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The Impact of Eco-innovation and Clean Energy on Sustainable Development: Evidence from USA

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In recent times, natural resources have been receiving greater acknowledgment from economies as it greatly offers a compensation for energy requirements. Solar energy appears to be a strong indicator to improve quality of air by reducing CO2 emissions, which has neglected by the available literature. Therefore, the study considers exploring the dynamic role of solar energy in CO2 emissions and economic growth in a sample of US. We applied the QARDL approach and covered the period ranging from 1990 to 2019. Our findings showcased that solar energy mitigates CO2 emissions by increasing economic growth in different quantiles in the USA. Solar energy use is increasing economic growth at higher quantiles in the USA. Eco innovations are also contributing to economic growth by reducing CO2 emissions in different quantiles. Bidirectional quantile causality was found between the constructs. This study suggested the usage of solar energy and eco-innovations in the sustainable growth pattern of the country.

Keywords: *Clean Energy; Eco-Innovation; Sustainable Development; USA.*

Introduction

Economies are putting greater effort to maximize industrial activities in order to increase economic growth. (Mehmood & Tariq, 2020; Mehmood, Tariq, Ul-Haq, & Meo, 2020; Shibli *et al.*, 2021; Tariq *et al.*, 2017). However, with the increase in economic activities, multifarious issues such as depletion of non- REW energy sources and environmental problems have been on rise due to high emissions (Hartani, Haron & Tajuddin, 2021; Mehmood, 2021a, 2021b; Wirsbinna & Grega, 2021). Due to this renewable energy (RE) usage has now become a serious thought of researchers in the developing and developed world. The Kyoto protocol 1997 has compelled the world to utilize RE to reduce the concentration of CO2 emissions. Therefore, now, the world community has understood that RE is an efficient means of sustainable development

Now the question arises, whether the consumption of RE contributes to economic growth. There is also a lack of consensus about the role of RE in economy growth in different parts of the world. In this regard, there exist four different hypotheses to present theoretical backgrounds. According to growth hypotheses, traditional energy resources are compulsory to achieve economic growth. Moreover, RE adversely affects economic growth. According to conservation hypotheses, RE exerts very little or at time no impact on EG. Feedback hypotheses explain the idea that RE and economic growth move together and are complementary to each other. Lastly, neutrality hypotheses argued that RE and energy conservative policies have no impacts on EG and no causality exists between RE and GDP.

Due to the focus of RE in industrial output, and its increasing discussion in economic activities, it is important to study RE connection with economic growth. A number of studies have explored the possible connection of RE with EG and CO2 emissions (Malla & Brewin, 2020; van Vuuren, 2020). Although positive shreds of evidence have been found, however, the results are still mixed for developing and developed nations. Some studies show that RE and environmental quality are in negative relation but surpassing the threshold, RE starts to improve air quality. The negative impacts of RE on climatic quality are mainly due to the poor storage and transmission systems. Therefore, to reduce the negative impacts of RE on environmental quality can be reduced by increasing technological advancements through research and development. Most of the past literature, which investigated the RE-CO2 emissions-economic growth nexus has considered RE as a % of total energy consumption. This study incorporates energy generation from solar power to find its association with economic growth and CO2 emissions (Danielle & Masilela, 2020; Habanabakize, 2020).

To transit into sustainable development, ecological innovation is an essential component (Dogaru, 2020; Jermsittiparsert, 2021; Ojogiwa, 2021). To diminish the ecological impacts the OECD frameworks eco-innovation which will include improvement of products, marketing strategies, processes, arrangements and corporate structures(OCED, 2009; Wirsbinna & Grega, 2021). Some researchers agree with the concept of OCED (Bossle, Dutra De Barcellos, Vieira, & Sauvee, 2016; Hall, O'Brien, & Woudsma, 2013; Tiberius, Schwarzer & Roig-Dobón, 2021). Consequently, ecological based innovation can be described in the three extents "eco-organizational innovation, eco-product innovation and eco-process innovation" (Cheng, Yang, & Sheu, 2014; Cheng & Shiu, 2012; Seddighi & Mathew, 2020).

The paper seeks to explore the association of solar energy generation, eco-innovation, capital formation, labour force, population, GDP and CO2 emissions in the United States of America (USA) over the period of 1990–2019.

Moreover, this study presents two empirical models for theoretical backgrounds namely neoclassical theory and the STIRPAT model. Moreover, to provide unbiased and reliable results, we use an innovative empirical method of the QARDL approach by (Anwar *et al.,* 2020; Cho, Kim, & Shin, 2015; Corras-Arias, 2020). Unlike the traditional linear empirical methods, the QARDL approach provides some advantages over other estimation techniques to explore the associations between solar energy use, eco-innovations and CO2 emissions. The quantile-based analysis provides non-linear asymmetric associations in low, medium and high quantiles in the time series. Moreover, the QARDL approach is efficient in capturing long and short-run coefficients between variables. Moreover, the QARDL approach incorporates non-linearity, structural breaks and asymmetries in different quantiles.

The paper is organized in 5 sections. First section covers the overall discussion of chosen topic. Following section includes the detailed review of literature. The next section is linked to methodologies. The 4th section includes the discussion on empirical findings. Finally, the paper is concluded in last section where several implications and recommendations are proposed.

Literature Review

Renewable Energy, GDP and CO2 Emissions

Fang, (2011)estimated Cobb-Douglas function for China and found that RE put positive impacts on economic growth from 1978 to 2008. They applied the ordinary least square (OLS) method and found that a 1 % increase in RE contributes 0.12 % towards economic growth. Inglesi-Lotz, (2016) used panel data to know the impacts of RE on economic prosperity. They found that RE as a share of total energy use is positive towards economic growth. Therefore, it is beneficial to invest in RE sources to gain economic benefits along with a clean environment. Silva, Soares, & Pinho, (2012) empirically investigated the impacts of RE on economic growth and CO2 emissions. The scholars included the USA, Spain, Denmark and Portugal over the time of 1960–2004. The impulse response function estimation showed that except in the USA, RE is increasing economic growth in Spain, Denmark and Portugal. Tiwari, (2011) conducted a study to compare the impacts of RE and non-RE towards GDP in Eurasian and European economies. They found negative impacts of non-RE on GDP and positive impacts of RE towards economic performance. Similarly, Cetin, (2016)analyzed E-7 economies from 1992 to 2012. The panel data techniques provide evidence that RE contributes to economic growth in E-7 nations.

Menegaki, (2011) applied random effect and error correction models for 27 European economies and found that RE has no impacts on GDP. On the other side, Lean & Smyth, (2014) analyzed the impacts of different fuel types on economic growth in Malaysia. They found that diesel and petrol have significant impacts on economic growth. Moreover, it will be a challenge to find alternatives energy sources that will not harm the economic performance of the country. Ikhidi, (2015) and Sarwar, Ming & Husnain (2020) attempted to find a connection non-RE, RE and GDP in Nigeria. They studied quarterly data of 1971–2013 and found that RE is contributing more towards GDP as compared to non-RE.

