frontiers in Energy Research

ORIGINAL RESEARCH
published: 11 March 2022
doi: 10.3389/fenrg.2021.804706

Towards Achieving Environmental Sustainability: The Role of Nuclear Energy, Renewable Energy, and ICT in the Top-Five Carbon Emitting Countries

Anam Azam[1], Muhammad Rafiq[2]*, Muhammad Shafique[3]* and Jiahai Yuan[1]*

[1]School of Economics and Management, North China Electric Power University, Beijing, China, [2]Department of Electrical Engineering, University of Engineering and Technology, Taxila, Pakistan, [3]Department of Architecture and Civil Engineering, City University of Hong Kong, Kowloon, Hong Kong SAR, China

OPEN ACCESS

Edited by:
Xiaohang Ren,
Central South University, China

Reviewed by:
Cheng Cheng,
Shanxi University of Finance and Economics, China
Yan Zheng,
Central South University, China

***Correspondence:**
Anam Azam
anamrafiq95@gmail.com
Muhammad Rafiq
jutt96@gmail.com
Muhammad Shafique
m.shafique@my.cityu.edu.hk

Specialty section:
This article was submitted to Sustainable Energy Systems and Policies,
a section of the journal Frontiers in Energy Research

Received: 29 October 2021
Accepted: 17 December 2021
Published: 11 March 2022

Citation:
Azam A, Rafiq M, Shafique M and Yuan J (2022) Towards Achieving Environmental Sustainability: The Role of Nuclear Energy, Renewable Energy, and ICT in the Top-Five Carbon Emitting Countries.
Front. Energy Res. 9:804706.
doi: 10.3389/fenrg.2021.804706

In the era of globalization, the incidence of global warming emerges from the issue of climate change, which attracts the attention of several scholars to attain sustainability with respect to ensuring sufficient energy access and diminishing environmental adversities. However, in view of these circumstances, this study examines the heterogenous impacts of nuclear energy, renewable energy, and information and communication technologies (ICTs) on pollution emissions reduction for the top-five emitter countries, covering the data from the period from 1995–2017. This study employs an advanced panel quantile regression model that takes into account both unobserved individual heterogeneity and distributional heterogeneity. The findings illustrate that the effect of all the selected explanatory variables on CO_2 emissions is heterogenous along the quantiles. Our outcome supports the notion that nuclear energy consumption is insignificant in contributing to lower environmental pollution. Renewable energy consumption and ICT significantly decrease the carbon emissions of emitter economies, but the negative influence is more robust at the quantiles level (0.30–0.80) and (0.10, 0.20), both factors correct the environmental pollution in the five emitter countries. Finally, the findings of the study provide crucial policy recommendations to policymakers.

Keywords: sustainability, economic growth, energy consumption, CO_2 emission, panel data

1 INTRODUCTION

Energy is the basic building block of all sectors of modern economic growth and is considered a basic factor of production, including capital and labor (Alam et al., 2016; Solarin et al., 2017). However, energy consumption has become a crucial aspect of the economic growth (GDP) of any nation (Azam et al., 2020a; Azam et al., 2020c; Iheonu et al., 2020; Azam et al., 2021a; Azam et al., 2021c). Due to the rapid growth of the global economy, energy consumption is rapidly increasing as a result of globalization and industrialization (Shafique et al., 2020; Shafique et al., 2021a). Most of this demand is fulfilled through fossil fuel energy sources: coal consumption (CC, 38%), and oil consumption (OC, 23%) globally. Fossil fuel combustion is the primary cause of global warming, which has resulted in greenhouse gas (GHG) emissions, with carbon dioxide (CO2) being the most significant contributor to environmental pollution (Chaudhry et al., 2012; Azam et al., 2020b; Azam et al., 2021b; Shafique and Luo, 2021; Azam et al., 2021c; Azam et al., 2021d).

The consequences of CO_2 emission endanger the atmosphere and bring climate change worldwide. Climate change and global warming are the most highlighted issues that threaten the world (Liu et al., 2020; Shafique et al., 2021b). The incidence of environmental degradation has serious implications for our health and economy (Yahya and Rafiq, 2020). According to the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC), the global temperature has increased by 1.5°C, which is quite high (IPCC, 2018a). Amidst the growing awareness of environmental jeopardy, a demand for clean energy has emerged. Thus, a considerable amount of attention has been paid to lessening CO_2 emissions and building a low-carbon economy.

The growing concerns including rapid climate change, environmental degradation, and requirements for clean energy justice, have become human rights issues globally (Azam et al., 2021e; Azam et al., 2021f; Baloch et al., 2019). However, ecologists and energy economists are urging policymakers to shift their energy usage toward clean energy sources (renewable and nuclear) in order to address the aforementioned environmental and health challenges. In this regard, the use of nuclear energy and renewable energy plays a crucial role in CO_2 emission reductions as well as establishing substantial economic and socioeconomic benefits. Globally, both nuclear and renewable energy sources are important for controlling energy security and pollution emission (Chu and Chang, 2012). Renewable energy and nuclear energy may have an adverse influence on CO_2 emission, an effect that is beneficial to the atmosphere (Menyah and Wolde-Rufael, 2010; Al-Mulali and Ozturk, 2016). Both energies have increased in use in recent years due to the lower cost as well as to achieve a sustainable environment. In the modern era of industrialization and globalization, the growing concerns of ICT contribute more to several economic sectors; consequently, the environmental performance of ICT cannot be ignored (Cheng et al., 2021). ICT plays a vital role in enhancing energy usage in terms of industrialization development; subsequently, growing energy consumption due to industrial development has a harmful effect on environmental quality (Khan et al., 2018). While on the other hand, ICT reduces mobility and physical presence, including e-commerce, e-government, e-banking, and virtual education; in this way, it has a crucial role in decreasing CO_2 emissions. Ambient air pollution can be improved through huge ICT development (Añón Higón et al., 2017). Consequently, a large investment in the latest technologies decreases environmental degradation (Wang et al., 2015; Latif et al., 2017). Despite the huge environmental pressure, the use of alternative and clean energy and ICT are considered well-known and sustainable to mitigate carbon emission reduction.

Currently, several pieces of literature on the energy-growth-environment nexus have been investigated by using different econometric techniques, countries, and regions over the years. Recently, some empirical studies such as (Bilgili et al., 2016; Bulut, 2017; Dong et al., 2018; Paramati et al., 2017) have argued that clean energy plays a crucial role in improving environmental quality. Still, apart from this, few studies (Apergis et al., 2010; Bölük and Mert, 2015) disagree with the statement that renewable energy consumption (REC) cannot mitigate CO_2 emission. **Table 1** summarizes the previous work to analyze nuclear energy, renewable energy, ICT, and environmental pollution nexus. As discussed by (Al-Mulali and Ozturk, 2016) the use of REC has a negative effect on CO_2 emission and helps to maintain and improve environmental sustainability.

Meanwhile, clean energy such as nuclear energy consumption (NEC) sources gets enormous attention among researchers (Azam et al., 2020b; Azam et al., 2021b). The development of nuclear power has huge potential and enhancing the share of nuclear energy is a viable target to reduce pollution in developing countries (Peng et al., 2019). According to recent literature (Menyah and Wolde-Rufael, 2010; Park et al., 2016; Lau et al., 2019; Peng et al., 2019; Hassan et al., 2020), nuclear energy is a capable and well-known energy source to mitigate CO_2 emission and improve environmental sustainability. However, some recent studies (Jin and Kim, 2018; Prăvălie and Bandoc, 2018; Aydın, 2020; Mahmood et al., 2020) report that nuclear energy has a positive and significant effect on CO_2 emissions due to the negative impact of radioactive waste and atomic accidents which have a serious impact on humans and the environment as well. Moreover, in recent years significant numbers of studies have discussed the influence of ICT on CO_2 emission; for instance, (Coroama et al., 2012; Al-Mulali et al., 2015; Asongu et al., 2018) states that ICT improves the environmental quality by a reduction of CO_2 emission.

From the literature reviewed, it can be concluded that the studies found mixed results for clean energy sources (renewable energy and nuclear power) and CO_2 emissions as well as ICT and CO_2 emissions. However, no consensus has been reached on whether consumption of renewable energy or nuclear energy can counteract environmental pollution, not by incorporating a recent factor of ICT. Therefore, this present study is motivated to investigate the effect of NEC, REC, and ICT on CO_2 emission in the top five CO_2 emitter countries.

