



Sustainable economic activities, climate change, and carbon risk: an international evidence

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Abstract

The employment of renewable resources and their association with the real economy's growth in mitigating the problem of carbon emission risk has been debated in the literature in a specific group of countries and regions. However, their relations and effects for a better sustainable energy transmission would need further research works in an international context. Motivated by that reason, this study contributes to the ongoing literature by revisiting the effects of renewable energy consumption, electricity output, and economic activities on carbon risk using a global sample of 219 countries over the period of 1990–2020. Using GMM estimation, simultaneous quantile, and panel quantile estimations; the study finds supportive findings showing that the higher the countries with renewable energy consumption and electricity output the better the capacity those countries can mitigate the environmental degradation by reducing the amount of total carbon emission over time. However, those relations are changed when using system GMM approaches, implying the role of FDI inflows and the difference in income groups in the selected sample countries. This can be intuitively explained that emerging countries might give more priority to the economic growth receiving FDI inflows from more advanced economies and balancing the trade-off between economic growth and environmental protection, while the developed economies with their advantages in green technologies and financial flexibility might have higher advantages in acquiring a sustainable transition and maintaining the real economy's growth without significant trade-off concerns. Finally, the study provides important policy implications and avenues for further research.

Keywords Renewable energy · Economic activities · Carbon dioxide emissions · Climate change

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1 Introduction

Over the last few decades, the sharp increase in environmental degradation has been attributed to excessive production activities, massive energy consumption, and economic growth. This phenomenon led many countries to think of alternative ways of energy consumption, thereby mitigating environmental pollution and improving economic indicators (Nathaniel & Khan, 2020). At present, environmental protection and economic growth are on the list of major global concerns. Maintaining a green and clean climate to get sustainable development is among the biggest challenges of the day (Rahman et al., 2019). The traditional ways of energy production and consumption are deteriorating the environment, especially the geopolitical uncertainties, the oil-based strategies for energies, the heavy uses of fossil fuel are worldwide in the limelight that calls for concentration on alternative renewable energy sources to materialize the sustainable future of the resources (Payne, 2012). Taking together, the economic growth coupled with the use of renewable energy resources have gained the interests of many researchers as the popular hypothesis, the environmental Kuznets curve (EKC), proposes that low air quality (heavy carbon dioxide emissions) initially have an inverse relationship with economic growth but at a later stage when the economy reaches to a certain threshold level, then both environmental quality and economic growth move positively (Grossman & Krueger, 1991; Shahbaz et al., 2019). The EKC hypothesis entails that economic growth can be achieved without compromising on the quality of the environment (Mohapatra et al., 2016). Though some researchers criticized the EKC hypothesis on the grounds that it ignores the influence of environmental policies and the positive effects of globalization (Husnain et al., 2020), yet, the nexus of environmental issues and economic growth needs to be investigated in the context of developing countries (Chien et al., 2021a).

Collectively, the research agendas in using alternative and renewable energy sources to mitigate the carbon risk problem toward a more sustainable economic growth are highly needed for economic, strategic, and environmental policymaking. Similarly, several studies in environmental economics have investigated the significant impacts of economic activities on the environment (Mehmet Akif Destek, 2020). Some economic activities have eminently inflated energy demand that impacts the global environment (Etokakpan et al., 2020). Reducing the environmental issues, the public–private partnership in the real economy's growth is also in attention and is deemed necessary for reducing the carbon risk. The investment of public–private partnerships, especially in renewable energy can improve the pollution level (Khan et al., 2020a, 2020b, 2020c). Economic activities via the public–private partnership is an enterprise that is established for long time cooperation between the public and private entities who are working under formal agreements for the provision of public goods and services (Shahbaz et al., 2020). These partnerships can facilitate better sustainable economic growth and environment-friendly development through partnering with government bodies, non-governmental organizations, and welfare organizations to promote public goods in the long term. Therefore, a more green sustainable economic growth has gained a new paradigm shift in the last decade for improvement in both environment and human development (Abid et al., 2021).

Today, a bigger challenge to attain the sustainable development goals (SDGs) is the environmental degradation and climate change risk (World Bank, 2000). The deteriorating air quality is caused by the emissions of greenhouse gases (GHGs), particularly carbon

dioxide (CO₂) emissions that have negative impacts on human health and the environment (Shahbaz et al., 2019). The CO₂ emission is the root of environmental disasters for approximately 80% of the total GHGs (Davidson, 2019). The GHGs are the outcome of fossil fuel burning like coal and oil and such gases are deteriorating the ecosystems that in turn escalate the earth's temperature. The low air quality gives rise to numerous human diseases and causes global climate change; hence, research works on those areas have increasingly attracted international scholars attention in recent years (Zhan et al., 2018).

