



Environmental sustainability and ecological balance dilemma: accounting for the role of institutional quality

Phillips O. Agboola¹ · Festus Victor Bekun^{2,3} · Divine Q. Agozie⁴ · Bright Akwasi Gyamfi⁵

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Abstract

Global warming is a global menace mainly driven by human anthropogenic activities. There is a need for environmental sustainability amidst increased economic growth. To this end, this study draws motivation from the United Nations Sustainable Development Goals (UNSDGs) with special focus on climate change mitigation and ecological balance. Thus, the present study analyses the dynamic relationship between economic growth, conventional energy consumption, access to technological innovation, economic globalisation, and the pertinent role of institutional quality for the case of the Russian Federation. This study employed novel combined Bayer and Hack cointegration test in conjunction with Pesaran's ARDL bounds testing for robustness. Both tests validate a long-run equilibrium relationship between the outlined variables. Furthermore, empirical results show that increase in economic activities and consumption of energy that stem from a fossil-fuel basis both have deteriorating effect on environmental sustainability for Russia. Additionally, effect of globalisation shows mixed results, such as, in the short run, economic globalisation dampens environmental quality as increase in global integration exacerbates environmental quality, while, in the long term, globalisation improves the quality of the environment. On the contribution of institutional quality, it improves environmental sustainability over the investigated period. Interestingly, renewable is seen as a panacea for environmental sustainability in the Russian Federation given its pertinent effect to improve the environment of Russia. From a policy lens, there is need for a paradigm shift to renewables and clean technologies to mitigate the effect of climate change issues. The concluding section presents more policy strategies.

Keywords Environmental sustainability · Carbon reduction · Ecological balance · Economic growth · Combined Bayer and Hanck cointegration · Russian Federation

Introduction

Despite the numerous challenges faced by the global environment, countries have only sought the expansion of socio-economic activities. Increased technological innovation, higher energy demand and economic globalisation have only

Responsible Editor: Ilhan Ozturk

✉ Festus Victor Bekun
fbekun@gelisim.edu.tr

Phillips O. Agboola
pagboola@ksu.edu.sa

Divine Q. Agozie
dagozie@ug.edu.gh

Bright Akwasi Gyamfi
bagyamfi@ticaret.edu.tr

² Faculty of Economics Administrative and Social Sciences, Istanbul Gelisim University, Istanbul, Turkey

³ Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon

⁴ Department of Operations and Management Information Systems, Business School, University of Ghana, Accra, Ghana

⁵ Economic and Finance Application and Research Center, Istanbul Ticaret University, Istanbul, Turkey

¹ Mechanical Engineering Department, College of Applied Engineering, King Saud University (Al Muzahimiyah Branch), Riyadh, Saudi Arabia

caused socioeconomic engagements and activity to increase; hence, these are touted as crucial determinants of ecological and environmental quality (Destek and Sarkodie 2019; Alola et al. 2019; Tinta 2021). The resultant effects on the ecology and the environment from the surging different forms of economic activity present the drastic need to transition to responsible and sustainable production methods, through the use of clean energy and technologies, coupled with policy reformations, regulations, and quality institutions (OECD, 2020).

Undeniably, the essence of economic globalisation and industrialisation of nations is to expand trade, drive financial development, and promote economic complexity (Khan et al. 2020). However, these developments also carry over detrimental impacts on the environment, like man-made greenhouse gas and CO₂ emissions, which threaten the climate, degrade, and pollute the environment (Bello et al. 2018; Pata and Caglar 2021). Thus, according to experts, this is the global challenge—to pursue economic development objectives, while maintaining environmental quality and balance between human activities and the natural regenerative resource capacity (Yin et al. 2021). To this end, global partners and international bodies like the UN and UNFCCC have since pushed for the realisation of the sustainable development paradigm (Mehmood and Tariq 2020; Rashid et al. 2018).