Why have we selected only the top emitter countries as our case study? The top five emitter economies (China, United States, India, Japan, and South Korea) have experienced rapid economic growth, much larger foreign direct investment, and engrossed extensive foreign exchange reserves. Consequently, together all these aspects contribute to carbon dioxide (CO_2) emission and other global warming emissions (Baloch and Wang, 2019; Duan et al., 2021; Ren et al., 2021). The total CO_2 emission in top emitter economies contributes significantly, such as in China (27.8%), United States (15.2%), India (7.3%), Japan (3.4%), and South Korea (2.1%) during the year 2019 (British Petroleum, 2018). Further, these countries together contribute 65% of global economic growth, 80% of total fossil fuel combustion at an international level, and 67.5% of total CO_2 emissions from fuel combustion worldwide (IPCC, 2018a).

Further, the top emitter economies all plan to diminish their CO_2 emission following the 2015 UN conference on climate change (COP21) which is starting to invigorate public and private actions target to decline the temperature worldwide

TABLE 1 | Summary of studies on the link between nuclear and renewable energy consumption- ICT on CO_2 emission.

Study	Countries (Period)	Methodology	Related variables	Key findings
Alsayed et al. (2020)	India (1969–2014)	ARDL Model	CO_2, NEC, OC,CC, trade openness	NEC mitigates CO_2 both in the long run and short run
Jin and Kim, (2018)	30 countries (1980–2014)	Panel Cointegration and Granger causality test	CO_2, REC, NEC, GDP, Coal price	Their results suggest that REC improves the environment in the long run but NEC cannot contribute to mitigating CO_2 emission. So the study suggests that REC plays a crucial role, not nuclear energy, in lowering environmental degradation
Hassan et al. (2020)	BRICS countries (1993–2017)	CUP-FM, CUP-BC	CO_2, REC, NEC, GDP	Their outcomes summarize that both NEC and REC improve environmental quality
Mahmood et al. (2020)	Pakistan (1973–2017)	ARDL	CO_2, GDP, NEC	They find that NEC has a negative impact on CO_2 emission and also find bidirectional causality between NEC and CO_2 emission
Khan et al. (2018)	Emerging economies (1990–2014)	MG, AMG analysis	CO_2,ICT, financial development, energy consumption, GDP, urbanization	In this study, the ICT and GDP mitigate the CO_2 emission, FD, EC, and stimulate the level of pollution
Baek, (2016)	United States (1960–2010)	ARDL	CO_2, GDP NEC,REC, Energy consumption	They suggest that NEC mitigate the CO_2 emission both in the short-run and long-run but REC is only helpful in the short term to improve the environment
Lee et al. (2017)	18 countries (1970–2015)	Panel cointegration test, DOLS	CO_2, GDP NEC, REC	Their results indicate that NEC improves environmental quality
Añón Higón et al. (2017)	1995–2010	142 countries	ICT, CO_2	ICT mitigate the CO_2 emission
Lau et al. (2019)	18 OECD countries (1995–2015)	GMM, FMOLS	NEC, non-renewable, trade openness	NEC improves environmental performance
Al-Mulali, (2014)	30 nuclear countries (1990–2010)	Panel co integration, FMOLS, VECM	CO_2, GDP NEC, investment, fossil fuels, urbanization	In this study, NEC has a significant impact on GDP in the long term but has no influence on CO_2 emission mitigation
Danish, (2019)	Belt and Road countries (1990–2016)	GLS	CO_2, GDP, ICT, Foreign direct investment, trade	The indicates that ICT improve the environment

(IPCC, 2018b). These countries have the latest technologies, skilled labor, political stability, and a significant share of nuclear and renewables in the total energy mix. So, these economies should develop policies to support the adoption of innovations that might help in the generation of renewable and nuclear energy. Hence, prompt action is required to decrease the total amount of CO_2 emissions without harming the economy (Baloch et al., 2019).

Against this backdrop, it is quite clear that studying the energy consumption-environment nexus for emitter countries is required regarding the energy efficiency policies and planning the ICT for alternative energy sources. For this, the novelties of this paper are as follows: 1) First, we believe that this is the first empirical study that takes the top five CO_2 emitter countries such as (China, United States, India, Japan, and South Korea) into account over the period 1995–2017. As previous works have paid attention to panel data of several country groups, namely; Emerging economies, BRICS (Brazil, Russia, India, China, and South Africa); Developed countries, Belt and Road countries, India; United States, Pakistan, nuclear countries, G-20 countries and the OECD (Organization for Economic Cooperation and Development). The highest CO_2 emitting countries have not been scrutinized in the energy-growth-environment literature. Particularly, the present study is the most inclusive study on disaggregated energy consumption, covering the top five economies with the highest CO_2 emissions globally. These five economies affairs, as countries with the greatest CO_2 emissions, make them of particular interest. Second, we examined the role of ICT in the process of pollution emission reductions. Further, we incorporated disaggregated energy such as nuclear energy, renewable energy, oil consumption, and coal consumption as determinants of CO_2 emission. Moreover, we include GDP as an additional variable as an important factor in environmental literature.

Third, the present study implies up-to-date econometrics techniques in an empirical analysis. It is evident that previous studies examined the energy-growth-environment nexus by using standard panel estimation techniques such as vector error correction and vector autoregressive method, fully modified ordinary least square, dynamic ordinary least square, generalized least squares, and no one use panel quantile regression (PQR) method on the evidence of nuclear energy consumption, renewable energy consumption, ICT and CO_2 emission. This method has been widely used and has become a core research subject in the economics literature (Huang et al., 2020; Ike et al., 2020). This method has some advantages; first, it

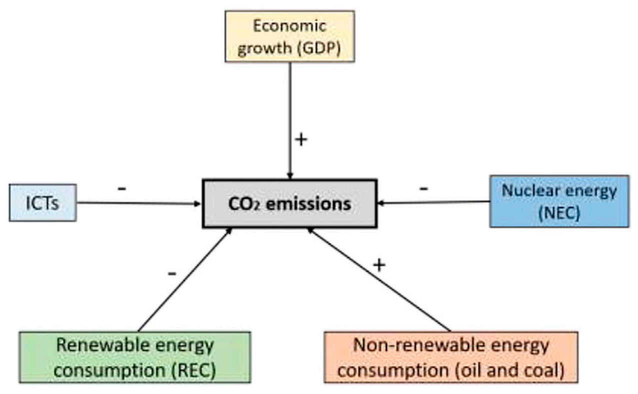

FIGURE 1 | Conceptual framework of this study.

can be applied in order to avoid over and underestimation of target and explanatory variables. It can explain the intact conditional distribution of the target variable (CO_2 emissions); therefore, it provides us a complete picture of the factors that cause pollutant emission; in particular, PQR presents one solution to each quantile. The outcomes of the PQR method are more efficient and reliable than conventional OLS regression because the findings are robust in order to capture outlying observations of the response variable, in particular when the error term is non-normal (Alsayed et al., 2020). Several policy questions remain. First, Does nuclear and renewable energy contribute to mitigating carbon emissions? Does ICT have an effect on CO_2 emission reduction? Finally, Does oil and coal energy consumption effect CO_2 emission?

2 DATA, MODEL AND ECONOMETRIC METHODOLOGY

2.1 The Theoretical Framework of the Study

Firstly, we talk about the present theoretical background of the study before constructing the econometric model specifications; this will help our study to choose the exposure variables for this research. The variable economic growth not only raises the economic structure but stimulates the level of CO_2 emission through the combustion of fossil fuel, transportation, structural transformation, and the behavioral demand of consumers in the country, which ultimately disturbs the environmental quality. Moreover, ICT and energy consumption reinforce each other, and therefore ICT increases environmental degradation through its role in aiding industrial development. Similarly, efficient and reliable nuclear and renewable energy is important to control CO_2 emissions. Keeping all this in view, we build a conceptual framework of the study as **Figure 1**.