Motivated by those reasons, this study focuses on the central research question that whether renewable energy consumption and electricity output matter to the mitigation of carbon emission risk, in order to have a more sustainable energy transformation and the real economy's growth. This research revisits the agenda of sustainable economic growth by investigating the roles and effects of renewable energy consumption, renewable electricity outputs, and FDI net inflows in reducing the carbon risk emission associated with the growth of the real economy around the world using a global sample of 219 countries over the period 1990–2020. The contributions of this study are not only crucial in reaffirming the relationship between renewable energy consumption, electricity outputs, economic growth, and their effects on carbon emission risk; but they are also important to highlight the role of FDI inflows, and trade-off balances between emerging and advanced economies. This research contribution is only allowed through employing a global sample rather than focusing on a specific group of countries and regions. Consequently, the findings of this study allow scholars, policymakers, private and public agencies, particularly transnational organizations making reference in their research agendas at both national and cross-country studies.

The remaining parts of the paper are structured as follows. Section 2 presents a related literature review on renewable energy, sustainable growth, public–private partnership investments, globalization, and air pollution. Section 3 describes the data collection procedure and empirical settings. Section 4 presents empirical results and interpretations. Section 5 highlights important contributions, critical implementations and provides suggestions for further studies.

2 Review of literature

Environmental experts and economists are working globally to understand the environmental issues and present their possible solutions. There are human factors stirred by economic expansion as well as certain natural phenomena that contribute to environmental issues. Iorember et al. (2020) acknowledged that the economic-driven and natural factors lead to air quality and environmental issues. The employment generations, production at mass level, the use of fossil energy sources are adding to the degradation of the environment both in developing and developed economies. In this context, this study examines the nexus between renewable energy, public–private partnership, globalization, economic growth, and air quality index.

2.1 Renewable energy and sustainable economic growth

Renewable energy, a substitution to conventional energy resources, is a major healer of air quality issues. Renewable energy is considered as the “fuel of the future,” that might set prerogatives of sustainable economic growth and stirs the trajectory of environment-friendly

developments (Singh et al., 2019). Recently, renewable energy consumptions, economic development was scrutinized and found that non-renewable energy consumption increases carbon emissions while renewable energy resources mitigate the carbon emissions (Anwar et al., 2021; Chien et al., 2021b; Hussain & Rehman, 2021). Renewable energy can mitigate the rising effects of GHGs, especially the CO₂ emission that constitutes almost 76.6% of the total, posing a threatening level in the developing economies (IPCC, 2013). Charfeddine and Khediri (2016); Sarkodie and Strezov (2019) found that non-renewable energy sources are increasing the level of CO₂ emissions that deteriorate air quality. Due to the growing focus on renewable energy resources (chiefly the use of solar and wind PV), the CO₂ emission in developed countries has flattened in 2019 (International Energy Agency (IEA), 2020). Softening the adverse effect of GHGs, renewable energy sources can be used in substitution that may protect the environment and ensure sustainable economic goals (Kasperowicz et al., 2020; Marimuthu et al., 2021).

Environmental degradation is mainly attributed to the heavy use of conventional energy resources which imperils sustainability and economic growth as these resources are costly, creates pollutions, and result into higher energy prices (Armeanu et al., 2017; Halicioglu & Ketenci, 2018). The visible benefits of renewable energy lie in the economic, social, and environmental spheres. The International Renewable Energy Agency reported that if the renewable energy resources are doubled in the global energy mix, it might increase the global gross domestic product by 1.1% by 2030, approximately adding further 1.3 Trillion US Dollars to economic activities (IRENA, 2020). Using the data from 2001 to 2018 from Nordic counties, Khan et al. (2020) concluded that by spurring international business and getting the ecological balance, the consumption of renewable energy can better accomplish environmental-quality goals.

2.2 Air pollution and sustainable economic growth

The past literature substantiates the adverse effects of air pollution on human health. Researchers found that large portion of deaths are associated with the air pollution that could be reduced by improving the air quality (Molina-Gómez et al., 2020). Many health and socio-economic issues are generated from polluted air like cardiovascular and respiratory diseases, visibility issues, economic losses, and climate changes (Etchie et al., 2017; Forbes et al., 2009; Maione et al., 2016). The report issued by World Health Organization (WHO) indicates that globally around 4.2 million deaths were caused by ambient air pollution in both rural and urban areas in 2016. These fatalities were attributed to “small particulate matter of 2.5 microns or less in diameter (PM_{2.5})”, that produced cancer, respiratory and cardiovascular diseases (World Health- rganization, 2018).

The GHGs, especially the carbon and methane emissions, not only endangers the air quality and threatens environmental landscapes (Khan et al., 2020; Sharif et al., 2019), but also leads to imperiling the economic growth (Lin et al., 2021). Regmi and Rehman (2021), Ahmad et al. (2021); Rehman et al. (2021) also found that CO₂ emissions negatively impact the environment and production that lead to low economic performance. In the context of China, it was also found that the CO₂ emissions and energy resources utilizations have a significant progressive association (Ahmad et al., 2020; Rehman et al., 2021). According to the international energy agency, some advanced countries (like Germany, Mexico, France, and the UK) have experienced a downward trend in carbon emissions and has improved their air quality, while the issue persists in the Indian sub-continent, China, and particularly the US economies are still ranked higher in terms of CO₂

emissions (IEA, 2020). Some studies also justify that urbanization, construction, and economic growth worsen the air quality that in turn reverses the sustainability goals (Liang & Yang, 2019). It is worth mentioning that though during the lockdowns in the COVID-19 period, the CO₂ emissions have been reduced, yet it requires more attention as the easing of restrictions may heavily increase the CO₂ emissions, thereby endangering human lives (Aktar et al., 2020).