The need to formulate and adopt appropriate policy regulations requires quality institutions for accurate impact assessment, of human economic development activity on the environment and its resources (Wandeda et al. 2021). Thus, Tinta (2022) believes that institutional quality is a crucial determinant of environmental quality among several other factors. Beyond this assertion, human activity factors like ecological footprint and CO₂ emissions have also received wide acceptance as environmental indicators (Abbas et al. 2021; Destek and Sarkodie 2019; Fakher 2019; Laurent et al. 2012).

According to the Global Footprint Network, (2012), the concept of ecological footprints “measures the biologically productive area of land and water required by an individual or population to produce all resources it consumes to accommodate urban infrastructure and absorb waste generated in the form of carbon dioxide using prevailing technology and quality management practices.” Ecological footprint is assessed along six perspectives of land use, namely, cropland (area for nutritious food production), pastureland (land for raising livestock), forestland (area for forest product supply), fisheries (fresh and sea water land for fish and sea products), built-up land (land for human infrastructure), and carbon uptake land (forest land needed to consume CO₂) (WWF 2018).

Additional indicators include CO₂ emission and biocapacity, which occur at the supply side. These indicators

largely determine the volume of pollution generated from economic engagements and the regenerative capacity of the environment to produce biological materials (Global Footprint Network 2012). For instance, if the ecological footprint exceeds an environment’s biocapacity, then there is an ecological deficit, hence greater pollution. However, where the environment’s biocapacity exceeds the ecological footprint, then an ecological reserve exists, hence lesser pollution (Galli et al. 2016; Torras et al. 2011).

Economic expansion in many newly industrialised countries (NICs) has characterised the rise in negative environmental consequences. For example, Russia measures ecological footprint of 5.48 and a biocapacity of 6.96, compared with other newly industrialised economies like India that shows an ecological footprint per capita of 1.19 and a biocapacity per capita of 0.43 hectares and China showing an ecological footprint of 3.71 hectares per capita and a biocapacity of 0.92 per capita indicating an ecological deficit of –3,435.62, the largest in the world (Wandeda et al. 2021). However, despite the positive signs of ecological reserves growing in Russia, the economic growth pattern of Russia shows an inconsistent impact on environmental quality and degradation. Thus, Russia is among the top five culprits of high carbon emissions (WWF 2018). The ecological footprint report on Russia indicates a 1% change in ecological reserve between 2017 and 2020 (see Fig. 1), while it is yet observed to be a high emission source of carbon dioxide in the world (see Fig. 2). Being among the world’s emerging industrialised economies, Russia has a land size equivalent to 11% of the world’s landmass, and, as such, it is perceived that it will also have a greater demand for energy to facilitate its industrialisation process (IRENA 2018). Russia depends significantly on fossil fuel revenue and has no plans of cutting down on its dependence on these energy sources (Bekun 2022). Thus, given the trend of Russia’s economic growth and expansion, it is likely to continue to produce greater volumes of greenhouse gas and carbon dioxide in the long term that may reduce its ecological reserves per capita and increase greater pollution. This situation amplifies the debate on the consequences of Russia’s economic globalisation goals, technological development, energy consumption, and environmental quality an important one requiring further attention (Rehman et al. 2021).

Whereas some scholars share the view that economic globalisation and other factors, such as technological development, energy consumption, and institutional quality, positively affect environmental degradation across (Ibrahiem 2015; Ling et al. 2015; Najan et al. 2007; Rehman et al. 2021; Shahbaz et al. 2015; Shahbaz et al. 2019), others believe that those countries in the process of industrialisation may not experience this positive impact on the environment. Thus, they argue that a weak system and institutions allow economic expansion activities consistent with the pollution

Fig. 1 Ecological footprint of Russia between 1992 and 2020. Source: Global Footprint Network (2018), www.footprintnetwork.org