2.2 Empirical Model Specifications

Most literature studying the determinants of CO_2 emission depends on the linear model such as (Hasnisah et al., 2019; Qiao et al., 2019; Salman et al., 2019)**.** Based on the conceptual model as presented above, we specify the following econometric form:

$$CO_{2=} f\,(GDP + ICT + NEC + REC + OC + CC) \qquad (1)$$

We transformed all variables into natural logarithms; the reason behind taking logarithms for each series is to investigate the elasticity between variables and to smooth the data. Thus, transforming **Eq. (1)** into log form as follows:

$$lnCO_{2=}\alpha_0 + \alpha_1 lnGDP + \alpha_2 lnICT + \alpha_3 lnNEC + \alpha_4 lnREC + \alpha_5 lnOC + \alpha_6 lnCC \qquad (2)$$

Following (Baloch et al., 2019), we incorporate the interaction variable between carbon dioxide emission and ICT in order to validate the assumption that ICT simultaneously improves the environment and economic growth in the highest co_2 emitting countries. In addition, this study used panel data for the top five emitter countries based on available data. The panel data model was first presented by (Al-Mulali et al., 2013). Panel data has numerous advantages such as it increases the degree of freedom which improve the capacity of econometrics evaluation, it requires a massive number of data points (N, T), to control the effects of heterogeneity and co-linearity problem between the variables, and also it is well-known for its consistency as compared to the time series model. In addition, the error term is added to the economic growth model. Thus, we can re-write **Eq. (2)** into panel data form expressed as follows:

$$lnCO_{2it=}\alpha_0 + \alpha_1 lnGDP_{it} + \alpha_2 lnICT_{it} + \alpha_3 lnNEC_{it} + \alpha_4 lnREC_{it} + \alpha_5 lnOC_{it} + \alpha_6 lnCC_{it} + \mu_{it} \qquad (3)$$

Where, in the above **Eq. 2**, CO_2 indicates the carbon dioxide emission, GDP indicates economic growth, ICT represents information and telecommunication technology, NEC is nuclear energy consumption, REC is the renewable energy consumption, OC means the oil consumption and CC denotes the coal consumption. The subscript t means the time dimensions, i shows the number of cross-sections; α_0 allows for the possible country-fixed effect while $\alpha_{1,}$ α_2, $\alpha_{3,}$ $\alpha_{4,}$ α_5, α_6 are the parameters with respect to GDP, ICT, NEC, REC, OC, and CC, μ indicates the white noise error term.

The expected sign of GDP is positive because economic growth increases the level of pollution, as shown in **Figure 1**. ICT can have either a positive or negative effect on the environment because the role of ICT in CO_2 emissions is unclear (Shahzad et al., 2020). Clean and sustainable energy sources such as REC and NEC get huge attention in the economics literature. Moreover, REC and NEC's positive and significant role is in curbing the emissions, which is the key focus of our study. The expected coefficient of OC and CC is positive because energy usage from non-renewable energy sources such as (oil and coal) causes environmental degradation.

2.3 Methodology

In our study, this paper establishes a fixed effect panel quantile regression model to investigate the impact of Nuclear energy consumption, renewable energy consumption, and ICT on CO_2 emission. The panel quantile regression technique was first introduced by Koenker and Bssett (1978), which helps to

TABLE 2 | Ellipsis used for variables (British Petroleum, 2014; IEA, 2015; The World Bank, 2015; The World Bank, 2015; British Petroleum, 2018).

Code	Description of variable	Source
CO_2	Carbon dioxide emissions (metric tons per capita)	WDI
GDP	Economic growth (as per capita constant 2010 US$)	WDI
ICT	Information and communication technology (number of people)	WDI
NEC	Nuclear energy consumption (KWH)	EIA
REC	Renewable energy consumption (KWH)	EIA
OC	Oil consumption (Mtoe)	BP, Statistical Review
CC	Coal consumption (Mtoe)	BP, Statistical Review

Note: annual data is used over the period 1995–2017.

study the distribution of variables' asymmetry (Sharif et al., 2020). In addition, this approach is a generalization of the median regression analysis to other quantiles. This method can model the full conditional distribution, so it provides a diversified effect of independent variables on the dependent variable due to variable quantiles. PQR additionally assesses multiple slope coefficients at different quantiles and controls hidden heterogeneity for each cross-section. Assessing the value of the coefficient at the extremity of the distribution is also interesting for policy considerations. To determine the effects and unobserved individual heterogeneity, the conditional quantile functions of the response of Y_{it} given X_{it} are illustrated as follows in **Eq. 4**:

$$Qy_{it}(\tau|X_{it}) = X_{it}^{'}\beta_{\tau} \tag{4}$$

Here, $Qy_{it}(\tau|X_{it})$ Indicates the τ-th conditional quantile of the target variable of CO_2, X_{it} represents the vector of exposure variables for each country i at time t for quantile τ and β_τ signify the parameters to be estimated of the explanatory variables for quantile τ. The conditional quantile function for quantile τ as follows in **Equation (5)**:

$$q\left(\frac{CO_{2it}}{\Omega_t}\right) = \alpha_{0\tau} + \alpha_{1\tau}lnGDP_{it} + \alpha_{2\tau}lnICT_{it} + \alpha_{3\tau}lnNEC_{it} + \alpha_{4\tau}lnREC_{it} + \alpha_{5\tau}lnOC_{it}\alpha_{6\tau}lnCC_{it} + \mu_{it} \tag{5}$$

Here, $q(CO_2/\Omega_t)$ indicates the conditional quantile of CO_2, Ω_t consist of available information at time t.

2.4 Data

2.4.1 Data Source

In panel data analysis, country selection is a decisive aspect and we should be careful in-country selection for analysis. This may influence not only the analysis of the result of our study but also encourage the possibility of country selection bias. In our analysis, we consider the following top five CO_2 emission countries such as China, the United States, India, Japan, and South Korea. The purpose of our study is to investigate the effect of ICT, NEC, and REC on CO_2 emission in a multivariate framework. Thus, we imply annual data of the top five emitting countries over the period 1995–2017.

In this empirical study, the dependent variable is carbon dioxide emission emitted by fuel combustion which is measured in metric tons per capita. Our main variables of interest are ICT, REC, and NEC. Economic growth is the independent variable expressed (as per capita constant 2010 US$), information and telecommunication technology is expressed in terms of (number of people). Moreover, disaggregated energy consumption such as nuclear energy consumption, renewable energy consumption, oil consumption, and coal consumption are also taken as independent variables measured in KWH and MTOE. The data is obtained from World Development Indicators (WDI) and EIA. In our paper, the data are preprocessed and we take logarithms of all larger values of variables. The description of each variable is illustrated as follows in **Table 2**.

2.5 Data Analysis

Table 3, depicts the statistical analysis of each variable consisting of their mean, median, maximum, minimum, standard deviation, and Jarque-Bera statistics, along with their corresponding *p*-values for the top five selected countries from 1997–2017. In statistical analysis, the mean value of CO_2 emission of the five countries is 1.838262 per capita metric tons with their standard deviation of 0.966141. The average value of GDP is 9.269712 with a standard deviation of 1.538287 billion US$. Further, the mean value for ICT is 19.54465 with a standard deviation of 1.274295. NEC of the sampled countries has an average value of 4.542592 with a standard deviation of 1.569634 (KWH). The mean value of REC is 4.732299 (KWH) with a standard deviation of 1.683789. On the other hand, non-renewable energy sources (such as coal and oil) have a mean value of 5.46884 and 5.5093831 respectively, withtheir standard deviation of 1.108366 and 0.803499 (MT oil equivalent).

In a descriptive statistical analysis apart from the mean and standard deviation, the basic statistics test is the Skewness, Kurtosis. The pre-conditions of the skewness and the Kurtosis test statistics coefficients are that the skewness coefficient needs to be equal to 0 and for kurtosis must be equal to three for normal distribution. In this study, based on our findings of skewness and kurtosis, we clearly find that the distribution of all series are skewed and the distribution of kurtosis values indicates that seven variables distribution are more concentrated than the normal distribution of the long tails. In addition, the Jarque-Bera test statistics determine whether the distribution of the variable is normal or not through probability values. The Jarque-Bera test statistics indicate that only NEC and CC are normally distributed, while all other variables are non-normal distribution rejecting the null hypothesis. When the data samples have non-normal distribution, the use of panel quantile regression methods is more appropriate to analyze the effects and veracity of influencing factors.