In another study, Apergis & Danuletiu, (2014) and Niaz (2021) examined RE-CO2 emissions nexus for 80 economies. They found feedback causality between RE and CO2 emissions in the long-run. Similarly, Marinas, Dinu, Socol, & Socol, (2018) and Mitic et al. (2020) applied ARDL approach over the period of 1994–2014. They also found similar results in Eastern and Central European countries. The mixed evidence has been found in a sample of different countries. Moreover, feedback causality was also found between the constructs

Leitao, (2014) and Yousaf et al. (2021) investigated the associations between globalization, GDP, CO2 emissions and RE and found a strong correlation between RE and GDP. Similarly, Soava, Mehedintu, Sterpu, & Raduteanu, (2018) found that RE contributes to economic growth in 28 European nations. Mikelsone et al. (2020) and Ntanos et al., (2018) also explored that RE exacts positive impacts on GDP in European countries. Recently, Lee, (2019) and Matuszewska-Pierzynka (2021) examined the impacts of RE on CO2 emissions and GDP in the European Union. They analyzed the annual data of 1961–2012 by applying co-integration, causality and vector error correction tests. Their findings showed strong associations between RE, industrialization, economic growth and CO2 emissions. Therefore, the usage of RE was suggested for sustainable development in the region. For Tunisia, Ben Jebli & Ben Youssef, (2015) revealed long-run associations between GDP, RE, non-RE, agricultural GDP and CO2 covering time period ranging from 1980 to 2011.

Oh, Yoo, & Kim, (2020) examined REW energy policy and its relationship with economic growth in Korean context. It is revealed that REW policies reduce economic growth, but this negative effect is reduced when greenhouse gases are regulated. They recommend that renewable energy policy can stimulate employment opportunities. Kouton, (2021) and Sell (2020) investigated the REW energy connection with economic growth in a sample of 44 African nations. They covered the period of 1991–2015. They found that renewable energy is increasing GDP in African countries. Venkatraja, (2020) probed annual data of 1990–2015 and found that a lower level of REW energy increases EG in BRICS. They recommend that REW energy will slow the pace of EG. Jan, Durrani, & Khan, (2021) investigated the association between clean energy and GDP in Pakistan. It is found in the study that clean energy plays a significant role in the economy of Pakistan. Moreover, a study on Pakistan suggests that dependency on imported energy can be reduced by increasing the production of REW energy (Hassan, Xia, Khan & Shah, 2019; Streimikiene & Akberdina, 2021).

Eco-Innovation and CO2 Emissions

Previous literature emphasized on the association of innovation (INN) and CO2 emissions. They found mixed results by applying different econometric methodologies. Most of the previous studies have adopted the number of patents as a proxy for INN Albino, Ardito, Dangelico, & Messeni Petruzzelli, 2014; Raiser, Naims, & Bruhn, (2017). Moreover, Zhou, Sandner, Martinelli, & Block, (2016) argued that innovative technologies significantly impact the concentration of CO2 emissions in China. Considering the drastic impacts of economic activities, the USA has shifted attention towards renewable energy production technologies. Santana, Rebelatto, Périco, Moralles, & Filho, (2015) has posted that the development of eco-innovative technologies has enabled the BRICS and G7 economies to attain sustainable growth. Yii & Geetha, (2017) studied the potential linkages between INN, GDP, electricity use, energy price and CO2 emissions in Malaysia. After analyzed the annual data of 1973–2013, it is revealed that INN decreases CO2 emissions. Lin & Xu, (2018) analyzed regional disparities in terms of technological innovation among different industrial units. They found that technological innovations are the most important factors that reduce CO2 emissions in China. Aldieri, Bruno, & Vinci, (2019) also presented the results that innovation accounts reduce CO2 emissions in OECD nations. At the same time, Su & Moaniba, (2017) revealed mixed results regarding INN and CO2 emissions. They argued that INN is not required to curb environmental pollution. Similarly, Raiser et al., (2017) supported the idea that patents are a hindrance to sustainable development across nations.

Atkociuniene & Siudikiene (2021) and Chien et al. (2022) investigated the impact of renewable energy and innovations on CO2 emissions in BRICS. They employed annual data of 1980-2016 and found heterogeneous effects of innovations on CO2 emissions. Braslauskas (2020) and Chen & Lee, (2020) probe the impact of technological innovations on CO2 emissions for a panel of 96 economies. They found that technological innovations reduce CO2 emissions significantly. Fethi & Rahuma, (2020) used the porter hypothesis to examine the impacts of eco-innovations on CO2 emissions for selected petroleum companies. They also validated the positive role of eco-innovations on CO2 emissions for the period of 2005–2016. Eco-innovation influences ecological, social and economic business performances (Ch'ng, Cheah, & Amran, 2021).QARDL approach has been used recently to examine linkage among technology innovation, tourism and CO_2 emissions.

After the examination of previous related literature, it is evident that various studies investigated explored RE and CO2 emissions in different regions. Most of the literature has incorporated RE as % of total energy consumption. Moreover, their findings are not consistent with one another. Considering the past literature, it is also evident that no study has been conducted for the USA, where solar energy used as a proxy for REW energy. Therefore, this paper scrutinizes associations of solar energy consumption, eco-innovations and CO2 emissions. Moreover, this study also incorporates other factors like population growth, labour productivity, capital formation and economic growth in empirical estimations. This study utilizes two models for theoretical grounds namely the neo-classical theory of economics and the STIRPAT model.

Methodology

Theoretical Model

This study applies the neo-classical model to find the association among construct in the sample USA. Therefore, equation 2 shows the neo-classical model.

$$GDP_t = f(CAP_t, LAB_t, ECO_t, SOL_t) \quad (1)$$

Where, $CAP_t, LAB_{t,}\ ECO_t, SOL_t$represents capital and labour force eco-innovations and solar energy consumption. Furthermore, our objective is to find how CO_2 emission is linked with solar energy and eco-innovations. We can use empirical analysis on the IPAT model for the identification of key factors of CO_2 emission (Paraschiv *et al.,* 2021; Raskin 1995; York, Rosa & Dietz, 2002). the approach includes population growth, labour productivity, capital formation and economic growth in empirical estimation and illustrated below

$$I = P \text{x} A \text{x} T \quad (2)$$

where I = the polluted or ecological factor
P = Population
A = Per captia Consumption
T = Efficiency of technolgical level

The STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model is a stochastic version of the basic model drawn-out by Dietz and Rosa (1994, 1997). With the modified version its hypotheses can be tested empirically. For our analysis, the empirical equation by using the STIRPAT model is:

$$CE_t = f(POP_t, PI_t, ECO_t, SOL_t) \quad (3)$$

It shows that CO_2 emissions are a function of $ECO_t, SOL_t POP_t, PI_t$ which represent natural logarithmic forms of eco-innovations, solar energy consumption, population growth and per capita income respectively. The purpose of model equation 3 is that how solar energy and eco-innovations impacts CO_2 emissions.