2.3 Sustainable economic growth

Sustainable economic growth is the development where the satisfaction of human needs is coupled with preserving the environment and maintaining natural resources for coming generations (Akhtar et al., 2020; Balisacan et al., 2014). The evolving concept of sustainable economic growth cares for scarce natural resources as well as prioritizes human needs (Ullah et al., 2021b; Abid et al., 2021). Such development carries the notion that all government institutions should be involved to preserve the environment through environment protection laws and their implementation practices (Adams et al., 2019a, b). The use of renewable energy and sustainability-based economic growth shape a soft image of any country that attracts foreign direct investment and other better opportunities (Khan et al., 2020a, 2020b, 2020c). The pro-environmental monetary and fiscal policy can also substantiate the goal of sustainable development (Chishti et al., 2021).

Given the adverse impact of environmental issues on human health, many researchers highlighted the air pollution with respect to socio-economic factors like population level, GDP growth, migration, and urbanization of human capital, transportation, and industry level (Hao & Liu, 2016; Liu et al., 2017; Liu et al., 2021). The nexus of energy usage, financial development, and economic growth, while using the EKC model, was ascertained by Haseeb et al. (2018) where they found that causality exists between energy consumption and economic growth. Energy consumption and economic growth have a significant (though at different levels) relationship with the environment depending on the industry, region, and country (Usman et al., 2020). The missing link in the way of economic growth is the use of fossil energy that though triggers economic growth but also poses risks for air quality due to the carbon emissions (Usman et al., 2020). Recently, Safi et al. (2021) found a significant link between carbon emissions and economic growth and suggested using environment-friendly uses of technology and energy resources. Marimuthu et al. (2021) concluded that the Chinese shift to economic trajectory and large use of electricity doubled the CO₂ growth while the use of non-fossil resources and improvement in energy helped reduced the CO₂ emission.

3 Methodology

3.1 Data source

Panel dataset for 219 countries around the world was used for the period from 1990 to 2020. All the used dataset was collected from (WDI) World Development Indicators (World Bank). This study uses CO₂ emissions (metric tons) as a dependent variable, for measuring the carbon emission risk. The independent variables are economic growth that is measured by the GDP growth (annual %); foreign direct investment is measured by using

Table 1 Variables description

Variables	Source
CO ₂ indicates the Carbon Dioxide Emissions (kt)	WDI (World Bank)
GDPGA indicates the GDP growth (Annual %)	
FDINI indicates the Foreign direct investment, net inflows (BoP, current US\$)	
REOTE indicates the Renewable electricity output (% of total electricity output)	
RECEC indicates the Renewable energy consumption (% of total final energy consumption)	
EIPE indicates the Energy intensity level of primary energy (MJ/\$2011 PPP GDP)	
UPTP indicates the Urban population (% of total population)	
UTLF indicates the Unemployment, total (% of total labor force)	
GI indicates the Gini index (World Bank estimate)	

Data extracted from the World Development Indicators offered by the World Bank (version 2021) can be accessed via <https://data.worldbank.org/>

FDI net inflows (BoP, current US\$), percentage of total electricity output was used to measure the renewable electricity; percentage of total final energy consumption was used for measuring the renewable energy consumption in the listed countries; energy intensity level of primary energy was measured by the (MJ/\$2011 PPP GDP); urban population in the listed countries was measured by the % of the total population, unemployment percentage rate of the total labor force; and Gini index of the World Bank was used for measuring the income distribution in the listed countries. The selected variables and their details are presented in Table 1.

3.2 Estimation method

The research scrutinizes the influence of the economic growth, foreign direct investment, renewable electricity out, renewable energy consumption, energy intensity, population, unemployment, and income inequality on carbon emission risk in 219 countries utilizing the dynamic difference and system generalized method of moments GMM models, simultaneous quantile and panel quantile regression, respectively. The study proposes the following baseline panel estimation:

$$\begin{aligned} \text{CO}_{2i,t} = & \beta_0 + \beta_1 \text{GDPGA}_{i,t} + \beta_2 \text{FDINI}_{i,t} \\ & + \beta_3 \text{REOTE}_{i,t} + \beta_4 \text{RECEC}_{i,t} + \beta_5 \text{EIPE}_{i,t} \\ & + \beta_6 \text{UPTP}_{i,t} + \beta_7 \text{UTLF}_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (1)$$

The study employs Eq. (1) to inspect the effect of the renewable electricity output, economic growth, and renewable energy consumption on the carbon risk across the countries in our sample. We further extend the study by including the income inequality measured by the Gini index offered by the World Bank to check the robustness as follows.