3 EMPIRICAL RESULTS

This study starts with the smooth scrutiny of the data series. Firstly, based on the unit root test results, we determine whether

TABLE 3 | Descriptive statistics.

Variable	Co_2	GDP	ICT	NEC	REC	OC	CC
Mean	1.838262	9.269712	19.54465	4.542592	4.732299	5.509383	5.468843
Median	2.244435	9.910020	19.51388	4.818748	5.024670	5.369242	5.316648
Maximum	3.004630	10.88524	21.04997	6.693286	7.407032	6.874819	7.585332
Minimum	0.172050	6.514149	17.62424	–0.916291	1.033184	4.010963	3.335770
Std. Dev	0.966141	1.538287	1.274295	1.569634	1.683789	0.803499	1.108366
Skewness	–0.800370	–0.491947	–0.160546	–0.409440	–0.909967	0.445942	0.171259
Kurtosis	2.346710	1.602597	1.531343	2.764595	2.837094	1.940873	2.106560
Jarque-Bera	14.32304[a]	13.99542[a]	10.82941[b]	3.478660	15.99792[b]	9.186618[b]	4.387027

[a]*Statistical significance at the 10%*
[b]*Statistical significance at the 5%*
[c]*Statistical significance at the 1%*

TABLE 4 | stationary test results of each variable.

Variable	Co_2	GDP	ICT	NEC	REC	OC	CC
Levels	—	—	—	—	—	—	—
Fisher-ADF	–1.870938	–2.106435	–2.187263	–2.763502	–2.884862	–3.075639	–2.983972
Fisher-PP	–1.946099	–2.203909	–2.279954	–2.628109	–2.940984	–2.941465	–1.707828
IPS	–1.05444	0.8091	1.3553	3.5448	4.06971	–1.6696[b]	-0.9927
LLC	2.16440	–0.96008	–0.25032	1.20728	2.29395	–1.69939[b]	–0.77261
Breitung	0.46243	6.83625	1.87213	1.85548	5.54988	–0.00219	1.49696
First-order difference	—	—	—	—	—	—	—
Fisher-ADF	–10.56107[c]	–10.46267[c]	–10.61352[c]	–11.08747[c]	–10.62464[c]	–12.94348[c]	–4.269482[c]
Fisher-PP	–10.56107[c]	–10.46267[c]	–10.61452[c]	–11.09732[c]	–10.63758[c]	–13.07853[c]	–14.34524[c]
IPS	–5.1183[c]	–1.6587[b]	–1.5483[a]	–3.7478[c]	–8.1333[c]	–7.2756[c]	–7.6716[c]
LLC	–1.96682[b]	–5.76085[c]	–2.10558[b]	–5.42958[c]	–9.68000[c]	–8.01406[c]	–4.73689[c]
Breitung	–1.73845[b]	–4.69853[c]	–1.58027[b]	–3.00294[c]	–5.33490[c]	–5.08637[c]	–7.16060[c]

[a]*Statistical significance at the 10%*
[b]*Statistical significance at the 5%*
[c]*Statistical significance at the 1%*

the panel cointegration method is appropriate for this study or not. Then, we apply a panel PQR technique for empirical analysis.

3.1 Results of the Stationary Test

Before using the PQR method, it is necessary to check the stability of each series. For this, the panel unit root test was applied. There have been five methods for selecting the unit root of the panel: the fisher type test, and Augmented-Dickey-Fuller (ADF), Phillips-Perron (PP) (Maddala and Wu, 1999; Breitung, 2001), IPS Im-Pesaran-Shin (Im et al., 2003), LLC (Levine, Lin, Chu (Levin et al., 2002). **Table 4** illustrates the results of panel unit root tests. The findings show that all series are stationary at the first-order difference and integrated at an order one I (1). The variables are significant at 1, 5, and 10% significance levels and after first-order difference, each variable becomes smooth.

3.2 Results of Panel Johansen Fisher Co-integration Method

Once it is confirmed that all the variables are integrated in the same order I (1), we can proceed to analyze the long-run relationship amid the variables by applying the panel Johansen Fisher cointegration method reported by (Maddala and Wu, 1999). The findings of Johansen Fisher's cointegration rely on the VAR system lag order. The panel Johansen Fisher co integration findings are illustrated in **Table 5** and the results indicate that six cointegrating vectors exist. Therefore, we reject the null hypothesis. So, based on the panel Johansen Fisher cointegration test, we confirmed that a long-run relationship exists amid the CO_2, GDP, ICT, NEC, REC, OC, and CC.

3.3 Panel Quantile Regression Results

On the basis of the PQR technique, the heterogeneous effects of NEC, REC, ICT, and other decisive factors on CO_2 emission are examined in this study. For comparison, we first provide the OLS regression estimation results. This method presents a baseline of average effects and then we compare these to estimates for separate quantiles in the conditional distribution of CO_2 emission. This research has used the nine quantiles for a comprehensive analysis of the NEC, REC, and determinant factors of $CO_{2.}$ emissions. Both OLS and panel quantile regression results are displayed in **Table 6** and **Figure 2** illustrates the graphics of estimated coefficients NEC, REC, and other factors on $CO_{2.}$ emissions of emitter countries. The results are reported for nine quantiles (i.e. 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th' and 90th quantiles). First, the conventional OLS results represent that GDP has a positive and significant impact on CO_2 emission, meaning that a 1% increase in per capita GDP will augment CO_2 emission by 0.237%. Also note the coefficient of ICT is negative and highly significant at a 1% level as expected, which shows that a 1% increase in ICT will decrease CO_2 emission by -0.343%. We further observe the

TABLE 5 | Fisher panel Johansen co-integration test results.

Hypothesized No. of CE(s)	Fisher stat. [a] (from trace test)	Prob	Fisher stat. [a] (from max-eigen test)	Prob
None	58.03	0.0000	58.03	0.0000
At most 1	262.5	0.0000	133.4	0.0000
At most 2	182.3	0.0000	111.0	0.0000
At most 3	104.1	0.0000	44.07	0.0000
At most 4	72.09	0.0000	44.29	0.0000
At most 5	40.95	0.0000	31.60	0.0005
At most 6	27.95	0.0018	27.95	0.0018

[a]*Probabilities are computed using asymptotic Chi-square distribution.*

TABLE 6 | Panel Quantile Regression results.

Variables	OLS	Quantile regressions								
—	—	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
GDP	0.237[c] (0.0000)	0.575[c] (0.0000)	0.578[c] (0.0000)	0.580[c] (0.0000	0.670[c] (0.0000)	0.695[c] (0.0000)	0.561[c] (0.0000)	0.551[c] (0.0000)	0.540[c] (0.0000)	0.521[c] (0.0000)
ICT	−0.343[c] (0.0000)	−0.717[c] (0.0000)	−0.623[c] (0.0000)	−0.535[c] (0.0000)	−0.456[c] (0.0000)	−0.352[c] (0.0000)	−0.230[c] 0.0052	−0.148[a] 0.0600	−0.361 0.3176	−0.470[a] 0.0923
NEC	−0.00066 (0.9562)	−0.016 (0.2171)	−0.00872 (0.2136)	−0.0088 (0.2019)	−0.0108 (0.1659)	−0.0092 (0.2099)	−0.0032 (0.6748)	−0.00079 (0.9273)	−0.012 (0.7544)	0.026 (0.0840)
REC	−0.236[c] (0.0000)	−0.529[c] (0.0000)	−0.527[c] (0.0000)	−0.568[c] (0.0000)	−0.608[c] (0.0000)	−0.596[c] (0.0000)	−0.551[c] (0.0001)	−0.581[c] (0.0009)	−1.031[c] (0.0000)	−0.551 (0.7507)
OC	0.293[c] (0.0000)	1.371 (0.0000)	1.322[c] (0.0000)	1.287[c] (0.0000)	1.216[c] (0.0000)	0.446[c] (0.0001)	0.417[c] (0.0000)	0.333[c] (0.0001)	0.317[c] (0.0000)	0.259[c] (0.0000)
CC	0.366[c] (0.0000)	0.729[c] (0.0005)	0.708[c] (0.0073)	−0.358[b] (0.0101)	−0.170[b] (0.0267)	−0.085 (0.2660)	−0.080 (0.2775)	0.236[a] (0.0677)	0.266[b](0.0154)	0.269[c] (0.0018)

[a]*Statistical significance at the 10%*
[b]*Statistical significance at the 5%*
[c]*Statistical significance at the 1%.*

estimated coefficient of NEC is negative, but the effect is feeble. The estimated coefficient of REC is negative and statistically significant at a 1% level. For the non-renewable energy sources (oil, coal), their impacts are positive and significant at a 1% level. The result illustrates that the augmentation of oil and coal by 1% increases environmental degradation. The conventional panel regression model has only one output, which is the estimation result of the mean of the dependent variable. The panel quantile regression model, on the other hand, is unique. The PQR model is used to estimate the different distributed results of the output variables, thus making the estimation more complete.

