highlighted by the fact that most economic organizations have resisted choosing priority economic sectors (or activities) that are classified as “green” (Guild, 2020). *GRFin* encourages investment in cutting-edge products and concepts, such as renewable energy. As a result, we are motivated to look into how dynamically *GRFin* affects *RECON* within the setting of the Chinese economy.

Moreover, green technology (*GTECH*) is also called clean or sustainable technology and it deals with generating products or services that offset the adverse effects on the environment. Additionally, it aids in diminishing the utilization of non-renewable resources. Therefore, the use of *GTECH* enables institutions to utilize renewable resources in their daily operations. This not only reduces overall costs but also promotes sustainable development (Sridhar *et al.*, 2022). As these technologies continue to advance and become more popular, they make renewable energy more accessible, reliable and cost-effective, leading to a considerable increase in its consumption. This, in turn, enables the transition to a more sustainable energy system and helps offset the environmental repercussions of traditional fossil fuels (Shan *et al.*, 2021). Therefore, this study analyses *GTECH* as a possible driver of green energy consumption to explore its effect in the context of China.

Several research studies have explored the impact of *GRFin* and *GTECH* on environmental quality from the perspective of several countries (Bozatli *et al.*, 2023; Sethi *et al.*, 2024). Besides, some researchers have explored the effect of green technology on energy demand (Paramati *et al.*, 2022). However, there is a paucity of empirical research that has explored the influence of *GRFin* and *GTECH* on green energy consumption (*RECON*). Therefore, this study makes multiple contributions to the existing literature to address this research void. Firstly, to the best of our knowledge, this is the first paper to investigate the green energy-green financing and green technology-green energy nexus in a single framework. Secondly, a significant portion of prior research has considered CO₂ emissions as a surrogate measure for environmental unsustainability while the deployment of such a limited proxy generated harsh criticism due to the possibility of distorted outcomes. In contrast, our study employs the environmental sustainability index (*ESI*) formulated by NASA's Earth data division. In this perspective, our work addresses the more comprehensive environmental quality indicator and adds to the body of literature by providing a better policy perspective on the nexus between climate change and green energy. Thirdly, there exists a mutually beneficial connection between green technology and green energy consumption, which catalyses sustainable development, fosters environmental preservation and addresses the issue of climate change. Therefore, it is imperative to establish a connection between green technology and green energy consumption to attain a sustainable and low-carbon future within the Chinese environment. Finally, to check the quantile-wise direction of causation between the variables in our research, this study uses the multivariate quantile-on-quantile regression (m-QQR) test. This econometric methodology considers the challenges associated with non-normality and heterogeneity in the context of econometric modelling; thus, the findings from this research can be considered unbiased and robust.

2. Brief Literature Survey

2.1 Nexus between green energy consumption (*RECON*) and economic growth (*PCGDP*)

An analysis of current energy use produces a stream of information pertaining to the association between *PCGDP* and *RECON*. *RECON* has different effects in different countries; nonetheless, only a few countries claim that economic progress leads to a more magnetic commitment to *RECON*. For example, Qudrat-Ullah and Nevo (2021), Dogan *et al.* (2020) and Ozturk (2010) have grouped *PCGDP* and energy variables for four testable hypotheses, *i.e.*, a conservation, growth, feedback and neutrality hypothesis.

According to the growth hypothesis, there is a one-way link between *PCGDP* and *RECON*. Qudrat-Ullah and Nevo (2021), for instance, discovered that the adoption and development of renewable energy will boost *PCGDP* on the African continent. According to Apergis and Payne (2012), *RECON* is crucial to the expansion of the economy. In other words, the growth theory directly contradicts the conservation hypothesis. It asserts a unidirectional causal relationship between *RECON* and *PCGDP*. We consider this in our analysis because there are few studies that concentrate on the conservation hypothesis in terms of renewable energy.

In addition, Apergis and Payne (2010) asserted that the best method to consider the energy use and *PCGDP* link is via the lens of the feedback hypothesis. Energy and economic policy should be examined jointly in this scenario because energy use and *PCGDP* are linked. For 16 countries, Apergis and Payne (2011) discovered a bidirectional association between energy and *PCGDP*. Bowden and Payne (2010), Menegaki (2011) and Yildirim and Aslan (2012) conducted empirical research to refute the neutrality hypothesis, demonstrating that there is no connection between energy use and *PCGDP*. In a similar vein, Bhattacharya *et al.* (2016) discovered that consuming clean energy affects *PCGDP* positively. According to Paramati *et al.* (2017), using clean energy affects *PCGDP* positively in the Next 11 countries. According to Paramati *et al.* (2018), clean energy has favourably influenced the *PCGDP* for major economies and G20 countries. The same finding was found by Q. Wang, Z. Dong, *et al.* (2022), Q. Wang, L. Wang, *et al.* (2022), Usman *et al.* (2021) and Shahbaz *et al.* (2020).

Aside from the favourable relationship between *RECON* and *PCGDP*, other research has shown the inverse relationship. For instance, Ocal and Aslan (2013) discovered that *RECON* had a detrimental influence on Turkey's *PCGDP*. They also discovered a unidirectional correlation between *PCGDP* and *RECON*. *RECON* has a detrimental influence on *PCGDP* in South Korea, according to Lee and Jung (2018). Finally, another line of research has shown no causal relationship between *RECON* and *PCGDP*. Menegaki (2011) studied 27 European economies,

whereas Assa *et al.* (2014) studied 11 African countries. Renewable energy only boosts growth in high-growing sectors, such as the service industry in high-income countries and the industry sector in middle-income countries (Doytch and Narayan, 2021).