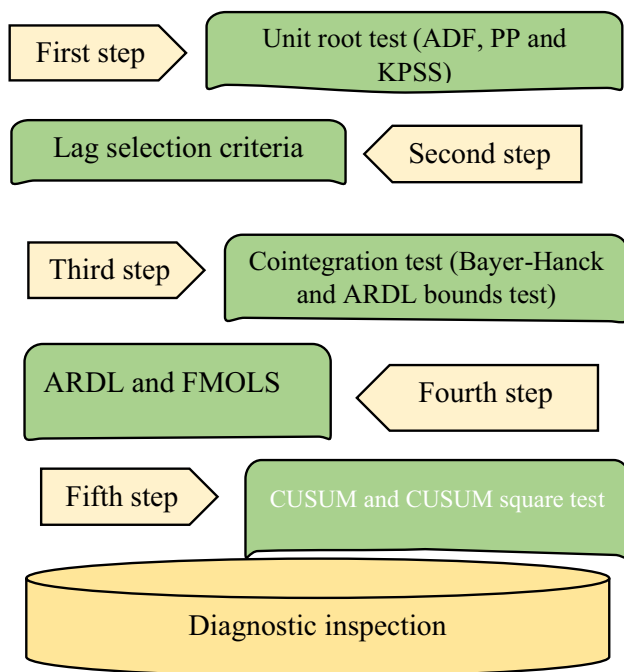
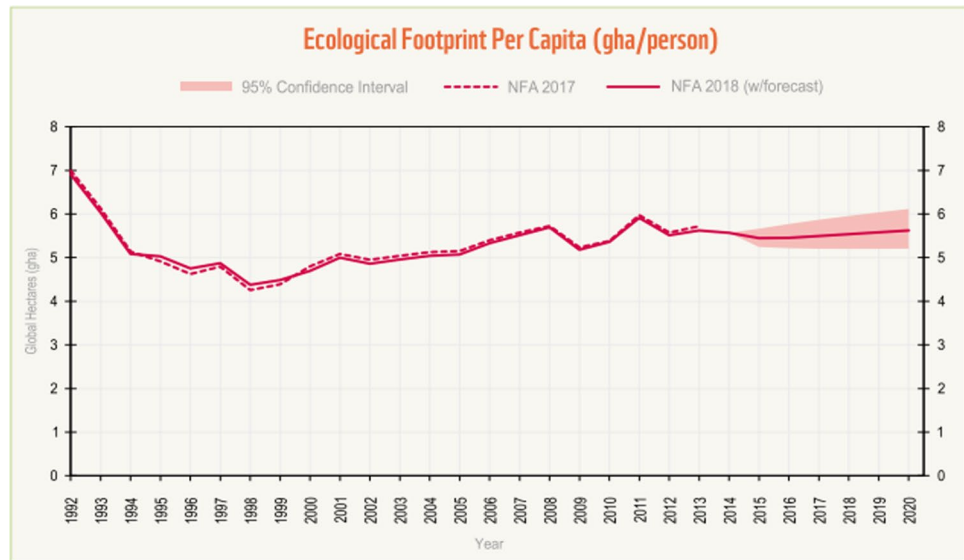


Fig. 2 Methodological flow diagram

haven framework, and pollution-intensive industrial sectors through the reliance on fossil fuel energy sources deepen environmental degradation in such countries undergoing industrialisation (Lu et al. 2021a, 2021b; Phong 2019; Wang and Dong 2021a, 2021b).

To sustain environmental quality and pursue economic growth, Russia's strategic goal over the past decade or two has been to transition to a sustainable economy, by gradually moving away from its existing natural resource-based development model and bringing under control the growth

of its natural resource-based economy by 2030. This situation has accumulated greater and greater momentum. Thus, it has become more apparent that Russia's natural resource-exporting model has been outlived; therefore, ensuring quality environments must be at the forefront of its new and emerging developmental models to slow the impact of the unsustainable trends of natural resource depletion.

The aforementioned goal presents evidence imperative to understand how economic development indicators link to ecological footprint and CO₂ emissions. Hence, the purpose of this study is to examine the long-run effects and causality between CO₂ emissions and ecological footprint and their determinants, including economic globalisation, access to technology, fossil fuel use, renewable energy consumption, and institutional quality over the period 1970 to 2019 in Russia.