Quantile Autoregressive Distributed Lag

The paper investigates the nonlinear association of solar energy consumption, eco-innovations, population, capital and labour on economic growth and environmental quality in the USA. We applied an innovative QARDL procedure by Cho et al., (2015). QARDL method can provide long-term quantile effects of independent variables towards dependent variables. To validate the robustness of our results, we applied the Wald test. Therefore, the traditional ARDL framework has explained as follows:

$$\text{Y}_t = \beta_0 + \sum_i^p \alpha_1 X_{1(t-1)} + \sum_i^q \alpha_2 X_{2(t-1)} + \sum_i^q \alpha_3 X_{3(t-1)} + + \sum_i^q \alpha_4 X_{4(t-1)} + \sum_i^{q4} \alpha_5 X_{5(t-1)} + \varepsilon_t \quad (4)$$

Where p and q are the numbers of lags and ε_t represent white noise residual while Y represents GDP_t and X_1, X_2, X_3, X_4up toX_5represents$GDP_t, CAP_t, LAB_t, ECO_t, SOL_t$which are the natural logarithmic forms of economic growth, capital formation, labour productivity, eco-innovations and solar energy consumption. Now the adjustment of equation 1 and 2 for quantile ARDL is as follows:

$$Q_{Y_t} = \beta(\tau) + \sum_i^p \alpha_1(\tau)X_{1(t-1)} + \sum_i^q \alpha_2(\tau)X_{2(t-1)} + \sum_i^q \alpha_3(\tau)X_{3(t-1)} + + \sum_i^q \alpha_4(\tau)X_{4(t-1)} + \sum_i^{q4} \alpha_5(\tau)X_{5(t-1)} + \varepsilon_t \quad (5)$$

Where, $\varepsilon_t(\tau) = Y_t - Q_{X_{1t}}(\tau/\varepsilon_{t-1})$ () and $0< \tau < 1$is quantile. This study estimates the consecutive quantiles (τ) of (0.05, 0.25, 0.50, 0.75, 0.95). For the serial correlations in the residuals, the ARDL equations for both models are as follows:

$$Q_{Y_t} = \beta(\tau) + X_{1(t-1)} + \omega_1 X_{2(t-1)} + \lambda_1 X_{3(t-1)} + \Theta_1 X_{4(t-1)} + \mu_1 X_{5(t-1)} + \sum_i^p \alpha_1(\tau)X_{1(t-1)} + \sum_i^q \alpha_2(\tau)X_{2(t-1)} + \sum_i^q \alpha_3(\tau)X_{3(t-1)} + + \sum_i^q \alpha_4(\tau)X_{4(t-1)} + \sum_i^{q4} \alpha_5(\tau)X_{5(t-1)} + \varepsilon_t \quad (6)$$

The equations for error correction terms of quantile ARDL model are as follows: $Q_{Y_t} = \beta(\tau) + \mathrm{p}(\tau)(X_{1(t-i)} - \omega_1(\tau)X_{2(t-i)} - \lambda_1(\tau)X_{3(t-i)} - \Theta_1(\tau)X_{4(t-i)} - \mu_1(\tau)X_{5(t-i)}) + \sum_i^p \alpha_1(\tau)X_{1(t-1)} + \sum_i^q \alpha_2(\tau)X_{2(t-1)} + \sum_i^q \alpha_3(\tau)X_{3(t-1)} + + \sum_i^q \alpha_4(\tau)X_{4(t-1)} + \sum_i^{q4} \alpha_5(\tau)X_{5(t-1)} + \varepsilon_t$ (7)

The combined short-run impact of past economic growth and CO2 emissions on present GDP and CO2 emissions is calculated by the delta method. The speed of adjustment (p) has to be significant and negative. For the long and short-run impacts of independent variables on dependent variables, we used the Wald test. QARDL approach provides some encouraging short and long-run estimations, because these estimations are based on quantiles. Different quantiles can have different values in each era.

Quantile Causality Test

To check the causal effect among different quantiles, we applied the causality method called, Granger causality in quantiles. Among the available granger causality tests, we applied the newly developed granger causality test by Troster, (2018). According to Chien et al., 2021, $x_i$does not cause $y_i$if the previous value of x_i does not cause the previous value of y_i. In this scenario, we assume that there is explain vector $(N_i = N_i^y, N_i^x)' \in \mathbb{R}^e$, s =o +q, where N_i^x represents the earlier indication of $X_i N_i^x = (X_{i-1}, \dots, X_{i-q})' \in \mathbb{R}^q$. Moreover, this research describes granger causality from X_i to Y_i as follows:

QAR (1):$m^1\left(N_i^y, \partial(\pi)\right) = \lambda_1(\pi) + \lambda_2(\pi)X_{i-1} + \mu_t \Omega_Y^{-1}(\pi)$ (8)

Where $\partial(\pi) = \lambda_1(\pi), \lambda_2(\pi)$ and μ_t are quantified in equal point of the quantile. Moreover, $\Omega_Y^{-1}(\pi)$ represent the opposite of the basic distribution function. Therefore, to estimate the causal effect among the variables, we quantify equation 6. Hence, the next equation for the QAR method will be as follows:

$Q_\pi^Y(Y_i N_i^Y, N_i^X) = \lambda_1(\pi) + \lambda_2(\pi)Y_{i-1} + \eta(\pi)X_{i-1} + \mu_t \Omega_Y^{-1}(\pi)$ (9)

Results and Discussion

The data of eco-innovation is collected from the OECD website, and it is represented by the number of patents registered related to the environment. Moreover, data on CO2 emission is collected from the British Petroleum (BP) website. The remaining variables data are collected from world-bank from 1990-2019. We transformed the all-time series into their logarithmic form for uniform calculations. The quadratic sum method is employed to convert data into quarter (Fischer, Fischer, & McCormick, 2020). We gathered data on solar energy consumption from 1990–2019.

Table 1

Descriptive Statistics

Constructs	Mean	Min.	Max.	Std. Dev.	J-B Stats
GDP	3.987	2.024	4.001	0.161	25.001***
CAP	4.654	3.321	6.071	1.012	18.101***
LAB	5.789	4.01	7.103	0.959	20.602***
CO2	2.789	1.201	3.811	0.016	37.057***
POP	3.456	2.001	5.253	1.111	19.711***
PI	4.123	3.019	6.01	0.195	17.919***
ECO	5.196	4.101	8.291	1.076	27.123***
SOL	6.285	5.258	9.152	0.582	22.987***

Source: Author Estimation

Table 1 presents descriptive of variables. The mean value for GDP is 3.987. Moreover, mean values of CAP, LAB, CO2, POP, PI, ECO and SOL are 4.654, 5.789, 2.789, 3.456, 4.123, 5.196 and 6.285 respectively. The current study utilizes Jarque-Bera statistics in order to check normality. This existence of non-linearity among the data further validates the application of QARDL for detail estimations. Table 2 is showing the results of the quantile unit root test. We apply ADF and ZA tests with structural breaks.

The results show that no variables except CO2 emissions are stationary at level, but all variables are stationary at their first difference. The break years may be due to the different economic and climatic uncertainties in the USA. These structural breaks and non-linear feature of variables provide the suitability of QARDL estimation.