2.2 Nexus between green energy and environmental sustainability

Fakher *et al.* (2023) hypothesized that there is a direct correlation between these two variables when they evaluated the impact of environmental sustainability on *RECON*. Using the panel vector autoregression approach and data from the MENA region, Charfeddine and Kahia (2019) divulged that *RECON* affects carbon dioxide emissions only slightly.

A large amount of empirical evidence appears to back up the notion that *RECON* reduces carbon emissions and improves environmental sustainability (Abbasi *et al.*, 2022; Pea-Assounga and Wu, 2022; Kirikkaleli Adebayo, 2021; Wang *et al.*, 2021; Zafar *et al.*, 2020, Alola *et al.*, 2019; Hossain *et al.*, 2023). Moreover, Sharif *et al.* (2019) discovered that *RECON* enhanced environmental quality in 74 different countries. Danish *et al.* (2019) discovered that *RECON* increases environmental sustainability. Destek and Sinha (2020) investigated the influence of *RECON* on the ecological footprint of 24 OECD countries using second-generation methodologies. The findings validated the role of renewables in enhancing environmental sustainability by lowering the OECD countries' ecological footprint.

However, the outcomes of various additional investigations have been inconsistent. For instance, Sharif *et al.* (2020) investigated the nexus between *RECON* and environmental quality for the 10 most polluted countries using the quantile-on-quantile analysis technique. Although their conclusions were conflicting, they discovered a bidirectional causal association between *RECON* and environmental performance. Saidi and Omri (2020) discovered a positive impact of *RECON* on environmental quality in 15 countries where it is a significant component of their energy mix, despite the absence of any long-term cause. The augmented mean group (AMG) technique was used by Nathaniel *et al.* (2020) to analyse data from MENA countries. They argued that factors including *PCGDP*, urbanization, population growth and the use of fossil fuels worsen the environment and that *RECON* has little impact on reversing this trend. In this context, our research seeks to ascertain whether environmental sustainability promotes the usage of clean energy sources.

2.3 Nexus between renewable energy consumption (*RECON*) and green technology (*GTECH*)

GTECH and *RECON* are critical components in achieving the carbon neutrality objective. However, research into the impact of *GTECH* on *RECON*, whether country-specific or using a panel dataset, remains limited. Most of the research has focused on the environmental impact of technology or *GTECH*. For example, Shan *et al.* (2021) found that *GTECH* and *RECON* reduce environmental deterioration in Turkey. Töbelmann and Wendler (2020) observed the effect of technical advancement and *RECON* on air pollution. Miao *et al.* (2017) also argued that *GTECH* innovation has a good role to play in enhancing ecological balance. Godil *et al.* (2021) looked at how technical innovation and *RECON* helped China to reduce emissions from 1990 to 2018. They discovered that technical innovation, *PCGDP* and *RECON* have a major impact on China's CO₂ emissions. Furthermore, Cheng and Yao (2021) noted that an increase in technical innovation reduces carbon intensity.

Several other experts have concluded that technical innovation has little impact on reducing carbon emissions in poor economies. For example, Ganda (2019) concluded that technological advancement contributes significantly to environmental degradation. Wang *et al.* (2020) looked at the relationship between carbon emissions, technological innovation, economic progress and renewable energy for the COP21 agreements. Since there is a lack of research into the nexus between *RECON* and *GTECH*, the present study tries to address this void in the extant literature.

2.4 Nexus between renewable energy consumption and green financing (*GRFin*)

Research into *GRFin* and environmental policy has recently gained a lot of attention. Agyekum *et al.* (2021) and Zhang *et al.* (2021) have focused on developing a framework and concept for *GRFin*. The current condition of *GRFin* was covered by Tolliver *et al.* (2019), who also stressed the parallels between *GRFin* and climate finance. On the other hand, there has not been much study on the connection between *GRFin* and the environment. According to Guild (2020), financing solar energy is crucial for achieving environmental sustainability. Similar to this, Sandberg *et al.* (2019) reported that environmental funding is required to stop environmental degradation since it increases technological investments and promotes innovation.

Research is still underway on the nexus between *GRFin* and CO₂ emissions. In this regard, Meo and Karim (2021) found that while the effect varies among quantiles, green spending has a negative influence on CO₂ in the top ten economies that support green finance. The effect varies depending on the *GRFin* market circumstances and the various countries. Overall, other research

concur that using *GRFin* as a practical financial tool to cut carbon emissions is important (Saidi and Mbarek, 2017). Guild (2020) investigated the connections between *GRFin* and CO₂ emissions in China and found a strong correlation between these.

There has not been much study on the nexus between *GRFin* and the production and use of sustainable energy. Li *et al.* (2021) discovered a one-way causality between investment in renewable energy and *GRFin*. Nguyen *et al.* (2021) investigated the nexus between green bonds and clean energy. Significant evidence of the impact of green bonds on the development of renewable energy was discovered. Green bonds as an acceptable instrument for *GRFin*, according to Tolliver *et al.* (2020), may minimize investment risk, boost financial return and attract worldwide investors to clean power developments. Liu *et al.* (2021) concluded that the green bond market is an efficient and successful tool for the implementation of environmental green energy projects, and thereby the consumption of clean energy. Similarly, Ye *et al.* (2022) demonstrated that in the selected developing country, green funding sources had a substantial positive linkage with renewable energy investment. However, no studies on the impact of *GRFin* on *RECON* in China have been uncovered; consequently, the present study tries to address this research gap.