The PQR findings suggest some important differences over different points in the conditional distribution of CO_2 emission. Regarding the GDP, we can observe that the impact of GDP on CO_2 emission is positive and statistically significant at a 1% level in all quantile levels, which indicates that environmental pollution increases with GDP. This finding is aligned with the previous works of (Chen et al., 2020; Zheng et al., 2021b). Concerning the role of ICT, the result shows that the coefficient of ICT is negative and significant in all quantiles except at high (80th) quantile it is negative but insignificant, it clearly shows that the environmental pollution lessens with ICT in top emitter economies which is consistent with the previous studies (Añón Higón et al., 2017; Danish et al., 2018). The effect of NEC on CO_2 emission is negative and insignificant in all quantiles except at (90th) high quantile, it is significant. These results are in line with (Jaforullah and King, 2015; Jebli et al., 2016; Mahmood et al., 2020). Moreover, the coefficient of renewable energy consumption is negative and significant in all quantiles, but it is not significant at the 95th quantile. However, our results are different from those studies (Apergis et al., 2010; Bölük and Mert, 2015) who stated that renewable energy accelerates, instead of mitigating carbon emission. In terms of non-renewable energy sources (oil, coal), we can find that oil and coal consumption increase environmental pollution in emitter countries. The coefficient of oil is positive and significant at 1% level in all quantiles level. This result is consistent with (Wen et al., 2020; Zheng et al., 2021a). The coefficient of coal consumption is significant at lower quantiles (10th and 20th), at other quantiles (30th, 40th, 50th, 60th), the coefficient is negative but significant but in (50th, 60th) quantile it is insignificant and at higher quantiles, it is positive and significant.

Our PQR results indicate that nuclear energy consumption, which is alternative and environmentally friendly, is negative but insignificant in explaining the environmental quality in emitter countries, as shown in **Figure 2**. This may occur because the share of NEC is a relatively low and insignificant contribution to the total

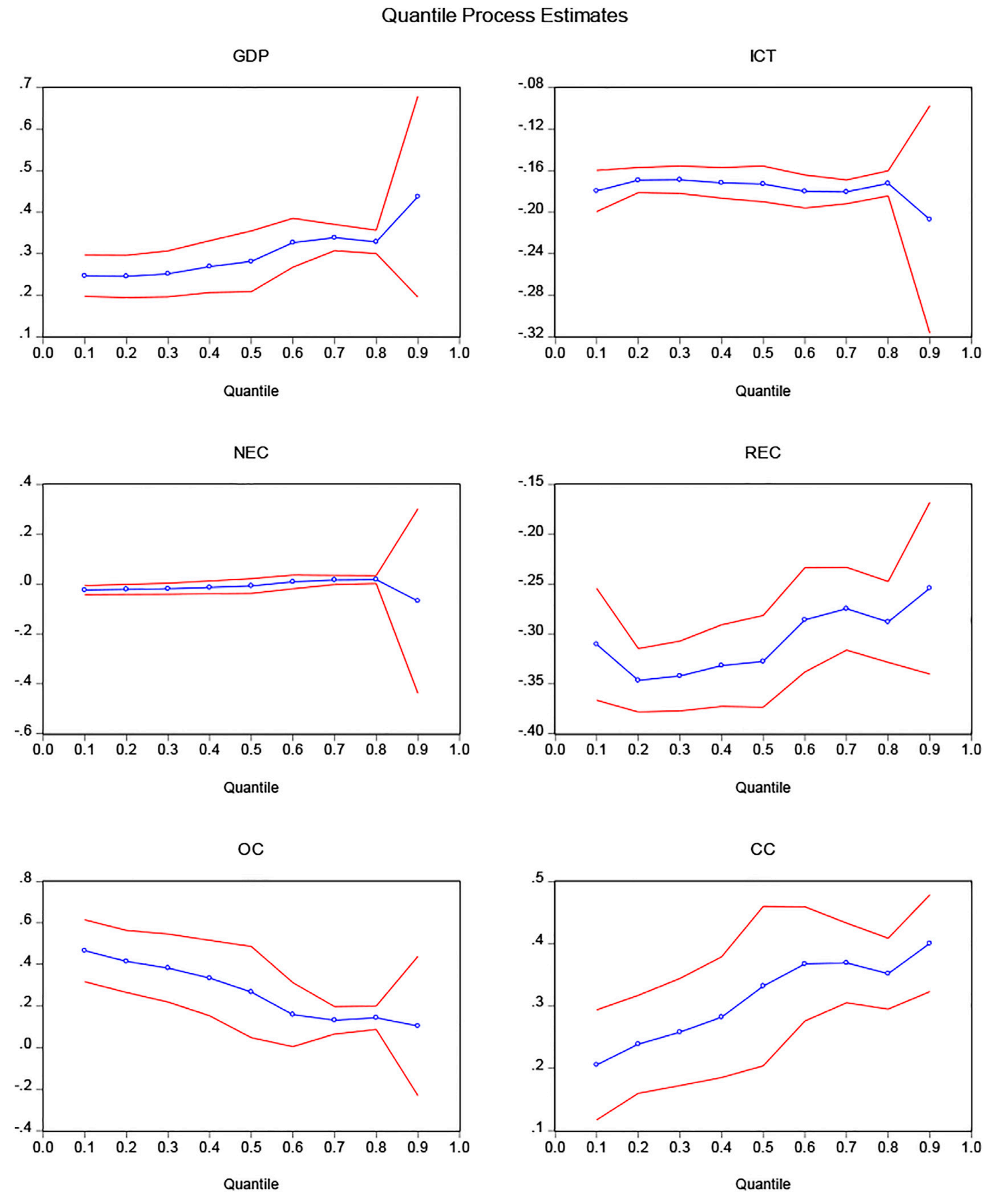

FIGURE 2 | Summary of the Quantile Process results.

energy supply in these countries. It is undeniable that nuclear energy is an alternative and better solution to improve environmental quality and has minimal risk compared to conventional energy sources. In addition, emitter economies should develop nuclear energy-related investment programs and strategies.

Further, renewable energy contributes to improve the environmental quality in these selected countries. Thus, emitter countries should follow initiate step-wise transformation from conventional energy sources (oil, coal) to clean and alternative energy implying in domestic use, industrial and commercial sectors. In addition, we find that the effect of renewable energy consumption is relatively low, but the investment of fossil fuel sources (coal, oil) is relatively large. For obvious understanding, emitter countries need to bring reforms to diminish the use of traditional energy consumption by amplification of nuclear energy and renewable energy sources. Innovation plays an important role in carbon emission mitigation, and focusing on technologies that can increase economic and environmental sustainability.

However, clean energy innovations and ICT needed more investment which might be helpful to increase environmental sustainability. The rapid advancement of technology is also contributing to global warming through destructive greenhouse gas emissions. The effect of ICT on CO emissions is heterogeneous and significantly negative at all quantiles and the effect is diverse at different quantiles. The ICT sector is one of the fastest expanding, influencing practically every other technology. Clean energy and global warming mitigation are now an ambition and reality for all policymakers and researchers involved in this technology. Therefore, a combined collaboration of clean technologies and innovations is needed for excessive energy supply and a sustainable environment.