Table 2

Unit Root Test

Variables	ADF (Level)	ADF (Δ)	ZA (Level)	Break Year	ZA (Δ)	Break Year
GDP	-0.483	-5.437***	-2.361	2010 Q1	-8.583***	2014 Q1
CAP	-1.038	-8.472***	-1.942	2005 Q1	-10.352***	2009 Q2
LAB	-0.226	-3.225***	-0.882	2001 Q1	-7.786***	2011 Q4
CO2	-4.573***	-9.003***	-6.331***	2000 Q1	-11.142***	2007 Q2
POP	-1.048	-3.996***	-2.011	1997 Q2	-6.189***	2014 Q4
PI	-0.588	-5.221***	-1.846	1995 Q2	-10.572***	2016 Q1
ECO	-0.729	-7.343***	-1.449	1997 Q2	-9.429***	2008 Q2
SOL	-0.264	-4.055***	-1.284	2005 Q2	-7.251***	2016 Q4

QARDL for Economic Growth Model

Table 3 depicts QARDL model findings, that indicates the value of $\rho^{*}$is statistically significant and negative in the quantiles (.05 to .7). This shows the existence of reversion towards long-run equilibrium between GDP, capital, labour, eco-innovation and solar energy consumption. It is noted that capital formation is positively significant in low to high quantiles of economic growth (0.20‒0.95). This is showing that capital formation is increasing economic growth in the USA. Labour productivity is positively impacting economic growth in low to middle quantiles of (0.05‒0.40). From middle to high quantiles of economic growth, labour productivity put positive but insignificant impacts. Eco-innovation is positively affecting economic growth from the middle to high quantiles of economic growth (0.40‒0.95). These results are indicating that eco-innovations will contribute towards economic growth in the USA. This finding is similar to Venkatraja, (2020), according to which, technological advancements stimulate economic growth in the long-run. Technological advancements provide efficient means of production to increase economic growth. Regarding the impacts of solar energy consumption, this study finds that solar energy consumption contributes towards economic growth in higher quantiles of (0.70‒0.95). This finding shows that clean energy is contributing to economic growth by providing an efficient source of renewable energy. From low to middle quantiles, solar energy consumption positively affects economic growth, but this association is insignificant.

Now according to short-run analysis, GDP positively associated with the lags of GDP in low quantiles of (0.05‒0.10). This association remains positive in middle to high quantiles with insignificant values. At higher quantiles of economic growth, GDP exacts positive impacts on GDP in the USA. Capital formation is positively affecting economic growth during (0.05-0.30) but afterwards, this impact is insignificant till the quantile .6 but in .7 and .8 capital formation impacts positively. Labour productivity put an insignificant impact on EG in all 11 quantiles. Eco-innovations are negatively affecting economic growth from the grids of (0.05‒0.30). Afterwards, the negative impacts of eco-innovations become insignificant to the highest quantile. Solar energy consumption also exacts negative impacts on economic growth from low to middle quantiles of (0.05–0.30). From middle to highest quantiles, the negative impacts of solar energy consumption become insignificant

.

Table 3

Quantile Autoregressive Distributed Lag (QARDL) for GDP

Quantiles (τ)	**Constant**	**ECM**	**Long-term estimates**				**Short-term estimates**					
	$\alpha_*(\tau)$	**$\rho_*(\tau)$**	**$\beta_{CAP}(\tau)$**	**$\beta_{LAB}(\tau)$**	**$\beta_{ECO}(\tau)$**	**$\beta_{SOL}(\tau)$**	**$\varphi_1(\tau)$**	**$\omega_0(\tau)$**	**$\lambda_0(\tau)$**	**$\theta_0(\tau)$**	**$\delta_0(\tau)$**	**$\delta_1(\tau)$**
0.05	.101 (.010)	-.202*** (-4.218)	.180 (.070)	.241*** (3.620)	.019 (0.103)	.025 (.216)	.512*** (3.013)	.100* (1.710)	.012 (0.121)	-.091*** (-5.089)	-.015*** (-4.105)	-.024 (-.102)
0.10	.001 (.101)	-.201*** (-4.170)	.151 (.051)	.232*** (3.567)	.057 (0.381)	.024 (.214)	.421*** (3.612)	.163* (1.810)	.021 (0.010)	-.062*** (-4.620)	-.028*** (-3.919)	-.051 (-.015)
0.20	.021 (.132)	-.201*** (-3.781)	.225** (2.212)	.232*** (4.818)	.244 (0.234)	.138 (.156)	.161 (1.026)	.161*** (3.651)	.101 (0.201)	-.115*** (-3.010)	-.045** (-2.005)	-.069 (-.162)
0.30	.204 (.120)	-.181** (-1.999)	.267** (1.989)	.214** (2.008)	.323 (1.155)	.112 (.021)	.142 (1.141)	.116*** (4.261)	.110 (0.312)	-.072** (-1.989)	-.046** (-2.016)	-.029 (-.192)
0.40	.010 (.301)	-.181** (-2.222)	.191** (2.202)	.208** (2.007)	.302* (1.812)	.152 (.057)	.145 (1.041)	.110 (0.101)	.016 (0.013)	-.011 (-1.013)	-.064** (-2.041)	-.017 (-0.117)
0.50	.014 (.031)	-.186** (-1.966)	.220*** (3.124)	.202 (1.025)	.275* (1.717)	.181 (.115)	.114 (1.213)	.101 (0.202)	.045 (0.014)	-.103 (-1.102)	-.025 (-1.035)	-.026 (-.217)
0.60	.050 (.124)	-.202* (-1.758)	.250*** (4.826)	.182 (1.101)	.312** (2.182)	.261 (1.410)	.185 (1.348)	.075 (1.040)	.017 (0.073)	-.035 (-0.518)	-.001 (-1.010)	-.089 (-.183)
0.70	.061 (.105)	-.186* (-1.721)	.285*** (3.987)	.105 (1.413)	.280** (1.991)	.223* (1.921)	.210 (1.300)	.053** (1.991)	.012 (0.203)	-.043 (-1.003)	-.023 (-1.342)	-.033 (-.161)
0.80	.201 (.317)	-.111 (-1.331)	.301*** (4.321)	.118 (1.382)	.312*** (4.122)	.305** (2.333)	.220* (1.701)	.080** (2.091)	.025 (0.305)	-.029 (-1.494)	-.061 (-1.116)	-.019 (-1.191)
0.90	.157 (.208)	-.103 (-1.202)	.322*** (3.007)	.182 (1.315)	.320*** (3.141)	.357*** (3.117)	.210* (1.651)	.071 (0.050)	.046 (0.062)	-.096 (-1.595)	-.013 (-1.131)	-.044 (-1.369)
0.95	.212 (.382)	-.101 (-1.313)	.281*** (3.801)	.153 (1.456)	.260*** (3.001)	.329*** (3.289)	.252* (1.712)	.047 (1.028)	.070 (0.137)	-.067 (-1.057)	-.032 (-1.234)	-.044 (-1.199)