3. Data and Methodology

3.1 Data description

Our analysis is based on a dataset that covers the years from 2000 to 2022 in China. After the data collection, the quadratic match-sum method is employed to convert the yearly frequency into quarterly frequency. This technique adjusts for seasonal fluctuations in the data by minimizing differences between individual data points when the data are transformed from a lower frequency to a higher frequency (Shahbaz *et al.*, 2018). The quadratic match-sum method is preferred over other interpolation methods due to its straightforward operating procedure. It is important to note that the scope of the study was chosen based on limitations in data availability. Table 1 provides a description of the data and sources.

Table 1: Variable descriptions

Data series	Notation	Unit of measurement	Sources
Green energy consumption	<i>RECON</i>	Gigajoules	IRENA
Economic growth	<i>PCGDP</i>	GDP per capita (Constant \$US 2015)	World Development Indicators
Environmental sustainability index	<i>ESI</i>	Composite index	NASA's SEDAC database
Green technology	<i>GTECH</i>	Patents using technology for environmental control	OECD
Green financing	<i>GRFin</i>	Millions of USD	IRENA

Source: Authors' own elaboration

3.2 Theoretical foundation and model specification

In the academia, there is no agreed-upon explanation of green financing. Green financing, according to available literature (Wang and Zhi, 2016; Ng, 2018), is a financial form that can efficaciously allot resources to low-power consumption and low-pollution enterprises through green investment instruments such as green lending, green bonds, carbon finance, *etc.*, to promote the green economy-environment nexus. *RECON*, on the other hand, refers to the quantity of energy consumed from clean sources that do not or minimally harm the environment. Financial support entails providing funds to facilitate the expansion of green energy businesses. The financial system may direct the flow of resources from ineffectual to high-efficiency sectors using the resource allocation mechanism. Furthermore, since they often include extensive monitoring and low-cost funding, *GRFin* sources offer higher return-generating potential. All of the aforementioned points have an impact on the green energy investment project and, as a result, *RECON*. However, since financial restrictions are unavoidable at the early stages of green energy generation and consumption, *GRFin*, which focuses on creating a clean environment, would have significant consequences.

Furthermore, eco-friendly green technology developments can help battle all types of pollutants while also increasing the generation of clean energy (Shao *et al.*, 2021). They cover pollution avoidance, energy conservation, waste recycling and environmental stewardship technologies (Huang *et al.*, 2019). By integrating environmentally friendly enhancements into present operations, *GTECH* can eliminate carbon emissions (Umar *et al.*, 2020). Thus, deploying *GTECH* in the generation and consumption of clean energy is unavoidable if the full potential benefit from green energy is to be realized. As a result, we have included it in our empirical model.

Furthermore, environmental sustainability and *RECON* are intertwined and serve as either side of the coin. Environmental sustainability, in particular, encourages *RECON*, whereas *RECON* encourages environmental sustainability. However, for a growing country such as China, capital-intensive renewable energy projects may be developed to assure *RECON* while maintaining environmental sustainability. Finally, an economy's growth factor is inextricably tied to *RECON*, since at the scale stage of development, an economy can largely rely on the usage of fossil fuels, but at the technique stage, it can transition to clean energy. As a result, *PCGDP* is included as a control variable in our model.

The model considers the aforementioned untapped variables, and the functional form of the model can be expressed as follows:

$$RECON = f(PCGDP, ESI, GTECH, GRFin) \quad (1)$$

To standardize the data and remove the issue of various units of variables, we transformed all the variables into natural logarithm form (Hossain *et al.*, 2022). In other words, converting data to logarithms makes it easier to understand coefficients as elasticities (Dahir and Mahi, 2021). By converting the variables into their natural logarithmic values, the model can be expressed as:

$$\ln RECON = f(\ln PCGDP, \ln ESI, \ln GTECH, \ln GRFin) \quad (2)$$

where $\ln RECON$ is the natural logarithmic form of green/renewable energy consumption, $\ln PCGDP$ is the logarithmic transformation of per capita GDP, and the natural logarithm of the environmental sustainability index is denoted by $\ln ESI$. Besides, $\ln GTECH$ and $\ln GRFin$ are the natural logarithms of green technology and green financing.

3.3 Estimation strategy

Prior to commencing the estimation process, it is imperative to ascertain whether the data series exhibits stationarity. Given the non-linear characteristics of the data utilized for the research, the adequacy of the augmented Dickey–Fuller (ADF) test might be questionable. To accomplish this, we employ the quantile autoregressive unit root test (QAR), a method developed by Koenker and Xiao (2004) and later by Galvao (2009). The quantile unit root test can be used to determine whether the data series is stable for both the conditional mean and probability distribution in each quantile. Using it has a distinct advantage compared to other commonly used tests. When the distribution of disturbances is asymmetrical, it is found that the QAR approach outperforms the classic ADF. In addition, Galvao (2009) extended the technique to incorporate the concept of covariate stationary behaviour and a linear time pattern. The conventional ADF test fails to consider this

asymmetry, but the QAR test analyses specific quantiles of the variable distributions across time. Consequently, there exists a substantial disparity between the QAR assessments and the ADF test. The τ -th conditional quantile of y has been calculated using the methodology described by Galvao (2009).