This study differs substantially from the existing few studies. First, it combines ecological footprint and CO₂ emissions as output variables, while previous studies have mainly examined ecological footprint or CO₂ emission separately. The present study builds on the carbon-income function, i.e. the trade-off between environmental degradation (ecological footprint) and economic growth in our study case linear version, while in the energy literature, the cubic form of this intuition on the trade-off between environmental degradation and economic growth is popularised in the literature as the environmental Kuznets curve (EKC) which our study leverages. In addition, it employs robust second-generation panel estimation models such as the ARDL, unit root test, and Bayer-Hanck cointegration testing procedure to ensure greater reliability and validity of findings. Further, at present, very few studies have sought the effect of the determinants of ecological footprint and CO₂ emission together in a single assessment and particularly in the Russian context;

no such studies exist to the best of our knowledge. Thus, the evidence of economic globalisation, technology access, renewable energy, fossil fuel consumption, and institutional quality's impact on ecological footprint and carbon dioxide emission from Russia presents new novelty into the causality direction between these factors for policy and decision-makers in Russia and Europe as a whole.

This remainder of this paper is structured as follows. We provide a review of relevant extant works in the “[Literature review](#)” section. Details of the data, model specification, and approach are explained in the “[Data and empirical technique](#)” section. The “[Result and interpretation](#)” and “[Conclusion and policy implications](#)” sections provide details of the empirical estimations, discussions and conclusion, practical implications, and recommendations for policy, respectively.

Literature review

Much evidence exists in the literature on efforts to understand the economic globalisation-energy-consumption-environmental-consequence linkage. Ecological footprint and carbon emissions have been the focus of many of these examinations that have sought to discern this relationship (Bekun 2022; Akadiri et al. 2021; Ansari et al. 2020; Chen et al. 2018; Egbetokun et al. 2020; Ibrahim 2020; Jebli et al. 2016; Karasoy and Akçay 2019; Liu et al. 2017; Munir and Ameer 2020; Shahbaz et al. 2017).

In a similar vein, other studies have equally investigated economic globalisation, population, renewable and non-renewable (fossil fuels) energy consumption and their link with environmental quality (Dong et al. 2018; Ibrahim 2018; Islam et al. 2017; Sapkota and Bastola 2017; Zoundi 2017). Specifically, Xu et al. (2018), Haseeb et al. (2019), Phong (2019), and Salahuddin et al. (2019) sought to understand the role of economic globalisation and energy consumption on environmental degradation using CO₂ emission as environmental quality determinant. However, it is argued that considering CO₂ alone does not provide the complete reflection on the extent of environmental damage perceived from the factors of environmental quality, e.g. technology, renewable and non-renewable (fossil fuel) energy utilisation, and economic globalisation, among others (Alola and Nwulu 2021; Phong 2019). In that singularly assessing CO₂ emissions alone present part of the total environmental consequence from these indicators (Fakher 2019). Hence, ecological footprint presents a significant additional comprehension of the situation (Galli et al. 2016; Uddin et al. 2019). This argument has been behind the rise in studies employing ecological footprint as an antecedent of environmental quality. For instance, Al-Mulali et al. (2015) studied ecological footprint as a determinant of environmental quality

by observing the effect of urbanisation, energy consumption, and trade. They found these factors to have negative consequences on environmental quality.

In addition, Ozturk et al. (2016) found energy consumption, urbanisation, and tourism income generation to increase ecological footprints. In a comparative analysis of socio-political indicators and ecological footprint, Charfeddine and Mrabet (2017) confirmed the validity of the EKC hypothesis among selected oil production countries. They observed urbanisation, fertility rate, energy consumption, technological development, and life expectancy rates negatively impact ecological footprint. Charfeddine (2017) also found financial development, demand for electricity, urbanisation, and trade openness (economic globalisation) decreased environmental quality. Some examinations from Asian country contexts suggest that most economic expansion indicators increase ecological footprint (Hassan et al. 2019). For instance, Uddin et al. (2019) found a quadratic relationship between ecological footprint and real income in Malaysia, India, Nepal, and Pakistan, while Hassan et al. (2019) confirmed a negative influence of natural resource use per capita on environmental quality.