$$\begin{aligned} \text{CO}_{2i,t} = & \beta_0 + \beta_1 \text{GDPGA}_{i,t} + \beta_2 \text{FDINI}_{i,t} \\ & + \beta_3 \text{REOTE}_{i,t} + \beta_4 \text{RECEC}_{i,t} + \beta_5 \text{EIPE}_{i,t} \\ & + \beta_6 \text{UPTP}_{i,t} + \beta_7 \text{UTLF}_{i,t} + \beta_8 \text{GI}_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

Presented in Eqs. 1 and 2 where the subscripts of i and t demonstrate country $i = 1, \dots, N$ at time $t = 1, \dots, N$, while ε is the error term. We employ CO_2 as the main dependent variable to measure the carbon risk in each country. We control for a vector of independent variables including GDP % annual growth rate for economic growth, foreign direct investment (FDINI), renewable electricity output—REOTE, renewable energy consumption—RECEC, energy intensity level—EIPE, the urban population for urbanization—UPTP, unemployment UTLF, and Gini index for measuring poverty—GI. In the later stages of the empirical procedure, the study uses the Gini index for the robustness check using the quantile regression approaches as the roles and influences of the consumption of renewable energy, renewable electricity output, and the economic growth in the used economies might be volatile given the different levels of income inequality across the sample countries.

This empirical dynamic panel strategy is applied to mitigate the potential issues of heteroskedasticity, endogeneity, control serial correlation, and heterogeneity, respectively. To be consistent with the literature, this study follows the previous studies in using a dynamic form of regression models for panel data (Asongu et al., 2016; Baltagi, 2008; Berk et al., 2020; Destek et al., 2016; Hanif et al., 2019; Muhammad et al., 2021; Neagu & Teodoru, 2019; Kripfganz & Schwarz, 2015; Shahbaz & Lean, 2012; Teng et al., 2020). According to the literature, the GMM models are estimated based on the instrumental models that have several advantages compared to the traditional two-stage least squares (2SLS) method. Fumio Hayashi (2000) indicates that the GMM models use the orthogonality conditions in generating efficient results for estimation with the presence of heteroscedasticity that is mainly caused by the unknown factor. Ullah et al. (2018); Ullah et al., (2021a) present the application of GMM models for panel data analysis to mitigate the problem of endogeneity and the employment of instrumental variables with a step-by-step guideline to address the endogeneity problem.¹ Therefore, this study applies the dynamic panel approaches by including the lagged levels of the carbon dioxide (CO_2) emissions following the Arellano and Bond (1991)'s GMM estimators for the formal analysis. The application of GMM models for Eqs. (1) and (2) are presented, respectively as follows:

$$\begin{aligned} \text{CO}_{2i,t} = & \beta_0 \text{CO}_{2i,t-1} + \beta_1 \text{GDPGA}_{i,t} + \beta_2 \text{FDINI}_{i,t} \\ & + \beta_3 \text{REOTE}_{i,t} + \beta_4 \text{RECEC}_{i,t} + \beta_5 \text{EIPE}_{i,t} \\ & + \beta_6 \text{UPTP}_{i,t} + \beta_7 \text{UTLF}_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (3)$$

As presented in Eqs. 3, CO_2 emission is used as the main proxy of carbon risk. β_0 is the indicator to be examined and the study control for a vector of critical explanatory variables in modeling the carbon dioxide emission as a function of economic development, the inflow of foreign direct investment, renewable electricity out, renewable energy consumption, energy intensity, population, unemployment, and poverty, respectively. μ indicate the countries-specific effects, error term is demonstrated by the ε . Lastly, the study estimates the values of β_1 to β_8 to capture the roles of the independent variables and their effects on carbon risk in the sample countries, respectively. As mentioned earlier, the models used are in the form of the dynamic panel models introduced by Arellano and Bond (1991). These models include the lagged values of $\text{CO}_{2i,t-1}$ that are correlated with the error term.

¹ For more details on how to implement GMM estimations in STATA, please see the recent works of Ullah et al. (2018); Ullah et al. (2021a).

Table 2 Descriptive statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Log of CO2 Emissions (kt)	5446	8.947	2.659	1.993	16.147
GDP growth (Annual %)	5914	3.499	6.183	-64.047	149.973
Foreign direct investments (in log form)	5332	19.917	2.857	2.303	27.322
Renewable electricity output	5694	28.535	33.66	0.0000	100.000
Renewable energy consumption	5444	30.838	31.093	0.0000	98.343
Energy intensity level	4947	7.04	5.915	0.002	57.988
Urban population	6502	56.906	24.518	5.416	100.000
Unemployment	5670	8.023	6.136	0.082	37.976
Gini index	1548	38.634	9.219	20.700	65.800

The study conducts further robustness tests using the quantile regression approaches. The study uses panel quantile regression and simultaneous quantile regression to examine the influence of economic growth, foreign direct investment, renewable electricity output, renewable energy consumption, energy intensity, population, unemployment, and poverty on the carbon dioxide emission risk.