Source: Author Estimations

Table 4

Quantile Autoregressive Distributed Lag (QARDL) for CE

Quantiles (τ)	**Constant**	**ECM**	**Long-term estimates**				**Short-term estimates**						
	$\alpha_*(\tau)$	$\rho_*(\tau)$	$\beta_{POP}(\tau)$	$\beta_{PI}(\tau)$	$\beta_{ECO}(\tau)$	$\beta_{SOL}(\tau)$	$\varphi_1(\tau)$	$\omega_0(\tau)$	$\omega_1(\tau)$	$\lambda_0(\tau)$	$\theta_0(\tau)$	$\theta_1(\tau)$	$\delta_0(\tau)$
0.05	.201 (.020)	-.613*** (-5.326)	0.190 (0.080)	0.162*** (4.512)	-0.013 (-1.001)	-.136** (-2.305)	0.423*** (3.124)	0.060* (1.809)	0.078 (1.576)	0.103 (0.303)	-0.182*** (-6.879)	-0.015 (-0.251)	-0.026*** (-5.216)
0.10	.002 (.203)	-0.612*** (-4.721)	0.232 (0.062)	0.141*** (4.659)	-0.046 (-1.272)	-0.135** (-2.025)	0.532*** (4.721)	0.017* (1.770)	0.026 (1.026)	0.160 (0.016)	-0.091*** (-4.910)	-0.032 (-0.203)	-0.039*** (-4.020)
0.20	.012 (.331)	-0.510*** (-3.501)	0.202** (1.960)	0.127*** (6.989)	-0.032 (-1.035)	-0.122* (-1.811)	0.250 (1.165)	0.072*** (5.087)	0.066 (1.001)	0.173 (0.037)	-0.066*** (-4.060)	-0.004 (-0.403)	-0.056** (-2.116)
0.30	.030 (.120)	-0.562** (-1.694)	0.301** (2.019)	0.201** (2.980)	-0.121 (-1.175)	-0.082 (-1.201)	0.359 (1.259)	0.032*** (5.704)	0.050 (1.005)	0.200 (0.210)	-0.059** (-2.859)	-0.024 (-0.402)	-0.023** (-2.013)
0.40	.011 (.201)	-0.572** (-2.110)	0.213** (2.101)	0.197** (2.102)	-0.202* (-1.702)	-0.032 (-1.019)	0.219 (1.019)	0.010 (0.001)	0.017 (0.714)	0.171 (0.071)	-0.060 (-0.019)	-0.031 (-0.013)	-0.013** (-2.031)
0.50	.015 (.041)	-0.467** (-2.907)	0.211*** (3.521)	0.103 (1.153)	-0.215* (-1.801)	-0.031 (-1.305)	0.228 (0.329)	0.012 (0.101)	0.097 (0.759)	0.306 (0.031)	-0.017 (-0.017)	-0.022 (-0.301)	-0.031 (-1.031)
0.60	.060 (.040)	-0.414* (-1.650)	0.206*** (4.021)	0.172 (1.230)	-0.206** (-2.062)	-0.041 (-1.770)	0.276 (0.348)	0.040 (1.100)	0.022 (1.206)	0.081 (0.038)	-0.017 (-0.067)	-0.022 (-0.205)	-0.027 (-0.200)
0.70	.052 (.201)	-0.475* (-1.861)	0.281*** (4.181)	0.159 (1.335)	-0.290** (-1.998)	-0.023 (-1.201)	0.227 (0.400)	0.063** (2.100)	0.077 (1.077)	0.275 (0.253)	-0.052 (-1.001)	-0.042 (-0.124)	-0.065 (-1.056)
0.80	.302 (.426)	-0.120 (-1.046)	0.310*** (5.552)	0.128 (1.216)	-0.308*** (-5.082)	-0.159* (-1.827)	0.314* (1.694)	0.091** (2.010)	0.060 (1.080)	0.059 (0.331)	-0.038 (-1.180)	-0.050 (-1.101)	-0.062 (-1.032)
0.90	.246 (.309)	-0.304 (-1.106)	0.333*** (4.537)	0.192 (1.254)	-0.390*** (-4.252)	-0.241** (-2.129)	0.378* (1.712)	0.077 (0.070)	0.096 (0.969)	0.267 (0.169)	-0.078 (-0.158)	-0.057 (-1.201)	-0.024 (-1.242)
0.95	.010 (.271)	-0.312 (-1.421)	0.292*** (4.920)	0.162 (0.406)	-0.390*** (-5.010)	-0.225** (-2.379)	0.319* (1.800)	0.035 (1.107)	0.093 (1.390)	0.170 (0.107)	-0.015 (-0.134)	-0.044 (-1.040)	-0.021 (-1.145)

QARDL for Carbon Dioxide Emission Model

Table presents QARDL model findings, exhibiting the value of $\rho^*$is statistically significant and negative in the quantiles of (0.05–0.70). This indicates existence of reversion towards long-run equilibrium between "CO2 emissions, population, per capita income, eco-innovation and solar energy consumption. It is noted that population growth is positively significant in low to high quantiles of CO2 emissions (0.20–0.95). This is showing that population growth is degrading in the USA.

Per capita income is positively impacting CO2 emissions in low to middle quantiles of (0.05–0.40). From middle to high quantiles of CO2 emissions, per capita income put positive but insignificant impacts. Regarding the impacts of eco-innovations, this study finds that eco-innovations are lowering CO2 emissions in higher quantiles of (0.40–0.95). This finding shows that technological advancement is contributing to sustainable development in the USA by providing an efficient source of renewable energy. From low to middle quantiles, eco-innovation negatively affects CO2 emissions, but this association is insignificant. Regarding the impacts of solar energy consumption, this study finds that solar energy consumption lowers CO2 emissions in higher quantiles of (0.80–0.95). This finding shows that clean energy is contributing to economic growth by providing an efficient source of renewable energy. From low to middle quantiles, solar energy consumption negatively affects CO2 emissions. During the middle quantiles, this association is insignificant.

Now according to short-run analysis, CO2 emissions are positively associated with the lags of CO2 emissions in low and higher quantiles. This association remains positive in middle to high quantiles with insignificant values. At lower quantiles of CO2 emissions, population growth exacts positive impacts on CO2 emissions in the USA. Per capita income is positively affecting economic growth during all quantiles, but this impact is insignificant. Eco innovations put a negative impact on CO2 emissions in lower quantiles but an insignificant negative impact in middle to higher quantiles of CO2 emissions. Solar energy consumption also exacts negative impacts on CO2 emissions in lower quantiles. From middle to highest quantiles, the negative impact of solar energy consumption becomes insignificant.

Table 5

Results of the Wald Test for the Constancy of Parameters

Variables	Wald-statistics (GDP)	Wald-statistics (CE)
ρ	4.654*** (0.000)	5.471*** (0.000)
β_{CAP}	7.543*** (0.000)	-
β_{LAB}	15.210** (0.000)	-
β_{POP}	-	6.366*** (0.000)
β_{PI}	-	2.574** (0.028)
β_{ECO}	3.083** (0.001)	5.370*** (0.000)
β_{SOL}	2.377** (0.043)	8.116*** (0.000)
φ_1	2.101* (0.060)	11.672*** (0.000)
ω_0	1.208** (.185)	5.082*** (.00)
ω_1	-	.432 -.682
λ_0	.042 (.999)	2.983** (.018)
θ_0	4.424*** (.00)	4.557*** (.00)
θ_1	-	0.082 -0.963
δ_0	5.010*** (.00)	3.852*** (.00)
δ_1	.051 (.999)	-
Cumulative short-term effect:		
ω*	-	1.144 (.321)
θ*	-	.874 (.217)
δ*	1.004 (0.376)	-

Source: Author Estimations

Table 5 is providing the results of the Wald test, which confirms the symmetric association between our variables in the long run. Now considering the short-run results, the Wald test fails to reject the null hypothesis of parametric dependability between the estimated variables during different quantiles.