It is noteworthy that some existing studies highlight positive and negative links between economic development indicators and environmental quality relative to CO₂ emissions. For instance, evidence from high renewable energy-reliant countries suggest that financial development (via market capitalisation) accelerates growth in these countries that have made significant ecological transitions (Cheng et al. 2020). Considering institutional quality, FDI, and demand for energy, Khan et al. (2021) observed a negative effect on environmental quality using a GMM model between 2002 and 2019. Among MENA states, a positive and bidirectional causality is observed between renewable and non-renewable energy and economic expansion (Amri 2017; Kahia et al. 2017), while among European countries in the EU, Balsalobre-Lorente et al. (2018) concluded that renewable energies showed greater positive effect on environmental quality than non-renewable energies (like fossil fuel sources). Shahbaz et al. (2021) examined 34 upper middle income-emerging economies from 1994 to 2015 and pointed out the fact that financial development drives renewable energy consumption, while economic expansion reduces renewable energy consumption.

In retrospect, this finding indicates that reduced renewable energy consumption drives the consumption of unclean energies, which will increase carbon dioxide emissions. Lahiani et al. (2021) studied the role of renewable energy and technological and financial development in the USA and found that, in the short run, only negative effects are observed from financial development and renewable energy, while positive effects are observed in the long run. Renewable energy positively impacts environmental quality.

Recently Alola and Nwulu (2021) sought evidence from Russia on the role of income and economic freedom as environmental quality variables. They conclude that renewable energy sources in Russia have environmental quality benefits. Furthermore, Akadiri et al. (2021) used additional dimensions of economic freedom within the EKC framework to study environmental quality among BRICS bloc of nations, which Russia is a part. The EKC framework was valid in the long run only, and the impact of the blocs energy mix showed undesirable environmental effects.

Despite the existence of these studies indicating the positive impacts of these indicators of environmental quality, other evidence exists in some cases that these indicators increase environmental quality. Sinha et al.'s (Sinha et al. 2018a, 2018b) study on eleven countries showed that economic growth indicators negatively impact environmental degradation. They found that, due to direct investment, inflows and technological growth increased renewable energy and pollution intensified economic growth declines. Aimer (2020) observed a negative association between economic growth and environmental quality. Many other studies (Shittu et al. 2021; Adedoyin et al. 2020, 2021b, 2021c; Ali et al. 2020; Pao and Chen 2019; Sasana and Ghazali 2017) exist with similar conclusions of a negative link between economic development and CO₂ emission.

A rare category of studies is also observed in this review, in that these studies are those that present a neutrality result, suggesting no linkage between environmental quality and its indicators. For instance, Adedoyin et al. (2020), Belaïd and Youssef (2017), Destek and Aslan (2017), and Taghvaei et al. (2017), from Algeria, twelve developing economies, and Iran, respectively, all found no significant association between renewable energy, economic expansion, and environmental quality. Karhan (2019) examined the causality between economic growth indicators and renewable energy and underlines that the role of renewable energy is unstable.

In conclusion, this literature search presents sufficient evidence of significant studies on the role of environmental quality indicators. However, the plethora of inconsistent findings opens the debate that the role of environmental quality indicators is only nascently explored. This review showed three broad categories of observations. Thus, studies found positive associations, negative, and neutral or insignificant findings.

Therefore, to better discern the actual role of the indicators of environmental quality, it is evident that more explorations into this nexus is required, from different and new contexts, indicators, and approaches for a holistic understanding of the phenomenon (Tinta 2022). Environmental and quality ecological systems are a global challenge. Hence, the current evidence presented in this review only supports the fact that only a nascent portion of its scope has been explored, especially in newly industrialised countries like Russia. Russia's

economic prospects indicate a 2.4% growth in 2022 on the back of a solid oil sector. Its formidable macro-economic stabilisation efforts have supported this steady growth despite the COVID-19 crisis that has reduced its economic lots in certain areas. The negative effects from ongoing travel and trade restrictions, learning losses, and reduced migrant flows because of the global pandemic (COVID-19) require aggressive policy attention. Thus, faster economic recovery from the recent crisis will rely on efforts to promote economic diversification and complexity, attract investment inflows, increase economic governance, and reduce ecological footprint (Caglar et al 2022).