$$\begin{aligned}
 Q_{CO_{2it}}(\tau_k/\beta_i, X_{i,t}) = & \beta_0 + \beta_1 GDPGA_{i,t} + \beta_2 FDINI_{i,t} \\
 & + \beta_3 REOTE_{i,t} + \beta_4 RECEC_{i,t} + \beta_5 EIPE_{i,t} \\
 & + \beta_6 UPTP_{i,t} + \beta_7 UTLF_{i,t} + \beta_9 GI_{i,t} + \varepsilon_{i,t}
 \end{aligned} \quad (4)$$

The panel quantile regression is presented in Eq. 4 above, where the characters of i and t present thirty-six OECD economies and the time period from 1990 to 2020, respectively. β_i in Eq. 4 demonstrates the unobserved individual impact, τ shows the number of quantiles of the conditional distribution, while renewable energy consumption, renewable electricity consumption, the economic growth of the used economies, urbanization, unemployment, and Gini index are the selected explanate variables that are applied to examine the influence of these elements on the carbon dioxide emissions. Additionally, τ th demonstrates the quantile of the conditional distribution applied to examine the coefficients by the equation as follows.

$$\widehat{\beta}(\tau) = \arg \min \sum_{i=1}^n \rho_{\tau}(y_i = x_i^{\tau} \beta) \quad (5)$$

In Eq. 5 where: $\rho_{\tau}(u) = u(\tau - I(u < 0))$, $I(u < 0) = \begin{cases} 1, & u < 0 \\ 0, & u > 0 \end{cases}$ is the function to be tested and $I(\cdot)$ is an indicator function.

4 Results and discussion

The descriptive statistics are presented in Table 2 with the total number of 5000 observations for the 219 countries from 1990 to 2020. The selected variables include carbon dioxide emissions (kt), yearly GDP growth rate, FDI (net inflows), renewable electricity

Table 3 Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Log of CO ₂	1.000								
(2) GDP growth	-0.109	1.000							
(3) log of Foreign direct investments	0.738	-0.070	1.000						
(4) Renewable electricity output	-0.360	0.043	-0.245	1.000					
(5) Renewable energy consumption	-0.577	0.116	-0.485	0.641	1.000				
(6) Energy intensity level	-0.068	0.063	-0.256	0.004	0.185	1.000			
(7) Urban population	0.447	-0.193	0.570	-0.144	-0.547	-0.265	1.000		
(8) Unemployment	0.003	-0.140	-0.065	-0.055	-0.212	-0.038	0.141	1.000	
(9) Gini index	-0.186	0.063	-0.242	0.336	0.311	-0.111	-0.134	0.023	1.000

Table 4 Dynamic panel GMM models

Variables/Selected GMM models	One-step difference GMM		Two-step system GMM	
	Log (CO ₂ emissions)	Log (CO ₂ emissions)	Log (CO ₂ emissions)	Log (CO ₂ emissions)
Log (CO ₂ emissions) _{<i>t-1</i>}	0.4845 (22.73)	0.9810 (142.94)	0.9812 (1507.3)	
GDP growth (annual %)	0.0000 0.0031 (8.96)	0.0000 0.0050 (12.64)	0.0000 0.0051 (310.13)	
Log (Foreign direct investments)	0.0000 0.0085 (4.16)	0.0000 0.0074 (2.18)	0.0000 0.0074 (46.45)	
Renewable electricity output (% of total output)	0.0000 -0.0012 (-3.10)	0.0300 0.00015 (1.90)	0.0000 0.00015 (8.34)	
Renewable energy consumption (% of total)	0.0020 -0.019 (-22.55)	0.0570 -0.0005 (-2.51)	0.0000 -0.0005 (-19.21)	
Energy intensity level of primary energy	0.0119 (6.12)	0.0120 0.0006 (0.97)	0.0000 0.0006 (8.71)	
Urban population (% of total population)	0.0000 0.0250 (13.11)	0.3310 -0.00035 (-2.42)	0.0000 -0.0003 (-8.74)	
Unemployment, total (% of total labor force)	0.0000 -0.0066 (-4.47)	0.0160 -0.000976 (-2.62)	0.0000 -0.0009 (-21.15)	
Constant	0.0000	0.0090 0.07656 (3.38)	0.0000 0.0738 (11.44)	0.0000

Table 4 (continued)