$$Q_{\tau}^y(y_t | I_t^y) = \mu_1(\tau) + \mu_2(\tau)t + \alpha(\tau)y_{t-1} + \sum_{i=1}^p \alpha_i(\tau)\Delta y_{t-i} + f_{\mu}^{-1}(\tau) \quad (3)$$

where Q_{τ}^y represents the τ -th quantile of y conditional on I_t^y and f_{μ}^{-1} is the reverse of the common distribution function of error. Assuming that $(y_t | I_t^y)$ is the conditional distribution of y_t , given I_t^y ; y_t is the strict stationarity of a given set of past information $I_t^y = (y_{t-1}, y_{t-2}, \dots, y_{t-s})' \in R^s$. Finally, this study tests quantile stationarity test utilizing t -statistics for a given null hypothesis $H_0: \alpha(\tau) = 1$.

Now, to consider the effect of *GRFin* on *RECON* consumption in China, extending the work of Shabaz *et al.* (2018) and Sim and Zhou (2015), we postulate the following equation:

$$\ln RECON_t = \beta^{\theta}(\ln GRFin_t) + U_t^{\theta} \quad (4)$$

where t represents the year, θ is the θ -th quantile of the conditional distribution of $\ln RECON_t$, while U_t^{θ} is the quantile error term. $\beta^{\theta}(\dots)$ is an unknown function because, by postulation, we lack prior knowledge of the relationship between $\ln RECON$ and $\ln GRFin$. Using $\ln GRFin^{\tau}$ as the τ -th quantile of $\ln GRFin_t$, in the neighbourhood of $\ln GRFin^{\tau}$, the equation is linearized by applying Taylor's expansion around the quantile of $\ln GRFin^{\tau}$ as the following:

$$\beta^{\theta}(\ln GRFin_t) = \beta^{\theta}(\ln GRFin^{\tau}) + \beta^{\theta}(\ln GRFin^{\tau}) \times (\ln GRFin_t - \ln GRFin^{\tau}) \quad (5)$$

In Equation (5), we model both θ and τ as dual indexed parameters and Equation (5) is further expanded as:

$$\ln RECON_t = \beta_0(\theta, \tau) + \beta_1(\ln GRFin^{\tau}) \times (\ln GRFin_t - \ln GRFin^{\tau}) + U_t^{\theta} \quad (6)$$

Now, by introducing the control variables, labelled as $\ln PCGDP_t$, $\ln ESI_t$ and $\ln GTECH_t$, Equation (6) can be written as:

$$\begin{aligned} \ln RECON_t = & \beta_{01}(\theta, \tau) + \beta_{11}(\theta, \tau) \times (\ln PCGDP_t - \ln PCGDP^{\tau}) + \\ & + \beta_{12}(\theta, \tau) \times (\ln ESI_t - \ln ESI^{\tau}) + \beta_{13}(\theta, \tau) \times (\ln GTECH_t - \ln GTECH^{\tau}) + \beta_{14}(\theta, \tau) \times \\ & \times (\ln GRFin_t - \ln GRFin^{\tau}) + \alpha_1(\theta) \ln RECON_{t-1} + \varepsilon_{1t} \end{aligned} \quad (7)$$

The β coefficients in Equation (7) are determined by minimizing the quantile loss function, as described by Sim and Zhou (2015).

Ultimately, we perform the quantile Granger causality test to investigate the causal relationship between variables at various quantiles. Granger (1969) found that if a lagged Z_t does not serve as a predictor of Y_t when considering the lagged Y_t , then it may be concluded that the variable Z_t does not produce the variable Y_t . Assume that we have an explanatory vector $X_t = (X_t^Y, X_t^Z)' \in R^d$, $d = s + q$, where X_t^Z is the previous information set of Z_t , $X_t^Z = (z_{t-1}, \dots, z_{t-q})' \in R^q$. Based on Z_t and Y_t , we establish the subsequent null hypothesis of Granger non-causality – $H_0^{X/Y}$: $F_Y(y|_t^Y, X_t^Z) = F_Y(y|_t^Z)$, for all $y \in R$, where $F_Y(y|_t^Y, X_t^Z)$ defines the conditional distribution of Y_t given (X_t^Y, X_t^Z) . For the entire $\pi \in \Gamma \subset [0, 1]$ we follow Troster (2018) and use a S_t test on the QAR function. We formulate the subsequent null hypothesis of non-Granger causality:

$$QAR(1): Q^{\frac{Y}{\tau}} \left(Y | X_t^{\frac{Y}{\tau}}, X_t^{\frac{Z}{\tau}} \right) = \mu_1(\tau) + \mu_2(\tau)Y_{t-1} + \beta(\tau)Z_{t-1} + \sigma_t\phi_u - 1(\tau) \quad (8)$$

In Equation (8), $\theta(\tau) = \mu_1(\tau)$, $\mu_2(\tau)$ is calculated in equally divided quantiles, whereas $\Phi_u - 1$ defines the normal distribution. In the QAR paradigm, we use lagged variables of one variable to Equation (8) to correct the causal relationship between the intended variables. Ultimately, we construct the QAR model using Equation (8) in the following manner:

$$Q^{\frac{Y}{\tau}} \left(Y | X_t^{\frac{Y}{\tau}}, X_t^{\frac{Z}{\tau}} \right) = \mu_1(\tau) + \mu_2(\tau)Y_{t-1} + \beta(\tau)Z_{t-1} + \sigma_t\phi_u - 1(\tau) \quad (9)$$

4. Empirical Findings and Discussion

Table 2 presents the calculated descriptive statistics for the variables. Among all the variables, renewable energy consumption shows the highest mean values, while per capita GDP and green financing rank second and third. As far as environmental sustainability is concerned, it ranks the last as per its mean value. Now, green financing has captured the most variability in it and it is clear from the maximum and minimum values. Furthermore, the estimated Jarque–Bera (JB) test demonstrates that all of the variables are non-normal. The fact that all of the series pass the significant JB test suggests that they are not regularly distributed. As a result, adopting quantile-based approaches for analysis, a trustworthy tool for this kind of distribution, is necessary to address the non-normality issue.