However, achieving these fiscal objectives only presents greater threats to environmental quality through economic growth. Russia's carbon intensity, for instance, is twice the global average, and it continues to rely massively on fossil fuel exports, suggesting that greater economic expansion will drive greater carbon intensity. However, Russia is committed to step up cooperation on climate change to improve environmental quality; thus, it is only necessary that experts and researchers alike take pre-emptive steps to facilitate the achievement of the goal of reduced environmental degradation in Russia. This makes this study's context a best fit for an examination of this kind.

To this end, this current research attempts to contribute to the debate of environmental quality and economic expansion by extending existing works on the economic-indicators-environmental quality nexus from the Russian context. Thus, it examines the impact of technological development (access to technology), renewable energy, economic globalisation, fossil fuel use, institutional quality on ecological footprint, and CO₂ emissions.

Data and empirical technique

Data description and model

This study makes use of annual frequency time series data from 1970 to 2020 for the case of the Russian Federation. The outcome variables are CO₂ emissions and ecological footprint, which serve as a proxy for environmental quality. To this end, the variables used for this analysis are renewable energy, access to technological innovation (ICT), fossil fuel (non-renewable energy), economic globalisation, and institutional quality on environmental quality (CO₂ emissions and ecological footprint). The choice of the variables for the present study is in line with previous empirical literature. However, we distinct by holistically combining the variables which draws motivation from the UNSDGs such as an energy variable (SDG-7), economic growth (SDG-8), and climate change mitigation (SDG-13). The definition of these variables, their value, symbol, and sources are in Table 1.

Table 1 Description of studied variables

Variable	Symbol	Description	Source
CO ₂ emission	CO ₂	CO ₂ emission (metric tons per capita)	BP
Renewable energy	REC	Renewable energy consumption (% of total final energy consumption)	BP
Ecological footprint	ECF	Global hectares per capita	GFN
Access to technological innovation	ICT	% of total population with access to mobile communication	WDI
Fossil fuel	NREC	% of total	BP
Economic globalisation	EG	KOF globalisation index	(Gygli et al. 2019)
Institution quality	INSQ	CPIA transparency, accountability, and corruption in the public sector rating	WDI

Sources: Author’s compilation, 2022. Note GFN Global footprint network

$$EG - JOH - BO - BDM = -2 [\ln(\rho EG) + (\rho JOH) + (\rho BO) + (\rho BDM)] \tag{3}$$

The structure of the framework is for both long- and short-run association between the used variables. The uniqueness to this study is in the context of Russia’s economy as well as adding ICT, which has huge impact on the ecological quality index to the existing literature (i.e. this differentiates this study from the existing studies). Therefore, the mathematical equation for the baseline models is fitted as shown in Equation (1) based on the previous work of Agboola et al. (2022), Appiah et al. (2022), and Kamel et al. (2022):

$$\ln I = f(\ln REC, \ln NREC, \ln ICT, \ln EG, \ln SQ) \tag{1}$$

where I denotes the two ecological quality (CO₂ emissions and ecological footprint), while the other variables have been defined in Table 1 where all variables except institution quality are transformed to their natural logarithm.

Econometric method

The short- and long-term coefficients of the variables under consideration were estimated using the novel ARDL simulation model (Pesaran et al. 2001). This model can estimate their long- and short-term associations. It is necessary to run a stationarity test to determine the order of integration among variables before adopting the novel ARDL simulations approach. Considering this, we use Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) standard unit root tests. After determining the stationarity properties of all variables, we proceeded on to the estimation of linear cointegration. This study uses the Bayer and Hanck (2013) combined cointegration test to analyse long-term cointegration among variables. This technique incorporates several individual tests such as Engle and Granger (1987), Johansen (1991), Boswijk (1995), and Banerjee et al. (1998). The Fisher equation is written as follows:

$$EG - JOH = -2 [\ln(\rho EG) + (\rho JOH)] \tag{2}$$

ρBDM , ρBO , ρJOH , and ρEG are the odds of diagnosing individual cointegration tests.