4 CONCLUSION AND DISCUSSION

In light of growing concern over greenhouse gas emissions from traditional energy sources (oil, coal, gas) and limited energy supply has ultimately elicited global attention to achieve sustainability to ensure adequate energy access and curb environmental risks. Keeping both these targets in mind, this study investigates the role of nuclear energy, renewable energy, and ICT in CO_2 emissions in the context of the five emitter countries by taking the longest available data span from 1995 to 2017. In differing from earlier studies, we apply the advanced panel quantile regression method to achieve the targets. This model takes into account the unobserved individual heterogeneity and distributional heterogeneity. Further, in contrast with OLS regression, the panel quantile regression model can help us achieve a more complete picture of the factors affecting CO_2 emissions.

Our findings show that the impact of GDP on CO_2 emission is positive and statistically significant, meaning that GDP has a positive influence on environmental pollution. With respect to nuclear energy consumption, which is insignificant in explaining environmental pollution, it shows that the contribution of nuclear energy contribution is unclear. Moreover, the coefficient of renewable energy consumption and ICT is negative and statistically significant, meaning that accelerated investment in renewable energy consumption and ICT would improve the environmental quality in emitter countries. In addition, fossil fuel energy sources (oil, coal) show that oil and coal consumption increase environmental pollution in emitter countries. The coefficient of oil is positive and significant at a 1% level in all quartiles level. The coefficient of coal consumption is significant at lower quantiles; at other quantiles, the coefficient is negative and significant but at higher quantiles, it is positive and significant.

In light of the outcomes of the study, some policy implications are recommended. Although, the coefficient of nuclear energy is negative its reduction effect is insignificant, nuclear energy is clean and environmentally friendly, and also cost-effective. However, it is worth bearing in mind that nuclear power ensures energy security as well as boosts economic growth, and is appropriate for environmental sustainability. Thus, improvement in infrastructure development for nuclear power generation should be the initial step as well as operational performance, efficiency, and monitoring checks are important to ensure environmental improvement. Therefore, emitter countries should maintain a clear sense of this dilemma and establish several effective short, medium, and long-term energy policies in order to mitigate the CO_2 emission level by adjusting the share of nuclear energy consumption in the total primary energy mix. Moreover, the potential of renewable energy to mitigate the CO_2 emission is negative and significant which suggests these countries should increase the share of renewable energy consumption in the long term. It is critical to enhance projects and investments that promote the role of renewable energy by offering incentives to renewable manufacturers and encouraging new renewable energy research. This will expand the role of renewable energy, which will not only help to create more jobs in construction and manufacturing but will also benefit renewable energy technologies in achieving economies of scale, lowering the cost of these energy sources. In addition, our results infer that the use of ICT lessens the CO_2 emission level in emitter countries. The ICT sector pursuing environmental sustainability and energy efficiency for its own sake, as well as it is also assisting in the reduction of electrical consumption by infusing technology into other sectors. = However, the development of energy-efficient ICT devices and to improve energy efficiency in systems and devices, particularly networks, a multidisciplinary R&D effort is necessary for these countries to lessen environmental degradation. In addition, skills and knowledge about the subject must be extensively disseminated so that it reaches all stakeholders, not just researchers. Last but not least, these countries must replace fossil fuel sources (coal and oil) with clean energy sources for sustainable economic development and environmental quality. In this paper, we investigate the impacts of nuclear energy, renewable energy, and ICT on CO_2 emissions in the top-five carbon emitting countries. However, the status of different dimensions is different for developing countries or developed countries. In addition, the methodology may be different for them. Therefore, in the future, we could apply different models and variables on CO_2 emissions for larger samples including developed and developing economies.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

AA: Conceptualization, Methodology, Software, Data curation, Writing e original draft, Visualization, Validation, Writing-Reviewing and Editing; MR: Conceptualization, Methodology, Software, Writing original draft, Writing-Reviewing and Editing; MS: Conceptualization, Methodology, Writing-Reviewing and Editing; JY: Conceptualization, Methodology, Supervision.

REFERENCES

Adebola Solarin, S., Al-Mulali, U., and Ozturk, I. (2017). Validating the Environmental Kuznets Curve Hypothesis in India and China: The Role of Hydroelectricity Consumption. *Renew. Sustainable Energ. Rev.* 80, 1578–1587. doi:10.1016/j.rser.2017.07.028

Al-Mulali, U., Fereidouni, H. G., Lee, J. Y., and Sab, C. N. B. C. (2013). Examining the Bi-directional Long Run Relationship between Renewable Energy Consumption and GDP Growth. *Renew. Sustainable Energ. Rev.* 22, 209–222. doi:10.1016/j.rser.2013.02.005

Al-Mulali, U. (2014). Investigating the Impact of Nuclear Energy Consumption on GDP Growth and CO 2 Emission: A Panel Data Analysis. *Prog. Nucl. Energ.* 73, 172–178. doi:10.1016/j.pnucene.2014.02.002

Al-Mulali, U., and Ozturk, I. (2016). The Investigation of Environmental Kuznets Curve Hypothesis in the Advanced Economies: the Role of Energy Prices. *Renew. Sustainable Energ. Rev.* 54, 1622–1631. doi:10.1016/j.rser.2015.10.131

Al-Mulali, U., Sheau-Ting, L., and Ozturk, I. (2015). The Global Move toward Internet Shopping and its Influence on Pollution: an Empirical Analysis. *Environ. Sci. Pollut. Res.* 22, 9717–9727. doi:10.1007/s11356-015-4142-2

Alam, M. M., Murad, M. W., Noman, A. H. M., and Ozturk, I. (2016). Relationships Among Carbon Emissions, Economic Growth, Energy Consumption and Population Growth: Testing Environmental Kuznets Curve Hypothesis for Brazil, China, India and Indonesia. *Ecol. Indicators* 70, 466–479. doi:10.1016/j.ecolind.2016.06.043

Alsayed, A. R. M., Isa, Z., Kun, S. S., and Manzi, G. (2020). Quantile Regression to Tackle the Heterogeneity on the Relationship between Economic Growth, Energy Consumption, and CO2 Emissions. *Environ. Model. Assess.* 25, 251–258. doi:10.1007/s10666-019-09669-7

Añón Higón, D., Gholami, R., and Shirazi, F. (2017). ICT and Environmental Sustainability: A Global Perspective. *Telematics Inform.* 34, 85–95. doi:10.1016/j.tele.2017.01.001

Apergis, N., Payne, J. E., Menyah, K., and Wolde-Rufael, Y. (2010). On the Causal Dynamics between Emissions, Nuclear Energy, Renewable Energy, and Economic Growth. *Ecol. Econ.* 69, 2255–2260. doi:10.1016/j.ecolecon.2010.06.014

Asongu, S. A., Le Roux, S., and Biekpe, N. (2018). Enhancing ICT for Environmental Sustainability in Sub-saharan Africa. *Technol. Forecast. Soc. Change* 127, 209–216. doi:10.1016/j.techfore.2017.09.022

Aydın, C. İ. (2020). Nuclear Energy Debate in Turkey: Stakeholders, Policy Alternatives, and Governance Issues. *Energy Policy* 136, 111041. doi:10.1016/j.enpol.2019.111041

Azam, A., Rafiq, M., Shafique, M., Yuan, J., and Salem, S. (n.d). Human Development Index, ICT and Renewable Energy-Growth Nexus for Sustainable Development: A Novel PVAR Analysis. *Front. Energ. Res.* 760. doi:10.3389/fenrg.2021.760758

Azam, A., Rafiq, M., Shafique, M., Ateeq, M., and Yuan, J. (2020a). Causality Relationship between Electricity Supply and Economic Growth: Evidence from Pakistan. *Energies* 13, 837. doi:10.3390/en13040837

Azam, A., Rafiq, M., Shafique, M., and Yuan, J. (2021b). Renewable Electricity Generation and Economic Growth Nexus in Developing Countries: An ARDL Approach. *Econ. Research-Ekonomska Istraživanja* 34, 2423–2446. doi:10.1080/1331677X.2020.1865180

Azam, A., Rafiq, M., Shafique, M., Ateeq, M., and Yuan, J. (2021a). Investigating the Impact of Renewable Electricity Consumption on Sustainable Economic Development: a Panel ARDL Approach. *Int. J. Green Energ.* 18, 1185–1192. doi:10.1080/15435075.2021.1897825