Variables/Selected GMM models		One-step difference GMM	One-step system GMM	Two-step system GMM
		Log (CO2 emissions)	Log (CO2 emissions)	Log (CO2 emissions)
<i>N</i>		3621	3925	3925
<i>Number of Instruments/Groups</i>		307/178	332/178	332/178
<i>Arellano–Bond test for AR (1) in first differences:</i>		– 19.43 (0.000)	– 22.37 (0.000)	– 5.32 (0.000)
<i>Arellano–Bond test for AR (2) in first differences:</i>		2.25 (0.025)	2.47 (0.395)	0.93 (0.354)
Values in () indicate the values of t–statistics				

output (% of total electricity output), renewable energy as percentage of total energy consumption, level of energy intensity, urban population as percentage of the total population, unemployment rate (% of the total labor force), and the Gini disposable income index. To transform all the variables into percentages and facilitate the empirical analysis and result interpretations, the study takes the natural logarithm of carbon emissions and FDI inflows. The examined findings of the descriptive statistics indicate that the mean value of the carbon dioxide emission is 8.978 with the minimum and maximum values ranging from 1.993 to 16.147, respectively. The average of the economic growth variable is 3.49 percent with a standard deviation of 6.183 for the 219 countries. The findings of the descriptive statistics table indicate that the mean value of the foreign direct investment is 19.917 with the minimum and maximum values between 2.303 and 27.322, respectively. The descriptive statistics present that the average value of the urbanization is 56.906 with the minimum and maximum values ranging from 5.416 to 100, respectively. The results of summary statistics are crucial for a numerical explanation of the study sample before further empirical tests are presented in the following sections.

Table 3 shows the findings of the matrix of correlations of the selected variables. The examined findings demonstrate that carbon dioxide emission has negative correlations with economic growth, renewable electricity output, renewable energy consumption, energy intensity and Gini inequality index; while carbon dioxide emission has positive correlations with FDI, urbanization and unemployment.

The examined results of dynamic panel models i.e., one-step difference, one-step system, and two-step system GMM demonstrate that GDP growth positively affects environmental degradations in our study countries, presented in Table 4 Columns 1–3, respectively. The examined findings interpret that an increase in economic growth causes the degradation of environment. The tested results of the economic growth (GDP) and carbon dioxide—CO₂ emissions are supportive and in line with the earlier studies. For instance, Khan and et al. (2019a, 2019b) investigated the influence of the real economy's growth on environmental degradation by using the dynamic ARDL simulations model in Pakistan. The authors show that carbon dioxide emission in Pakistan is positively impacted by the country's economic activities. Teng et al. (2021) investigated the relation between economic growth and environmental degradation in ten different countries showing the similar evidence. Zhang et al. (2021) inspected the shock of natural resources depletions and GDP growth on carbon risk and carbon footprint in Pakistan. The authors revealed that economic development in Pakistan positively influences environmental degradation. From a global perspective, the estimated results of this study reaffirm that the negative nexus between the real economy's activities, growth and deterioration of the environment in the truly global sample for the 219 countries worldwide.

Column 1 of Table 4 reports results using the one-step difference GMM approach indicate that FDI (net inflows) positively affects the environmental deterioration in the countries while the results of the one-step system and two-step system GMM approaches demonstrate that the net inflows of FDI assist in mitigating the debasement of environment in the selected economies presented in Columns 2 and 3, respectively. The empirical results can be intuitively explained that the developed economies of the world invest more in the developing countries though offering newly developed technologies and environmental-related solutions that help those developing economies with the reduction of environmental degradations. For instance, Khan and et al. (2019a, 2019b) accessed the relation among FDI inflows and carbon risk in an emerging economy. The authors presented the positive impact of net inflows of FDI on environmental degradation. Similarly, Teng et al. (2021)

inspected the effects of FDI on carbon dioxide emission in a panel of countries showing the similar findings on the positive influence of FDI investment on carbon risk.

For the renewable electricity output, the findings of the one-step difference GMM model indicate that the renewable energy production has an inverse impact on the devaluation of environment in the sample countries, while the estimations of one-step and two-step system GMM indicate positive influence on the deterioration of environment in the sample countries. The estimated findings of renewable energy production intuitively demonstrate that traditional energy resources are used for renewable energy production might escalate the environmental degradation in the study countries. Regarding the outcomes of the one-step difference GMM model in Table 4 Column 1, we find that enhancing the consumption of renewable energy reduces the environmental harm and assist improving air quality in the study countries. In the context of the prior literature, Saidi and Omri (2020) examined the influence of renewable energy consumption on the environment in fifteen renewable energy consumption countries by using panel data for results analysis. The examined results indicate that the employment of renewable energy increases GDP growth and reduce the environmental degradations in the sample countries which is in line with the empirical results of this study with a global experience.

For the level of energy intensity, The examined findings of the one-step difference, one-step system and two-step system GMM models presented in Columns 1–3 of Table 4 indicate that the energy intensity level has positive and significant impacts on the environmental degradation in the study countries. Yaw Naminse and Zhuang (2018) investigated the impact of economic growth and energy intensity on carbon dioxide emission in China. They indicated that energy intensity reduces the environmental devaluation by using alternative sources for energy consumption.

The results of the one-step difference GMM indicate that urbanization positively and significantly impacts the disintegration of environment in the study countries. Urbanization inversely affects environment for construction purposes which is the root of the escalating environmental degradations. We also examined outcomes of the unemployment present significant inverse impact on the devaluation of environment. In the context of the prior literature, Khan and et al. (2019a, 2019b) investigated the influence of urbanization on environmental quality using time series data in Pakistan. The examined results interpret that urbanization in Pakistan increases the problem of environmental degradation.