The ARDL bound testing (Pesaran et al. 2001) procedure is considered in this research to assess the robustness of Bayer and Hanck’s (2013) cointegration test. The ARDL bound testing technique can be implemented with the variables at different orders of integration either I(0) or I(1), in contrast to typical cointegration tests. This approach has the advantage of producing effective findings in investigations with small sample sizes. Furthermore, both short- and long-run coefficients can be computed at the same time. To determine ARDL bounds, the following model was created for the two models:

$$\begin{aligned} \text{Model 1 : } \Delta(\ln CO_2)_t = & \theta_0 + \sum_{i=1}^t \theta_1 \Delta \ln CO_{2t-i} + \sum_{i=1}^t \theta_2 \Delta \ln REC_{t-i} \\ & + \sum_{i=1}^t \theta_3 \Delta \ln NREC_{t-i} + \sum_{i=1}^t \theta_4 \Delta \ln ICT_{t-i} \\ & + \sum_{i=1}^t \theta_5 \Delta \ln EG_{t-i} + \sum_{i=1}^t \theta_6 \Delta \ln SQ_{t-i} \tag{4} \\ & + \lambda_1 \ln CO_{2t-1} + \lambda_2 \ln REC_{t-1} \\ & + \lambda_3 \ln NREC_{t-1} + \lambda_4 \ln ICT_{t-1} \\ & + \lambda_5 \ln EG_{t-1} + \lambda_6 \ln SQ_{t-1} + u_t \end{aligned}$$

$$\begin{aligned} \text{Model 2 : } \Delta(\ln ECF)_t = & \theta_0 + \sum_{i=1}^t \theta_1 \Delta \ln ECF_{t-i} + \sum_{i=1}^t \theta_2 \Delta \ln REC_{t-i} \\ & + \sum_{i=1}^t \theta_3 \Delta \ln NREC_{t-i} + \sum_{i=1}^t \theta_4 \Delta \ln ICT_{t-i} \\ & + \sum_{i=1}^t \theta_5 \Delta \ln EG_{t-i} + \sum_{i=1}^t \theta_6 \Delta \ln SQ_{t-i} \tag{5} \\ & + \lambda_1 \ln ECF_{t-1} + \lambda_2 \ln REC_{t-1} \\ & + \lambda_3 \ln NREC_{t-1} + \lambda_4 \ln ICT_{t-1} \\ & + \lambda_5 \ln EG_{t-1} + \lambda_6 \ln SQ_{t-1} + u_t \end{aligned}$$

where t denotes the lag length, $t-i$ is the optimal lags derived applying the Akaike information criteria (AIC), u_t signifies the error term, Δ is the first difference operator, and the long-term association is examined by the λ . In the bound testing strategy, a hypothesis test is necessary to formulate a long-run nexus among the variables under review. The null and alternative hypotheses are no cointegration ($H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$) and evidence of cointegration ($H_{\text{alternative}}: \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq 0$), respectively. In this approach, the derived F statistics are compared to the lower and upper bound critical values. When the estimated F statistics are less than the upper bound value, the null hypothesis is not refuted. The rejection of the null hypothesis occurred whenever the estimated F statistics were greater than the upper bound critical value, suggesting that the variables have a long-term relationship (Abbas et al. 2021; Islam et al. 2017; Bekun et al 2021a).