Azam, A., Rafiq, M., Shafique, M., and Yuan, J. (2021e). An Empirical Analysis of the Non-linear Effects of Natural Gas, Nuclear Energy, Renewable Energy and ICT-Trade in Leading CO2 Emitter Countries: Policy towards CO2 Mitigation and Economic Sustainability. *J. Environ. Manage.* 286, 112232. doi:10.1016/j.jenvman.2021.112232

Azam, A., Rafiq, M., Shafique, M., and Yuan, J. (2021c). Does Nuclear or Renewable Energy Consumption Help to Control Environmental Pollution? New Evidence from China. *Renew. Energ. Focus* 39, 139–147. doi:10.1016/j.ref.2021.08.002

Azam, A., Rafiq, M., Shafique, M., Zhang, H., Ateeq, M., and Yuan, J., (2021d). Analyzing the Relationship between Economic Growth and Electricity Consumption from Renewable and Non-renewable Sources: Fresh Evidence from Newly Industrialized Countries. *Sustainable Energ. Tech. Assessments* 44(3):100991. doi:10.1016/j.seta.2021.100991

Azam, A., Rafiq, M., Shafique, M., Zhang, H., and Yuan, J. (2021f). Analyzing the Effect of Natural Gas, Nuclear Energy and Renewable Energy on GDP and Carbon Emissions: A Multi-Variate Panel Data Analysis. *Energy* 219 (13), 119592. doi:10.1016/j.energy.2020.119592

Baek, J. (2016). Do nuclear and Renewable Energy Improve the Environment? Empirical Evidence from the United States. *Ecol. Indicators* 66, 352–356. doi:10.1016/j.ecolind.2016.01.059

Baloch, M. A., and Wang, B. (2019). Analyzing the Role of Governance in CO2 Emissions Mitigation: The BRICS Experience. *Struct. Chang. Econ. Dyn.* 51, 119–125. doi:10.30848/pjb2019-3(32)

Baloch, M. A., Mahmood, N., and Zhang, J. W. (2019). Effect of Natural Resources, Renewable Energy and Economic Development on CO2 Emissions in BRICS Countries. *Sci. Total Environ.* 678, 632–638. doi:10.1016/j.scitotenv.2019.05.028

Ben Jebli, M., Ben Youssef, S., and Ozturk, I. (2016). Testing Environmental Kuznets Curve Hypothesis: The Role of Renewable and Non-renewable Energy Consumption and Trade in OECD Countries. *Ecol. Indicators* 60, 824–831. doi:10.1016/j.ecolind.2015.08.031

Bilgili, F., Koçak, E., and Bulut, Ü. (2016). The Dynamic Impact of Renewable Energy Consumption on CO 2 Emissions: A Revisited Environmental Kuznets Curve Approach. *Renew. Sustainable Energ. Rev.* 54, 838–845. doi:10.1016/j.rser.2015.10.080

Bölük, G., and Mert, M. (2015). The Renewable Energy, Growth and Environmental Kuznets Curve in Turkey: An ARDL Approach. *Renew. Sustainable Energ. Rev.* 52, 587–595. doi:10.1016/j.rser.2015.07.138

Breitung, J. (2001). *The Local Power of Some Unit Root Tests for Panel Data*. Emerald Group Publishing Limited.

British Petroleum (2014). *BP Statistical Review of World Energy*. Br. Pet. doi:10.1016/j.egypro.2013.06.172

British Petroleum (2018). *Statistical Review of World Energy | Energy Economics | Home [WWW Document]*. Stat. Rev. World Energy.

Bulut, U. (2017). The Impacts of Non-renewable and Renewable Energy on CO_2 Emissions in Turkey. *Environ. Sci. Pollut. Res.* 24, 15416–15426. doi:10.1007/s11356-017-9175-2

Chaudhry, I. S., Safdar, N., and Farooq, F. (2012). Energy Consumption and Economic Growth: Empirical Evidence from Pakistan. *Pakistan J. Soc. Sci.* 32, 371–382.

Chen, X., Li, Y., Xiao, J., and Wen, F. (2020). Oil Shocks, Competition, and Corporate Investment: Evidence from China. *Energ. Econ.* 89, 104819. doi:10.1016/j.eneco.2020.104819

Cheng, C., Ren, X., Dong, K., Dong, X., and Wang, Z. (2021). How Does Technological Innovation Mitigate CO2 Emissions in OECD Countries? Heterogeneous Analysis Using Panel Quantile Regression. *J. Environ. Manage.* 280, 111818. doi:10.1016/j.jenvman.2020.111818

Chu, H.-P., and Chang, T. (2012). Nuclear Energy Consumption, Oil Consumption and Economic Growth in G-6 Countries: Bootstrap Panel Causality Test. *Energy Policy* 48, 762–769. doi:10.1016/j.enpol.2012.06.013

Coroama, V. C., Hilty, L. M., and Birtel, M. (2012). Effects of Internet-Based Multiple-Site Conferences on Greenhouse Gas Emissions. *Telematics Inform.* 29, 362–374. doi:10.1016/j.tele.2011.11.006

Danish (2019). Effects of Information and Communication Technology and Real Income on CO2 Emissions: The Experience of Countries along Belt and Road. *Telematics Inform.* 45, 101300. doi:10.1016/j.tele.2019.101300

Dong, K., Sun, R., and Dong, X. (2018). CO2 Emissions, Natural Gas and Renewables, Economic Growth: Assessing the Evidence from China. *Sci. Total Environ.* 640-641, 293–302. doi:10.1016/j.scitotenv.2018.05.322

Duan, K., Ren, X., Shi, Y., Mishra, T., and Yan, C. (2021). The Marginal Impacts of Energy Prices on Carbon price Variations: Evidence from a Quantile-On-Quantile Approach. *Energ. Econ.* 95, 105131. doi:10.1016/j.eneco.2021.105131

Hasnisah, A., Azlina, A. A., and Taib, C. M. I. C. (2019). The Impact of Renewable Energy Consumption on Carbon Dioxide Emissions: Empirical Evidence from Developing Countries in Asia. *Ijeep* 9, 135–143. doi:10.32479/ijeep.7535

Hassan, S. T., Danish, M. A., Salah-Ud-Din khan, Z. H., Awais Baloch, M., and Tarar, Z. H. (2020). Is Nuclear Energy a Better Alternative for Mitigating CO2 Emissions in BRICS Countries? An Empirical Analysis. *Nucl. Eng. Technology* 52, 2969–2974. doi:10.1016/j.net.2020.05.016

Huang, Y., Zhu, H., and Zhang, Z. (2020). The Heterogeneous Effect of Driving Factors on Carbon Emission Intensity in the Chinese Transport Sector:

Evidence from Dynamic Panel Quantile Regression. *Sci. Total Environ.* 727, 138578. doi:10.1016/j.scitotenv.2020.138578

IEA (2015). *Energy and Climate Change, World Energy Outlook Special Report*.

Iheonu, C. O., Asongu, S. A., Odo, K. O., and Ojiem, P. K. (2020). Financial Sector Development and Investment in Selected Countries of the Economic Community of West African States: Empirical Evidence Using Heterogeneous Panel Data Method. *Financ. Innov.* 6, 1–15. doi:10.1186/s40854-020-00195-0

Ike, G. N., Usman, O., and Sarkodie, S. A. (2020). Testing the Role of Oil Production in the Environmental Kuznets Curve of Oil Producing Countries: New Insights from Method of Moments Quantile Regression. *Sci. Total Environ.* 711, 135208. doi:10.1016/j.scitotenv.2019.135208

Im, K. S., Pesaran, M. H., and Shin, Y. (2003). Testing for Unit Roots in Heterogeneous Panels. *J. Econom.* 115 (1), 53–74. doi:10.1016/S0304-4076(03)00092-7

IPCC (2018a). *An IPCC Special Report on the Impacts of Global Warming of 1.5˚C.* IPCC. doi:10.1002/9780470996621.ch50

IPCC (2018b). *Global Warming of 1.5 ˚C. IPCC Special Report 1.5 Summary for Policymakers*. IPCC. doi:10.1017/CBO9781107415324

Jaforullah, M., and King, A. (2015). Does the Use of Renewable Energy Sources Mitigate CO 2 Emissions? A Reassessment of the US Evidence. *Energ. Econ.* 49, 711–717. doi:10.1016/j.eneco.2015.04.006