Table 6

Granger Causality in Quantile Test Results

Quantiles	ΔGDP_t ↓ ECO_t	ΔECO_t ↓ ΔGDP_t	ΔGDP_t ↓ ΔSOL_t	ΔSOL_t ↓ ΔGDP_t	$\Delta CO2_t$ ↓ ΔECO_t	ΔECO_t ↓ $\Delta CO2_t$	$\Delta CO2_t$ ↓ ΔSOL_t	ΔSOL_t ↓ $\Delta CO2_t$
[0.05-0.95]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
0.10	0.000	0.000	0.000	0.102	0.000	0.000	0.000	0.000
0.20	0.000	0.000	0.000	0.120	0.000	0.000	0.000	0.000
0.30	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000
0.40	0.000	0.000	0.000	0.210	0.000	0.000	0.000	0.000
0.50	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000
0.60	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000
0.70	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000
0.80	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000
0.90	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
0.95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Authors Estimation

Table 6 depicts granger causality results. The significant probability values in different quantiles reject the null hypothesis of no causality. Feedback causality exists between GDP and eco-innovations at a 1 % level of significance. Except for the quantiles of (0.10–0.40), two-way causality exists between EG and SE. Moreover, CO2 emissions and eco-innovations have bidirectional causality at a 1 % level in all 11 quantiles. At the same time, there exists a two-way causal effect between SE consumption and CO2 emissions in all quantiles.

Conclusion

This study is a pioneer attempt to investigate the quantile performance of linkages of solar energy consumption, eco-innovation, population growth, economic growth, capital, labour productivity and CO2 emissions in the USA. We took annual data from 1990–2019 and convert it into quarterly. We applied the QARDL approach by Cho et al., (2015)and causality in quantiles by Troster, (2018). This study shows that the association is quantile dependent in the USA. Unlike traditional co-integrating techniques, the QARDL approach allows for different co-integrating coefficients in different quantiles. The ECM value was recorded negative and significant across quantiles, which shows the speed of adjustment towards long-run equilibrium between estimated variables. Our findings show that capital formation is positively affecting GDP during the quantiles of (0.20–0.95). Labour productivity is increasing GDP in quantiles of (0.05–0.30). Eco innovations are also increasing GDP in the higher quantiles of (0.40–0.95). Solar energy consumption is positively associated with economic growth during the quantiles of (0.70-0.95). According to short-run analysis, GDP positively associated with the lags of GDP in low quantiles of (0.05–0.10). This association remains positive in middle to high quantiles with insignificant values. At higher quantiles of economic growth, GDP exacts positive impacts on GDP in the USA. Capital formation is positively affecting economic growth during (0.05–0.30) but afterwards, this impact is insignificant till the quantile of 0.60 but again during grids of (0.70–0.80) capital formation impacts positively. Labour productivity put an insignificant positive impact on economic growth in all 11 quantiles. Eco-innovations are negatively affecting economic growth from the grids of (0.05–0.30). Afterwards, the negative impacts of eco-innovations become insignificant to the highest quantile. Solar energy consumption also exacts negative impacts on economic growth from low to middle quantiles of (0.05–0.30). From middle to highest quantiles, the negative impacts of solar energy consumption become insignificant.

According to the QARDL model for CO2 emissions, $\rho^*$is statistically significant and negative in the quantiles of (0.05–0.70). This shows the existence of reversion towards long-run equilibrium between CO2 emissions, population, per capita income, eco-innovation and solar energy consumption. It is noted that population growth is positively significant in low to high quantiles of CO2 emissions (0.20–0.95). This is showing that population growth is degrading in the USA. Per capita income is positively impacting CO2 emissions in low to middle quantiles of (0.05–0.40). From middle to high quantiles of CO2 emissions, per capita income put positive but insignificant impacts. Regarding the impacts of eco-innovations, this study finds that eco-innovations are lowering CO2 emissions in higher quantiles of (0.40–0.95). This finding shows that technological advancement is contributing to sustainable development in the USA by providing an efficient source of renewable energy. From low to middle quantiles, eco-innovation negatively affects CO2 emissions, but this association is insignificant.

This study finds that solar energy consumption lowers CO2 emissions in higher quantiles of (0.80–0.95). This finding shows that clean energy is contributing to economic growth by providing an efficient source of renewable energy. From low to middle quantiles, solar energy consumption negatively affects CO2 emissions. During the middle quantiles, this association is insignificant. According to short-run analysis, CO2 emissions are positively associated with the lags of CO2 emissions in low and higher quantiles. This association remains positive in middle to high quantiles with insignificant values. At lower quantiles of CO2 emissions, population growth exacts positive impacts on CO2 emissions in the USA. Per capita income is positively affecting economic growth during all quantiles, but this impact is insignificant. Eco innovations put a negative impact on CO2 emissions in lower quantiles but an insignificant negative impact in middle to higher quantiles of CO2 emissions. Solar energy consumption also exacts negative impacts on CO2 emissions in lower quantiles. From middle to highest quantiles, the negative impact of solar energy consumption becomes insignificant.

From the policy perspective, this study provides some important instruments for sustainable development in the USA. This study finds that eco-innovations and solar energy consumption contribute to more economic growth in different quantiles. Moreover, eco-innovations and solar energy consumption are reducing CO2 emissions in different quantiles, which means that the USA can achieve sustainable development through the channels of eco-innovations and solar energy consumption. In light of our findings, solar energy consumption reduces CO2 emissions with increasing GDP. Solar energy considered as the most suitable alternative for non-renewable energy. Therefore, the government should continue to invest more in eco-innovation projects to increase the ratio of renewable consumption through solar energy. Our study also finds that population growth and per capita income are increasing CO2 emissions, which means that population growth is currently harmful and there is a need to consider population-related policies to reduce air pollution.

References

Albino, V., Ardito, L., Dangelico, R. M., & Messeni Petruzzelli, A. (2014). Understanding the development trends of low-carbon energy technologies: A patent analysis. *Applied Energy*, 135, 836–854. https://doi.org/10.1016/j.apenergy.2014.08.012

Aldieri, L., Bruno, B., & Vinci, C. P. (2019). Does environmental innovation make us happy? An empirical investigation. *Socio-Economic Planning Sciences*, 67, 166–172. https://doi.org/10.1016/j.seps.2018.10.008

Anwar, M., Khattak, M. S., Popp, J., Meyer, D. F., & Mate, D. (2020). The nexus of government incentives and sustainable development goals: is the management of resources the solution to non-profit organisations?. *Technological and Economic Development of Economy*, 26(6), 1284–1310. https://doi.org/10.3846/tede.2020.13404

Apergis, N., & Danuletiu, D. C. (2014). Renewable Energy and Economic Growth: Evidence from the Sign of Panel Long-Run Causality. *International Journal of Energy Economics and Policy*, 4(4), 578–587.