Table 2: Descriptive statistics

	ln RECON	ln PCGDP	ln ESI	ln GTECH	ln GRFin
Mean	10.912	6.995	3.275	4.773	5.972
Median	10.863	7.219	3.284	5.086	6.243
Maximum	11.817	7.655	3.335	5.638	7.770
Minimum	10.080	6.092	3.194	2.826	1.899
Std. dev.	0.519	0.520	0.045	0.908	1.348
Skewness	0.197	−0.482	−0.379	−0.854	−1.310
Kurtosis	1.936	1.846	1.758	2.524	4.637
Jarque–Bera	13.513	23.742	22.226	32.998	100.229
Probability	0.001	0.000	0.000	0.000	0.000

Source: Authors' own calculations

The results of the quantile unit root test are displayed in Table 3. The results of $\alpha(\tau)$, the t -statistics and critical thresholds at a 5% level are provided for each variable. The null hypothesis (H_0) asserts that the value of $\alpha(\tau)$ is equal to 1 for the grid of eleven quantiles ranging from 0.05 to 0.95. H_0 is disregarded when the t -statistic exceeds the threshold value. The retention parameters in bold indicate a significance threshold of 5% for rejecting H_0 . The results indicate that stationarity is verified for all the variables at a 5% significance level across all quantiles.

We present the findings from m-QQR by means of a graphical representation as depicted in Figure 2. From the diagram, in Panel (A), the intercept term shows overall positive values in the conjecture of middle quantiles (ranging from 0.3 to 0.8) of *RECON* and middle quantiles (ranging from 0.4 to 0.8) of *GRFin*. Therefore, in a general sense, we can say that *GRFin* increases *RECON* in China in the median quantiles. The main reasons behind this type of outcome may appear either due to the efficiency of the green energy projects where the green investment has been made, and thereby the increase in the clean energy consumption, or due to the fact that green financing may minimize investment risk, boost financial return and attract worldwide investors to clean power developments (Liu *et al.*, 2021; Tolliver *et al.*, 2020). Negative values at the extreme quantiles of *RECON* and *GRFin* also emerged from our study and it is quite natural as per Nguyen *et al.* (2021). According to the authors, extreme use of these two economic indicators only leads to exploitation of resources.