After the application of GMM approaches for investigating the relation among the consumption of renewable energy, carbon emission and economic activities presented in Table 4 above. We present the empirical results of simultaneous quantile regression and panel quantile regression to check the robustness of the empirical models by including Gini index, as presented in Table 5. The estimated results of economic growth demonstrate significant opposite impacts on environmental devaluation in the sample countries. The estimated findings of economic growth indicate that an increase in the real economy's growth reduces the environmental degradation in the sample countries. The empirical results estimated by the simultaneous quantile and panel quantile regressions indicate that foreign direct investment (FDI) inversely impacts the disintegration of environment. The results from simultaneous quantile regression and panel quantile regression of renewable energy consumption document a negative impact on environmental degradation in the selected countries; on the other hand, the findings of using renewable energy imply that the utilization of renewable energy sources assists in reducing the depreciation of environment across the economies in our sample.

Findings of the simultaneous quantile regression and panel quantile regression indicate that energy intensity positively and significantly impact the environmental disturbance

Table 5 Robustness check - quantile regression

	Simultaneous quantile regression				QRPD
	Q25	Q50	Q75	Q95	Log (CO2)
GDP growth (annual %)	-0.0325 (-2.68) 0.008	-0.0434 (-3.01) 0.003	-0.0267 (-3.25) 0.001	-0.0137 (-0.81) 0.419	-0.0320 (-15.75) 0.000
Log (Foreign direct investments)	0.648 (21.78) 0.000	0.690 (17.02) 0.000	0.646 (22.02) 0.000	0.444 (6.92) 0.000	0.690 (180.98) 0.000
Renewable electricity output (% of total output)	0.0003 (0.19) 0.852	-0.0026 (-1.16) 0.246	-0.0042 (-1.25) 0.212	-0.0136 (-2.75) 0.006	-0.0019 (-4.57) 0.000
Renewable energy consumption (% of total)	-0.0260 (-7.39) 0.000	-0.0281 (-7.21) 0.000	-0.0256 (-5.03) 0.000	-0.0252 (-2.74) 0.006	-0.0302 (-42.59) 0.000
Energy intensity level of primary energy	0.0642 (3.47) 0.001	0.0936 (6.92) 0.000	0.100 (3.88) 0.000	0.127 (4.02) 0.000	0.0976 (23.99) 0.000
Urban population (% of total population)	-0.00623 (-1.48) 0.140	-0.00713 (-1.65) 0.100	-0.00921 (-2.42) 0.016	-0.00814 (-1.40) 0.162	-0.00741 (-13.24) 0.000
Unemployment, total (% of total labor force)	-0.00242 (-0.31) 0.757	-0.0138 (-1.80) 0.071	-0.0140 (-2.25) 0.025	-0.0565 (-3.04) 0.002	-0.0166 (-5.16) 0.000
Gini index	0.0280 (5.53) 0.000	0.0306 (6.14) 0.000	0.0241 (4.02) 0.000	0.0376 (4.27) 0.000	0.0288 (46.82) 0.000
Constant	-4.457 (-7.62) 0.000	-4.461 (-4.36) 0.000	-2.518 (-2.81) 0.005	2.976 (1.81) 0.071	
Pseudo R2	0.4224	0.4622	0.4341	0.3679	
N	1273				1273
<i>t</i> statistics in parentheses					

in the sample countries, while the results of the urbanization and unemployment demonstrates negative impact on the environmental disturbance. The examined findings of the simultaneous quantile regression and panel quantile regression of the Gini Index indicate significant and positive impacts on the devaluation of environment.

5 Conclusion

Employing a large panel data of from 219 countries worldwide over the period 1990–2020, the study revisits and examines the long-run nexus between economic growth, the use of renewable energy, electricity output and their effects on carbon emission risk from a truly global experience. By applying the one-step, two-step system and difference GMM models with the form of dynamic panel data as well as the quantile regression approaches for the robustness check with the inclusion of income inequality in our sample economies, the paper reaffirms and provides important evidence to the literature as follows:

First, the higher the economic activities and growth measured by the annual GDP growth rate and the foreign direct investments (net inflow) seem like the root cause of the environmental degradation if they are for non-environmentally friendly purposes. From a statistical perspective, given one percent increase in GDP growth causes an overall increment in carbon risk by 0.003 and 0.005 percent presented in Table 4 Columns 1 to 3 through the: (a) one-step difference, (b) two-step difference, and (c) system GMM models, respectively. Second, while the real economy's growth and FDI net inflows co-moves with the carbon emission, the higher renewable energy consumption, and electricity output reduce the total carbon emission leading to improved environmental problems. In the other words, the empirical findings imply that countries with higher consumption of renewable energy resources, and electricity output would be able to enhance their overall environmental circumstances by immediately reducing the total carbon risk. For instance, given one percent escalation in the output of renewable electricity and the use of renewable energy, the amount of carbon dioxide emissions is decreased by 0.001 and 0.01 percent presented in Table 4 Column 1 with the one-step difference GMM, respectively. Interestingly, the relation between renewable electricity output and carbon risk is inverse when using the one-step difference and two-step system GMM approaches exhibited in Columns 2 and 3 of Table 4, respectively. The findings can be intuitively explained by the levels of income inequality and the movement of FDI net inflows among developing and developed economies. The recent literature documents the importance and the role of FDI net inflows and income inequality including Dinh Su and Phuc Nguyen (2020); Huynh, Nguyen, Nguyen, and Nguyen (2020); Nguyen et al. (2021).