Atkociuniene, Z. O., & Siudikiene, D. (2021). Communication management in promoting knowledge and creativity in fostering innovations in the creative organizations. *Creativity Studies*, 14(2), 549–576. https://doi.org/10.3846/cs.2021.15550

Ben Jebli, M., & Ben Youssef, S. (2015). The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. *Renewable and Sustainable Energy Reviews*, 47, 173–185. Elsevier Ltd. https://doi.org/10.1016/j.rser.2015.02.049

Bossle, M. B., Dutra De Barcellos, M., Vieira, L. M., & Sauvee, L. (2016, February). The drivers for adoption of eco-innovation. *Journal of Cleaner Production*, 113, 861–872. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2015.11.033

Braslauskas, J. (2020). Effective creative intercultural communication in the context of business interaction: theoretical and practical aspects. *Creativity studies*, 13(1), 199–215. https://doi.org/10.3846/cs.2020.12094

Cetin, M. A. (2016). Renewable energy consumption-economic growth nexus in E-7 countries. *Energy Sources, Part B: Economics, Planning and Policy*. https://doi.org/10.1080/15567249.2016.1156195

Ch'ng, P. C., Cheah, J., & Amran, A. (2021). Eco-innovation practices and sustainable business performance: The moderating effect of market turbulence in the Malaysian technology industry. *Journal of Cleaner Production*, 283, 124556. https://doi.org/10.1016/j.jclepro.2020.124556

Chen, Y., & Lee, C.-C. (2020). Does technological innovation reduce CO2 emissions?Cross-country evidence. *Journal of Cleaner Production*, 263, 121550. https://doi.org/10.1016/j.jclepro.2020.121550

Cheng, C. C. J., Yang, C. L., & Sheu, C. (2014). The link between eco-innovation and business performance: A Taiwanese industry context. *Journal of Cleaner Production*, 64, 81–90. https://doi.org/10.1016/j.jclepro.2013.09.050

Cheng, C. C., & Shiu, E. C. (2012). Validation of a proposed instrument for measuring eco-innovation: An implementation perspective. *Technovation*, 32(6), 329–344. https://doi.org/10.1016/j.technovation.2012.02.001

Cho, J. S., Kim, T. H., & Shin, Y. (2015). Quantile cointegration in the autoregressive distributed-lag modeling framework. *Journal of Econometrics*. https://doi.org/10.1016/j.jeconom.2015.05.003

Corras-Arias, M. A. (2020). Determinants of foreign banking in Spain. An analysis by country of origin. *Journal of Economics and Finance*, 43(121).

Danielle, N. E. L., & Masilela, L. (2020). Open governance for improved service delivery innovation in South Africa. *International Journal of eBusiness and eGovernment Studies*, 12(1), 33–47. https://doi.org/10.34111/ijebeg.202012103

Dogaru, L. (2020). Eco-innovation and the contribution of companies to the sustainable development. *Procedia Manufacturing*, 46, 294–298. Elsevier B.V. https://doi.org/10.1016/j.promfg.2020.03.043

Fang, Y. (2011). Economic welfare impacts from renewable energy consumption: The China experience. *Renewable and Sustainable Energy Reviews*, 15(9), 5120–5128. https://doi.org/10.1016/j.rser.2011.07.044

Fethi, S., & Rahuma, A. (2020). The impact of eco-innovation on CO2 emission reductions: Evidence from selected petroleum companies. *Structural Change and Economic Dynamics*, 53, 108–115. https://doi.org/10.1016/j.strueco.2020.01.008

Fischer, A., Fischer, F., & McCormick, S. T. (2020). Matroid optimization problems with monotone monomials in the objective. *Discrete Applied Mathematics*. https://doi.org/10.1016/j.dam.2020.04.004

Habanabakize, T. (2020). The effect of economic growth and exchange rate on imports and exports: The south african post-2008 financial crisis case. *International Journal of Economics and Finance Studies*, 12(1), 223–238. https://doi.org/10.34109/ijefs.202012114

Hall, P. V., O'Brien, T., & Woudsma, C. (2013). Environmental innovation and the role of stakeholder collaboration in West Coast port gateways. *Research in Transportation Economics*, 42(1), 87–96. https://doi.org/10.1016/j.retrec.2012.11.004

Hartani, N. H., Haron, N., & Tajuddin, N. I. I. (2021). The impact of strategic alignment on the sustainable competitive advantages: Mediating role of it implementation success and it managerial resource. *International Journal of eBusiness and eGovernment Studies*, 13(1), 78–96.

Hassan, S. T., Xia, E., Khan, N. H., & Shah, S. M. A. (2019). Economic growth, natural resources, and ecological footprints: evidence from Pakistan. *Environmental Science and Pollution Research*, 26(3), 2929-2938. https://doi.org/10.1007/s11356-018-3803-3

Ikhidi. (2015). September 2015. *Current History*, 114(775), 328–328. https://doi.org/10.1525/curh.2015.114.775.328

Inglesi-Lotz, R. (2016). The impact of renewable energy consumption to economic growth: A panel data application. *Energy Economics*, 53, 58–63. https://doi.org/10.1016/j.eneco.2015.01.003

Jan, I., Durrani, S. F., & Khan, H. (2021). Does renewable energy efficiently spur economic growth? Evidence from Pakistan. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-019-00584-1

Jermsittiparsert, K. (2021). Linkage between energy consumption, natural environment pollution, and public health dynamics in ASEAN. *International Journal of Economics and Finance Studies*, 13(2), 1–21.

Kouton, J. (2021). The impact of renewable energy consumption on inclusive growth: panel data analysis in 44 African countries. *Economic Change and Restructuring*. https://doi.org/10.1007/s10644-020-09270-z

Lean, H. H., & Smyth, R. (2014). Disaggregated energy demand by fuel type and economic growth in Malaysia. *Applied Energy*, 132, 168–177. https://doi.org/10.1016/j.apenergy.2014.06.071

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

Leitao, N. C. (2014). Economic Growth, Carbon Dioxide Emissions, Renewable Energy and Globalization. *International Journal of Energy Economics and Policy*, 4(3), 391–399.

Lin, B., & Xu, M. (2018). Regional differences on CO2 emission efficiency in metallurgical industry of China. *Energy Policy*, 120, 302–311. https://doi.org/10.1016/j.enpol.2018.05.050

Malla, S., & Brewin, D. G. (2020). An economic account of innovation policy in Canada: a comparison of canola, wheat, and pulses.

Marinas, M.-C., Dinu, M., Socol, A.-G., & Socol, C. (2018). Renewable energy consumption and economic growth. Causality relationship in Central and Eastern European countries. *PLOS ONE*, 13(10), e0202951. https://doi.org/10.1371/journal.pone.0202951

Matuszewska-Pierzynka, A. (2021). Relationship between corporate sustainability performance and corporate financial performance: Evidence from US companies. Equilibrium. Quarterly Journal of *Economics and Economic Policy*, 16(4), 885–906. https://doi.org/10.24136/eq.2021.033

Mehmood, U. (2021a). Renewable-nonrenewable energy : institutional quality and environment nexus in South Asian countries. https://doi.org/10.1007/s11356-021-12554-0

Mehmood, U. (2021b). The interactional role of globalization in tourism-CO 2 nexus in South Asian countries. https://doi.org/10.1007/s11356-021-12473-0

Mehmood, U., & Tariq, S. (2020). Globalization and CO 2 emissions nexus: evidence from the EKC hypothesis in South Asian countries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-020-09774-1

Mehmood, U., Tariq, S., Ul-Haq, Z., & Meo, M. S. (2020). Does the modifying role of institutional quality remains homogeneous in GDP-CO2 emission nexus? New evidence from ARDL approach. *Environmental Science and Pollution Research*, 1–8. https://doi.org/10.1007/s11356-020-11293-y