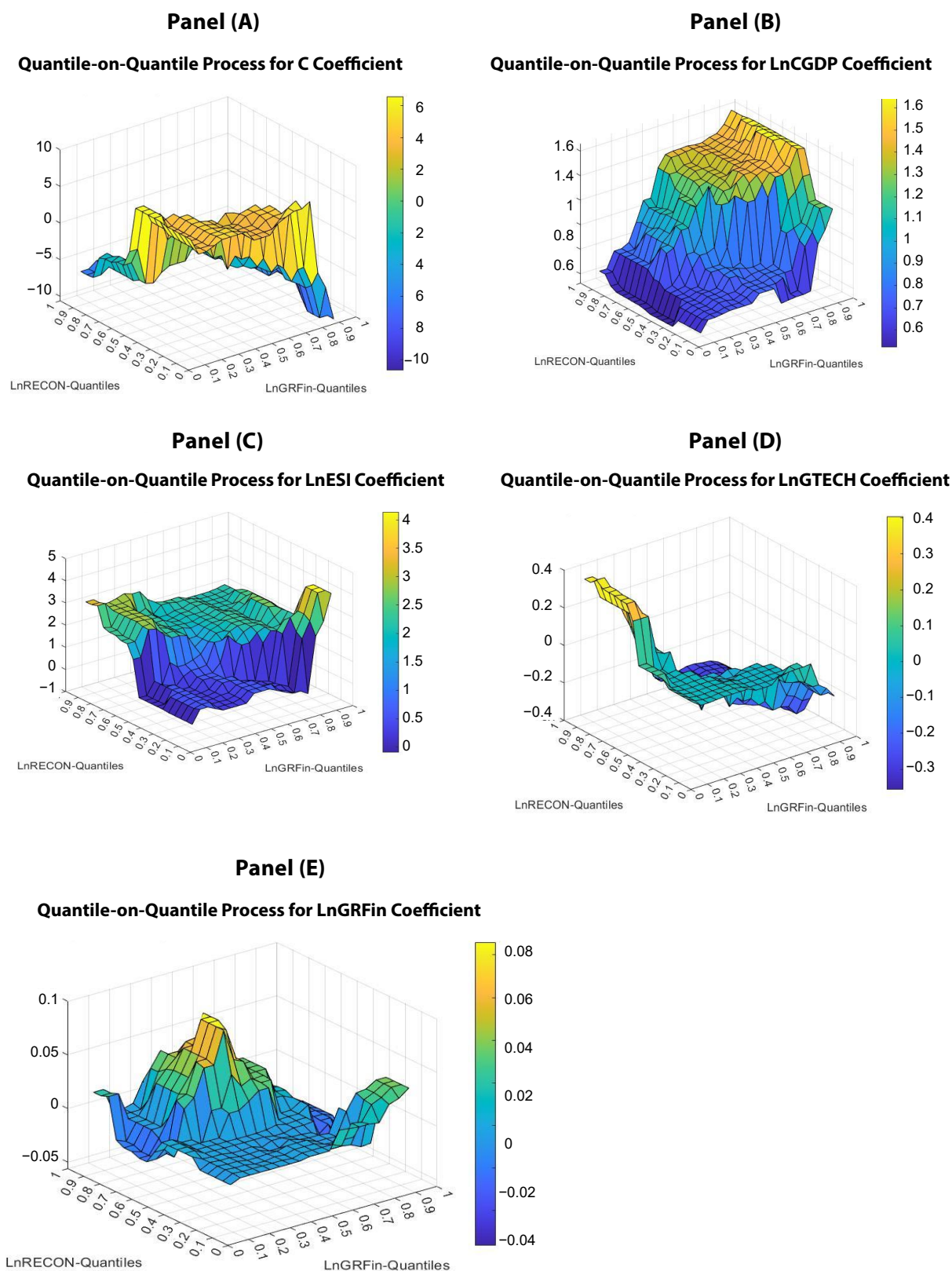
Table 3: Quantile unit root analysis

Variable		$\tau = 0.05$	$\tau = 0.10$	$\tau = 0.20$	$\tau = 0.30$	$\tau = 0.40$	$\tau = 0.50$	$\tau = 0.60$	$\tau = 0.70$	$\tau = 0.80$	$\tau = 0.90$	$\tau = 0.95$
In RECON	$\alpha(\tau)$	1.001	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.001	1.001
	t-stat.	0.196	0.176	0.156	0.155	0.142	0.135	0.144	0.152	0.150	0.182	0.204
	CV	-2.538	-2.491	-2.442	-2.441	-2.409	-2.392	-2.414	-2.433	-2.428	-2.506	-2.556
In PCGDP	$\alpha(\tau)$	0.995	0.997	0.997	0.999	0.999	0.998	0.999	0.999	0.999	0.995	0.994
	t-stat.	0.144	0.134	0.128	0.131	0.113	0.113	0.116	0.128	0.139	0.163	0.210
	CV	-2.414	-2.390	-2.375	-2.382	-2.339	-2.339	-2.346	-2.376	-2.401	-2.460	-2.566
In ESI	$\alpha(\tau)$	1.005	1.003	0.999	0.999	0.999	0.999	0.999	0.998	0.998	0.995	0.995
	t-stat.	0.055	0.065	0.052	0.045	0.038	0.035	0.033	0.047	0.047	0.060	0.064
	CV	-2.308	-2.308	-2.308	-2.308	-2.308	-2.308	-2.308	-2.308	-2.308	-2.308	-2.308
In GTECH	$\alpha(\tau)$	0.998	0.998	0.997	0.997	0.996	0.997	0.997	0.992	0.990	0.990	0.986
	t-stat.	0.167	0.136	0.122	0.126	0.118	0.118	0.123	0.129	0.129	0.183	0.242
	CV	-2.470	-2.396	-2.362	-2.371	-2.351	-2.351	-2.364	-2.377	-2.378	-2.507	-2.623
In GRFin	$\alpha(\tau)$	1.014	1.008	1.001	0.997	0.993	0.984	0.983	0.982	0.983	0.975	0.975
	t-stat.	0.195	0.169	0.111	0.111	0.110	0.121	0.115	0.115	0.124	0.159	0.207
	CV	-2.536	-2.474	-2.334	-2.334	-2.333	-2.360	-2.344	-2.344	-2.366	-2.449	-2.561

Notes: This table reports the outcomes of the quantile unit root test. The table provides $\alpha(\tau)$ as a quantile persistence parameter, t-statistics and critical value (CV) at a 5% level of significance. If the t-statistics are greater than the critical value, we reject the null hypothesis of the presence of a unit root. Persistence parameters in bold indicate rejection of the null hypothesis at a 5% level.

Source: Authors' own calculations

Figure 2: Multivariate QQR analysis



Source: Authors' own elaboration

In Panel (B) of Figure 2, we find an overall negative impact of economic growth proxied by *PCGDP* on *RECON* given the level of *GRFin*. It is quite interesting to note that the impact of per-capita GDP on the middle quantiles of *RECON* ranging from 0.4 to 0.8 given the 0.6 to 0.9 quantiles of *GRFin* depicts a high impact. On the other hand, the relationship between *PCGDP-RECON* is less clear in the quantiles of *RECON* ranging from 0.1 to 0.4 given the quantiles of *GRFin* ranging from 0.1 to 0.8. These findings corroborate the present state of affairs in China, where there has been a notable expansion of the economy in recent years, resulting in a rising need for energy. At medium to high quantiles of both *RECON* and *GRFin*, the effect of *PCGDP* on *RECON* is strong. These findings suggest that *PCGDP* has become a key factor in China's *RECON*. This empirical evidence supports similar results of Xie *et al.* (2023) as they have postulated the same conservation hypothesis for the Next 11 economies. Besides, a similar effect was observed by Behmiri and Manso (2012) and Raza *et al.* (2015) for Portugal and Pakistan, respectively, who showed that economic growth influences energy use.