The empirical findings of this study reaffirm and are in line with the previous literature. For example, Shahbaz et al. (2020), Khan et al. (2020a, 2020b, 2020c), and Kirikkaleli and Adebayo (2021) document the effects of technology and public–private partnership (PPP) in energy on the carbon emissions in China and India; Lee and Min (2015) and Fernández et al. (2018) present the importance of green research and development in mitigating carbon emissions as well as environmental degradation. Using a global sample for the period 1990–2020, the study sheds further light on the movement among renewable energy consumption, renewable electricity output, economic growth, and CO₂ emission risk worldwide.

This paper specifies critical implication in solving environment-related issues that hamper the prospects of the sample economies. First, the world economies need to proactively work toward a more sustainable energy and economic transformation through boosting the employment of alternative and renewable resources. This could be challenging to emerging economies with a trade-off between green growth and economic priorities and given the limited budget and economic advantages compared to more advanced economies. To overcome this challenge, those countries might take advantage of private–public partnerships in promoting green transition and other economic priorities through FDI inflows, research

and development, and green-oriented technology transfer agreement. Consequently, the government and other related bodies can use those global economic activities for supporting each other in achieving sustainable development goals. Furthermore, the economic activities with heavy industrialization need to be reassessed for mitigating the negative environmental concerns. The related research agendas are important to be investigated further by researchers, climate change activists and national level policy making bodies. Hence, climate and environmental economics/finance are urgent growing fields with a wide range of research perspectives that need to be investigated for better understating on how the world can have a more sustainable transition.

Appendix

See Table 6 and Figs. 1, 2, 3 and 4.

Table 6 Abbreviations and definitions

PPP=Public–Private Partnership
CO ₂ =Carbon Dioxide
R&D=Research and Development
GMM=Generalized Method of Movements
EKC=Environmental Kuznets Curve
SDGs=Sustainable Development Goals
GHGs=Greenhouse Gases
GDP=Gross Domestic Product
FDI=Foreign Direct Investment
REOTE=Renewable Electricity Output
RECEC=Renewable Energy Consumption
EIPE=Energy Intensity Level
UPTP=Urban Population for Urbanization
PPPIE=Public–Private Partnership Investment in Energy
RDE=Research and Development Expenditure
GI=Gini index for measuring poverty
ARDL=Autoregressive Distributed Lag Model



Fig. 1 CO2 emissions by country



Fig. 2 Renewable electricity output by year

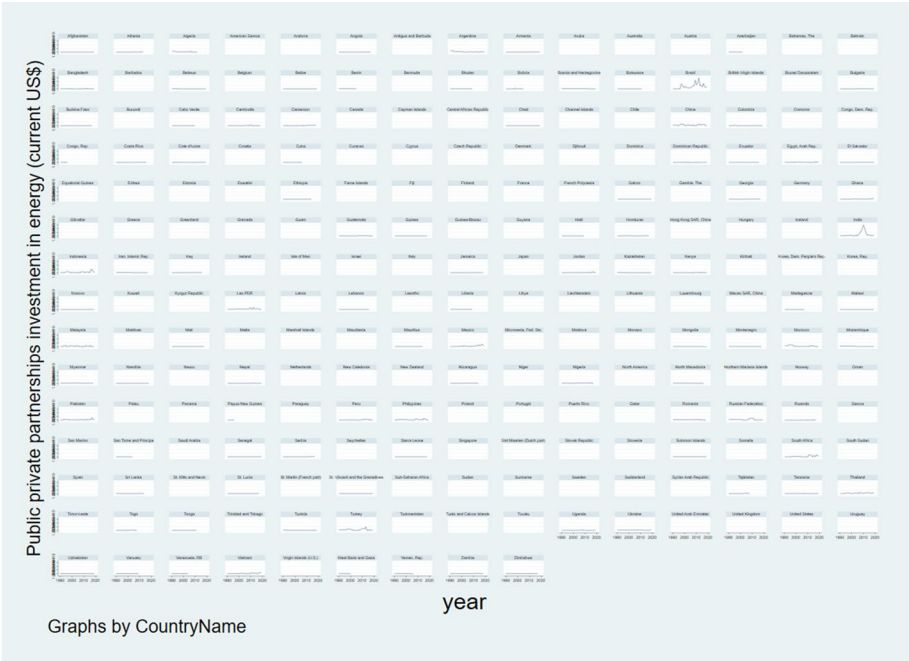


Fig. 3 Public–private partnership investment in energy by Country



Fig. 4 GDP annual growth in %

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