Menegaki, A. N. (2011). Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy Economics*, 33(2), 257–263. https://doi.org/10.1016/j.eneco.2010.10.004

Mikelsone, E., Spilbergs, A., Volkova, T., & Liela, E. (2020). Idea management system application types in local and global context. Equilibrium. *Quarterly Journal of Economics and Economic Policy*, 15(1), 151–166. https://doi.org/10.24136/eq.2020.008

Mitic, P., Kostic, A., Petrovic, E., & Cvetanovic, S. (2020). The relationship between CO2 emissions, industry, services and gross fixed capital formation in the Balkan countries. *Inzinerine Ekonomika-Engineering Economics*, 31(4), 425–436. https://doi.org/10.5755/j01.ee.31.4.24833

Ntanos, S., Skordoulis, M., Kyriakopoulos, G., Arabatzis, G., Chalikias, M., Galatsidas, S., … Katsarou, A. (2018). *Renewable Energy and Economic Growth: Evidence from European Countries*,10(8), 2626. https://doi.org/10.3390/su10082626

Niaz, M. U. (2021). Socio-Economic development and sustainable development goals: a roadmap from vulnerability to sustainability through financial inclusion. *Economic Research-Ekonomska Istrazivanja*, 1–33. https://doi.org/10.1080/1331677X.2021.1989319

OCED. (2009). Sustainable Manufacturing and Eco-Innovation Synthesis Report Framework, Practices and Measurement eco-innovation.

Oh, I., Yoo, W. J., & Kim, K. (2020). Economic effects of renewable energy expansion policy: Computable general equilibrium analysis for Korea. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph17134762

Ojogiwa, O. T. (2021). The crux of strategic leadership for a transformed public sector management in Nigeria. *International Journal of Business and Management Studies*, 13(1), 83–96.

Paraschiv, D. M., Manea, D. I., Titan, E., & Mihai, M. (2021). Development of an aggregated social inclusion indicator. Disparities in the European Union on inclusion/exclusion social determined with social inclusion index. *Technological and Economic Development of Economy*, 27(6), 1301–1324. https://doi.org/10.3846/tede.2021.15103

Raiser, K., Naims, H., & Bruhn, T. (2017). Corporatization of the climate? Innovation, intellectual property rights, and patents for climate change mitigation. *Energy Research & Social Science*, 27, 1–8. https://doi.org/10.1016/j.erss.2017.01.020

Santana, N. B., Rebelatto, D. A. D. N., Perico, A. E., Moralles, H. F., & Filho, W. L. (2015). Technological innovation for sustainable development: an analysis of different types of impacts for countries in the BRICS and G7 groups, 1–12. https://doi.org/10.1080/13504509.2015.1069766

Sarwar, B., Ming, X., & Husnain, M. (2020). Economic policy uncertainty and dividend sustainability: new insight from emerging equity market of China. *Economic research-Ekonomska istrazivanja*, 33(1), 204–223. https://doi.org/10.1080/1331677X.2019.1708769

Seddighi, H. R., & Mathew, S. (2020). Innovation and regional development via the firm's core competence: some recent evidence from North East England. *Journal of Innovation & Knowledge*, 5(4), 219–227. https://doi.org/10.1016/j.jik.2019.12.005

Sell, F. L. (2020). Static and Dynamic Price Effects Motivated by Innovation and Imitation: Novel Insights Using the Barone's Curve. *Contemporary Economics*, 14(1), 73–90. https://doi.org/10.5709/ce.1897-9254.333

Shibli, R., Saifan, S., Ab Yajid, M. S., & Khatibi, A. (2021). Mediating Role of Entrepreneurial Marketing Between Green Marketing and Green Management in Predicting Sustainable Performance in Malaysia's Organic Agriculture Sector. *AgBioForum*, 23(2), 37–49.

Silva, S., Soares, I., & Pinho, C. (2012). The impact of renewable energy sources on economic growth and co 2 emissions - A svar approach. *European Research Studies Journal*. https://doi.org/10.35808/ersj/374

Soava, G., Mehedintu, A., Sterpu, M., & Raduteanu, M. (2018). Impact of renewable energy consumption on economic growth: Evidence from European Union countries. *Technological and Economic Development of Economy*. https://doi.org/10.3846/tede.2018.1426

Streimikiene, D., & Akberdina, V. (2021). Public Views of the Economy of the Renewable Energy Sources: Evidence from Russia. *Contemporary Economics*, 15(3), 256–267. https://doi.org/10.5709/ce.1897-9254.447

Su, H.-N., & Moaniba, I. M. (2017). Does innovation respond to climate change? Empirical evidence from patents and greenhouse gas emissions. *Technological Forecasting and Social Change*, 122, 49–62. https://doi.org/10.1016/j.techfore.2017.04.017

Tariq, S., Ul-Haq, Z., Imran, A., Mehmood, U., Aslam, M. U., & Mahmood, K. (2017). CO2 emissions from Pakistan and India and their relationship with economic variables. *Applied Ecology and Environmental Research*. https://doi.org/10.15666/aeer/1504_13011312

Tiberius, V., Schwarzer, H., & Roig-Dobon, S. (2021). Radical innovations: Between established knowledge and future research opportunities. *Journal of Innovation & Knowledge*, 6(3), 145–153. https://doi.org/10.1016/j.jik.2020.09.001

Tiwari, A. K. (2011). Comparative performance of renewable and nonrenewable energy source on economic growth and CO2 emissions of Europe and Eurasian countries: A PVAR approach. *Economics Bulletin*, 31(3), 2356–2372.

Troster, V. (2018). Testing for Granger-causality in quantiles. *Econometric Reviews*. https://doi.org/10.1080/07474938.2016.1172400

van Vuuren, H. J. (2020). The Disclosure of Corporate Governance: a Tick-Box Exercise or Not?. *International Journal of Business and Management Studies*, 12(1), 50–65.

Venkatraja, B. (2020). Does renewable energy affect economic growth? Evidence from panel data estimation of BRIC countries. *International Journal of Sustainable Development and World Ecology*. https://doi.org/10.1080/13504509.2019.1679274

Wirsbinna, A., & Grega, L. (2021). Assessment of Economic Benefits of Smart City Initiatives. *Cuadernos de Economia*, 44(126), 45–56.

Yii, K. J., & Geetha, C. (2017). The Nexus between Technology Innovation and CO2 Emissions in Malaysia: Evidence from Granger Causality Test. *Energy Procedia*, 105, 3118–3124. https://doi.org/10.1016/j.egypro.2017.03.654

Yousaf, Z., Radulescu, M., Nassani, A., Aldakhil, A. M., & Jianu, E. (2021). Environmental Management System towards Environmental Performance of Hotel Industry: Does Corporate Social Responsibility Authenticity Really Matter?. *Inzinerine Ekonomika-Engineering Economics*, 32(5), 484–498. https://doi.org/10.5755/j01.ee.32.5.28619

Zhou, H., Sandner, P. G., Martinelli, S. L., & Block, J. H. (2016). Patents, trademarks, and their complementarity in venture capital funding. *Technovation*. https://doi.org/10.1016/j.technovation.2015.11.005

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