Panel (C) presents the impact of the *ESI* on *RECON* given the green financing. We find that the impact is highest in the 0.2 to 0.3 quantiles of *RECON* given the upper quantiles ranging from 0.8 to 1 of *GRFin*. Nonetheless, the middle quantiles of *RECON* (0.3 to 0.7) is negatively affected, given the 0.2 to 0.9 quantiles of *GRFin*. This finding is certain for developing countries such as China and aligns with the findings of Ugwuoke *et al.* (2012). In a developing country such as China, when *RECON* is low, then a certain increase in *GRFin* leads to a rise in the number of renewable and sustainable energy projects, which in turn increases environmental sustainability. After some time, however, the developing country faces a lack of infrastructure and scientific knowledge to discard outdated energy technologies, which raises pollutants as a result.

When considering Panel (D), the impact of green technologies (*GRTECH*) on *RECON* is high in the conjecture of the topmost quantiles of *RECON* and bottom quantiles of *GRFin* (ranging from 0.1 to 0.5) and the impact is less than all other lower quantiles of *RECON*, given the upper quantiles of *GRFin* (ranging from 0.5 to 1). This phenomenon again validates the previous statement made for Panel (C) in other ways. Due to new inventions and modern technology adoption via *GRFin*, a developing country such as China may experience a higher impact on *RECON* but the major problem arises when it comes to discarding the old one. This finding is in line with the study by Ganda (2019). Lastly, in Panel (E), the impact of *GRFin* on *RECON* is highly positive in the upper quantiles of *RECON* (0.8 to 1 quantiles) given the middle quantiles (0.6 to 0.7) of *GRFin*, while the impact is less in the middle quantiles of *RECON* and it is negative in the 0.6 to 0.8 quantiles of *RECON* given the 0.9 to 1 quantiles of *GRFin*. These results indicate the impact of the dynamism of *GRFin* on *RECON*. With a continuous inflow of green financing in the economy, China is gaining its benefit in terms of increasing green energy consumption only in the mid-levels of green investment projects. If it takes more new high funding projects after

this threshold, then the active projects may lose their potential and eventually, the green energy consumption will fall.

Table 5: Quantile Granger causality analysis

H_0	$\tau = 0.05$	$\tau = 0.10$	$\tau = 0.20$	$\tau = 0.30$	$\tau = 0.40$	$\tau = 0.50$	$\tau = 0.60$	$\tau = 0.70$	$\tau = 0.80$	$\tau = 0.90$	$\tau = 0.95$
$\ln PCGDP \rightarrow \ln RECON$	1.603 (0.170)	5.442*** (0.000)	28.925*** (0.000)	26.687*** (0.000)	4.282*** (0.002)	5.067*** (0.000)	3.453*** (0.009)	3.840*** (0.004)	0.414 (0.798)	1.671 (0.157)	1.446 (0.219)
$\ln RECON \rightarrow \ln PCGDP$	30.074*** (0.000)	15.393*** (0.000)	2.718** (0.031)	5.515*** (0.000)	5.559*** (0.000)	1.096 (0.359)	1.074 (0.367)	0.158 (0.959)	3.710*** (0.006)	1.131 (0.342)	3.453 (0.009)
$\ln ESI \rightarrow \ln RECON$	0.735 (0.598)	0.459 (0.806)	1.675 (0.141)	1.870* (0.090)	0.354 (0.879)	0.345 (0.885)	0.171 (0.973)	2.473** (0.033)	3.746*** (0.003)	3.912*** (0.002)	3.704*** (0.003)
$\ln RECON \rightarrow \ln ESI$	4.028*** (0.002)	0.212 (0.957)	2.845** (0.016)	0.609 (0.693)	0.414 (0.839)	1.459 (0.204)	1.216 (0.302)	1.074 (0.376)	0.784 (0.562)	2.188* (0.056)	2.842** (0.016)
$\ln GTECH \rightarrow \ln RECON$	0.340 (0.850)	12.780*** (0.000)	20.774*** (0.000)	2.025* (0.092)	9.122*** (0.000)	8.171*** (0.000)	0.667 (0.615)	1.330 (0.259)	0.380 (0.823)	2.195* (0.070)	1.290 (0.275)
$\ln RECON \rightarrow \ln GTECH$	9.412*** (0.000)	4.544*** (0.002)	3.869*** (0.005)	4.124*** (0.003)	1.586 (0.179)	0.791 (0.532)	0.885 (0.474)	14.324*** (0.000)	23.644*** (0.000)	23.188*** (0.000)	2.540** (0.041)
$\ln GRFin \rightarrow \ln RECON$	0.166 (0.955)	0.960 (0.430)	6.956*** (0.000)	20.012*** (0.000)	22.220*** (0.000)	14.677*** (0.000)	2.739** (0.029)	0.491 (0.743)	0.035 (0.998)	1.932 (0.106)	2.975** (0.020)
$\ln RECON \rightarrow \ln GRFin$	22.967*** (0.000)	10.364*** (0.000)	3.397*** (0.008)	1.463 (0.214)	1.208 (0.308)	16.006*** (0.000)	22.989*** (0.000)	20.074*** (0.000)	24.140*** (0.000)	7.340*** (0.000)	10.752*** (0.000)

Notes: τ is the representative of quantiles; $\rightarrow$ implies no Granger cause. ***, ** and * note significance at less than 1%, 5% and 10% levels, respectively. In parenthesis, we provide the p -values. Values in bold indicate the significant indicators.