Jin, T., and Kim, J. (2018). What Is Better for Mitigating Carbon Emissions - Renewable Energy or Nuclear Energy? A Panel Data Analysis. *Renew. Sustainable Energ. Rev.* 91, 464–471. doi:10.1016/j.rser.2018.04.022

Khan, N., Baloch, M. A., Saud, S., and Fatima, T. (2018). The Effect of ICT on CO2 Emissions in Emerging Economies: Does the Level of Income Matters? *Environ. Sci. Pollut. Res.* 25, 22850–22860. doi:10.1007/s11356-018-2379-2

Latif, Z., Jianqiu, Z., Salam, S., Pathan, Z. H., Jan, N., and Tunio, M. Z. (2017). FDI and 'political' Violence in Pakistan's Telecommunications. *Hsm* 36, 341–352. doi:10.3233/HSM-17154

Lau, L.-S., Choong, C.-K., Ng, C.-F., Liew, F.-M., and Ching, S.-L. (2019). Is Nuclear Energy Clean? Revisit of Environmental Kuznets Curve Hypothesis in OECD Countries. *Econ. Model.* 77, 12–20. doi:10.1016/j.econmod.2018.09.015

Lee, S., Kim, M., and Lee, J. (2017). Analyzing the Impact of Nuclear Power on CO2 Emissions. *Sustainability* 9, 1428. doi:10.3390/su9081428

Levin, A., Lin, C. F., and Chu, C. S. J. (2002). Unit Root Tests in Panel Data: Asymptotic and Finite-Sample Properties. *J. Econom.* 108 (1), 1–24. doi:10.1016/S0304-4076(01)00098-7

Liu, M., Ren, X., Cheng, C., and Wang, Z. (2020). The Role of Globalization in CO2 Emissions: a Semi-parametric Panel Data Analysis for G7. *Sci. Total Environ.* 718, 137379. doi:10.1016/j.scitotenv.2020.137379

Maddala, G. S., and Wu, S. (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxf. Bull. Econ. Stat.* 61, 631–652. doi:10.1111/1468-0084.0610s1631

Mahmood, N., DanishWang, Z., Wang, Z., and Zhang, B. (2020). The Role of Nuclear Energy in the Correction of Environmental Pollution: Evidence from Pakistan. *Nucl. Eng. Technology* 52, 1327–1333. doi:10.1016/j.net.2019.11.027

Menyah, K., and Wolde-Rufael, Y. (2010). CO_2 Emissions, Nuclear Energy, Renewable Energy and Economic Growth in the US. *Energy Policy*, 38, 2911–2915. doi:10.1016/j.enpol.2010.01.024

Paramati, S. R., Mo, D., and Gupta, R. (2017). The Effects of Stock Market Growth and Renewable Energy Use on CO2 Emissions: Evidence from G20 Countries. *Energ. Econ.* 66, 360–371. doi:10.1016/j.eneco.2017.06.025

Park, S.-H., Jung, W.-J., Kim, T.-H., and Lee, S.-Y. T. (2016). Can Renewable Energy Replace Nuclear Power in Korea? An Economic Valuation Analysis. *Nucl. Eng. Technology* 48, 559–571. doi:10.1016/j.net.2015.12.012

Peng, L., Zhang, Y., Li, F., Wang, Q., Chen, X., and Yu, A. (2019). Policy Implication of Nuclear Energy's Potential for Energy Optimization and CO2 Mitigation: A Case Study of Fujian, China. *Nucl. Eng. Technology* 51, 1154–1162. doi:10.1016/j.net.2019.01.016

Prăvălie, R., and Bandoc, G. (2018). Nuclear Energy: Between Global Electricity Demand, Worldwide Decarbonisation Imperativeness, and Planetary Environmental Implications. *J. Environ. Manage.* 209, 81–92. doi:10.1016/j.jenvman.2017.12.043

Qiao, H., Zheng, F., Jiang, H., and Dong, K. (2019). The Greenhouse Effect of the Agriculture-Economic Growth-Renewable Energy Nexus: Evidence from G20 Countries. *Sci. Total Environ.* 671, 722–731. doi:10.1016/j.scitotenv.2019.03.336

Ren, X., Cheng, C., Wang, Z., and Yan, C. (2021). Spillover and Dynamic Effects of Energy Transition and Economic Growth on Carbon Dioxide Emissions for the European Union: A Dynamic Spatial Panel Model. *Sustainable Development* 29, 228–242. doi:10.1002/sd.2144

Salman, M., Long, X., Dauda, L., and Mensah, C. N. (2019). The Impact of Institutional Quality on Economic Growth and Carbon Emissions: Evidence from Indonesia, South Korea and Thailand. *J. Clean. Prod.* 241, 118331. doi:10.1016/j.jclepro.2019.118331

Shafique, M., Azam, A., Rafiq, M., and Luo, X. (2020). Evaluating the Relationship between Freight Transport, Economic prosperity, Urbanization, and CO2 Emissions: Evidence from Hong Kong, Singapore, and South Korea. *Sustainability* 12, 10664. doi:10.3390/su122410664

Shafique, M., Azam, A., Rafiq, M., and Luo, X. (2021a). Investigating the Nexus Among Transport, Economic Growth and Environmental Degradation: Evidence from Panel ARDL Approach. *Transport Policy* 109, 61–71. doi:10.1016/j.tranpol.2021.04.014

Shafique, M., Azam, A., Rafiq, M., and Luo, X. (2021b). Life Cycle Assessment of Electric Vehicles and Internal Combustion Engine Vehicles: A Case Study of Hong Kong. *Res. Transp. Econ.* 101112. doi:10.1016/j.retrec.2021.101112

Shafique, M., and Luo, X. (2021). Environmental Life Cycle Assessment of Battery Electric Vehicles from the Current and Future Energy Mix Perspective. *J. Environ. Manage.* 303, 114050. doi:10.1016/j.jenvman.2021.114050

Shahzad, K., Jianqiu, Z., Hashim, M., Nazam, M., and Wang, L. (2020). Impact of Using Information and Communication Technology and Renewable Energy on Health Expenditure: A Case Study from Pakistan. *Energy* 204, 117956. doi:10.1016/j.energy.2020.117956

Sharif, A., Mishra, S., Sinha, A., Jiao, Z., Shahbaz, M., and Afshan, S. (2020). The Renewable Energy Consumption-Environmental Degradation Nexus in Top-10 Polluted Countries: Fresh Insights from Quantile-On-Quantile Regression Approach. *Renew. Energ.* 150, 670–690. doi:10.1016/j.renene.2019.12.149

The World Bank (2015). *World Development Indicators*. DataBank. DataBank [WWW Document].

Wang, W.-H., Himeda, Y., Muckerman, J. T., Manbeck, G. F., and Fujita, E. (2015). CO2 Hydrogenation to Formate and Methanol as an Alternative to Photo- and Electrochemical CO2 Reduction. *Chem. Rev.* 115, 12936–12973. doi:10.1021/acs.chemrev.5b00197

Wen, F., Zhao, L., He, S., and Yang, G. (2020). Asymmetric Relationship between Carbon Emission Trading Market and Stock Market: Evidences from China. *Energ. Econ.* 91, 104850. doi:10.1016/j.eneco.2020.104850

Yahya, F., and Rafiq, M. (2020). Brownfield, greenfield, and Renewable Energy Consumption: Moderating Role of Effective Governance. *Energ. Environ.* 31, 405–423. doi:10.1177/0958305x19872936

Zhang, B., Wang, B., and Wang, Z. (2017). Role of Renewable Energy and Non-renewable Energy Consumption on EKC: Evidence from Pakistan. *J. Clean. Prod.* 156, 855–864. doi:10.1016/j.jclepro.2017.03.203

Zheng, Y., Yin, H., Zhou, M., Liu, W., and Wen, F. (2021a). Impacts of Oil Shocks on the EU Carbon Emissions Allowances under Different Market Conditions. *Energ. Econ.* 104, 105683. doi:10.1016/j.eneco.2021.105683

Zheng, Y., Zhou, M., and Wen, F. (2021b). Asymmetric Effects of Oil Shocks on Carbon Allowance price: Evidence from China. *Energ. Econ.* 97, 105183. doi:10.1016/j.eneco.2021.105183

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.