Source: Authors' own calculations

The findings of the causality-in-quantiles test can be found in Table 5. The non-parametric model proposed by Balcilar *et al.* (2016) is used to estimate the causal relationship between pairs of variables at various quantiles. The calculated relationships are then assessed against the critical value at significance levels of 1%, 5% and 10%. Empirical evidence suggests that there is a Granger causal relationship between *PCGDP* and *RECON* in the lower to middle quantiles (0.10 to 0.70), with *PCGDP* causing changes in *RECON*. Conversely, in the upper and lower quantiles, there is evidence that *RECON* Granger causes *PCGDP*. Thus, the findings reveal a reciprocal relationship between *PCGDP* and *RECON*. Similarly, the link between *ESI* and *RECON* is mutually influential in both lower and upper quantiles at various levels of significance. The re-

sults indicate that *GTECH* has a Granger causal effect on *RECON* in the lower to middle quantiles (0.10–0.50) and the upper quantile (0.90). Similarly, *RECON* has a Granger causal effect on *GTECH* in the lower, middle and upper quantiles. Therefore, there is a bidirectional Granger causal relationship between *RECON* and *GTECH*. Similarly, the *GRFin* Granger causes *RECON* and *RECON* has a Granger causality effect on *GRFin*, across several quantiles (lower, middle and upper). Regarding the quantile Granger causality test, we have discovered a bidirectional causation between the variables. However, the bidirectionality of the variables differs among different quantiles. Consequently, officials in China must exercise utmost prudence when designing environmental and energy policies. Moreover, in the event of any neglect occurring during the formulation of policies, there could be a detrimental effect on the natural ecosystem.

5. Conclusion and Policy Recommendations

This study examined the impact of green financing (*GRFin*), green technology (*GTECH*), environmental sustainability (*ESI*) and economic growth (*PCGDP*) on renewable energy consumption (*RECON*) in China for the period 2000–2022. We employed the innovative multivariate quantile-on-quantile regression (QQR) method to evaluate the association. In this regard, to test the stationarity properties of the variables, we used the quantile unit root test and to justify the model specification, we used the quantile Granger causality technique.

Our results suggest that an asymmetric impact of *GRFin* on *RECON* is present. China benefits in terms of rising *RECON* only at the mid-levels of green investment projects, thanks to a steady input of *GRFin* into the economy. If more high-cost projects are added beyond this point, the potential of active projects diminishes and *RECON* declines. In assessing the relationship between *PCGDP* and *RECON*, we found that the conservation hypothesis is valid for the Chinese case as higher economic growth leads to a higher level of *RECON*. When *RECON* is low in China, a rise in *GRFin* results in an increase in the number of renewable and sustainable energy projects while increasing environmental sustainability. However, over time, the Chinese economy would encounter a lack of infrastructure and scientific understanding, making it difficult to abandon outdated energy technologies, which will increase pollution. The Chinese economy may enjoy a greater impact on green energy consumption due to new innovation and current technology adoption via green funding, but the biggest challenge occurs when it comes to discarding the old ones. The findings also revealed that there is bidirectional Granger causation between the variables under research, meaning that in the green growth-clean energy-green financing nexus, one cannot achieve by inferring from another.

In light of our findings, we recommend that Chinese governments and policymakers focus on the right use of green investment to increase green energy consumption. We previously

observed that green financing is a significant driver of clean energy consumption; as a result, governments should establish and implement long-term supportive policies to increase private sector involvement in renewable project investment utilizing green finance. In practice, the administration, financial organizations and industries must work together to increase the beneficial promotional role of green finance on renewable energy usage. The main goal is to emphasize the importance of green finance as a resource provisioning guide. Besides, the government may create a green financial system by enacting laws that support the green business through fiscal, monetary and environmental regulations, as well as providing green funds. However, doubling the amount of released green bonds as a means of green financing may foster a revival of renewable energy projects as well as economic expansion. This financial instrument has the potential to provide suitable investment income for investors while also promoting environmental harmony by generating and utilizing renewable energy.

Furthermore, our research revealed that environmental sustainability has a substantial impact on renewable energy use. Therefore, implementing appropriate tax policies is essential in promoting a sustainable environment. These policies will not only encourage and motivate individuals to use green technologies but also embrace renewable energy alternatives. Nevertheless, this presumption can result in a rise in the utilization of sustainable energy sources. To meet the increasing need for renewable energy, individuals must possess a requisite level of comprehension, which can be attained through inventive educational and technical training programmes. As a result, increasing clean energy consumption requires investments in green technology innovation, stringent adherence to regulated environmental legislation and more public awareness.

5.1 Study limitations and future research

Even though the current study looked at a fascinating field of environmental research while taking into consideration important factors that contribute to renewable energy consumption, a prospective investigation could enhance the existing information by examining underexplored variables, such as public-private partnerships (PPPs), investment in renewable energy research and development (R&D), energy subsidies and crude oil prices, as potential indicators of renewable energy utilization. Conducting thorough and standardized study on both established and developing countries, as well as specific country groups utilizing panel data, can provide valuable insights for governments in their efforts to promote environmentally friendly economic growth and adoption of clean energy. Although the study employed multivariate quantile regression, it is limited in its ability to explore the impact of more than three variables while keeping the impact of one variable constant.

Declarations

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