Result and interpretation

This section focuses on the discussion of empirical outcomes and begins with a preliminary analysis of summary statistics and correlation coefficient analysis. Table 2 presents the basic measure of central tendency and dispersion of the variables under review, where we observe ICT that shows highest average and ecological footprint with least average over the investigated period. We also observed that there are both positive and negative skewed over the examined period. From the outcome, it is observed that CO₂ emission, ecological footprint, non-renewable energy, and institutional quality have positive skewness, while renewable energy, ICT, and economic globalisation have negative skewness. In terms of dataset peaks as reported by Kurtosis, all variables show light tails. The normality analysis test shows that all series are normally distributed, which is desirable as we

Table 2 Basic statistics and correlation matrix analysis

	CO ₂	ECF	REC	NREC	ICT	EG	INSQ
Mean	14.306	-0.044	3.815	4.510	17.684	3.152	2.339
Median	14.299	-0.100	3.871	4.509	18.622	3.214	2.380
Maximum	14.420	0.156	3.997	4.525	20.843	3.390	2.589
Minimum	14.217	-0.198	3.583	4.494	11.24	2.749	2.230
Std. dev.	0.052	0.128	0.148	0.008	3.040	0.190	0.117
Skewness	0.370	0.396	-0.375	0.391	-0.620	-1.014	0.667
Kurtosis	2.499	1.552	1.515	2.477	2.068	2.773	2.545
Jarque-Bera	0.734	2.496	2.539	0.813	2.204	3.820	1.825
Correlation							
CO ₂	1						
ECF	-0.724 ^a	1					
REC	-0.724 ^a	-0.987 ^a	1				
NREC	0.371 ^b	-0.477 ^b	0.545 ^a	1			
ICT	0.690 ^a	0.857 ^a	-0.892 ^a	-0.725 ^a	1		
EG	0.383 ^b	0.326	-0.398 ^b	-0.7181 ^a	0.687 ^a	1	
INSQ	0.691 ^a	0.907 ^a	-0.903 ^a	-0.399 ^a	0.814 ^a	0.382 ^a	1

^a and ^b denote the significance at 1% and 5% level, respectively

Table 3 Unit root test

Variable	ADF test		PP test		KPSS test	
	Level	Difference	Level	Difference	Level	Difference
lnCO ₂	-2.780	-3.998 ^b	-3.372	-4.018 ^a	-0.001	14.245 ^a
lnECF	-1.577	-4.315 ^b	-1.575	-4.315 ^a	0.008	-0.239 ^a
lnREC	-1.682	-2.488 ^a	-1.954	-2.515 ^b	-0.011	4.048 ^a
lnNREC	-4.514	-16.443 ^a	-2.127	-2.262 ^b	-0.001	4.519 ^a
lnICT	-0.988	-4.014 ^a	-0.988	-4.025 ^a	0.972 ^a	12.957 ^a
lnEG	-1.391	-5.010 ^a	-1.364	-5.005 ^a	0.060	2.970 ^a
INSQ	-2.683	-2.265 ^a	-3.204	-3.212 ^a	0.012	2.170 ^a

^a, ^b, and ^c represent statistical significance rejection level at 1%, 5%, and 10%, respectively. The critical values and probability of KPSS test are based on Kwiatkowski-Phillips-Schmidt-Shin (1992). where a= 1% b=5% c=10% respectively

Table 4 Lag length criteria for ARDL model

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	212.211	NA	7.67e-18	-19.543	-19.195	-19.468
1	355.625	177.560c	1.27e-21c	-28.535c	-25.750c	-27.931c

LR sequential modified LR test statistic, FPE final prediction error, AIC Akaike information criterion, SIC Schwarz information criterion, HQ Hannan-Quinn information criterion. c Symbolises lag order selected by the criterion

Table 5 Results of ARDL bound test

	Level of significance	Lower bound I(0)	Upper bound I(1)	Long-run relationship
F-statistics MODEL 1				
4.883	10%	2.26	3.35	Present
	5%	2.62	3.79	
	2.5%	2.96	4.18	
	1%	3.41	4.68	
F-statistics MODEL 2				
4.818	10%	2.26	3.35	Present
	5%	2.62	3.79	
	2.5%	2.96	4.18	
	1%	3.41	4.68	

fail to reject the Jarque-Bera probability. Subsequently, we seek to explore the pair-wise correlation between the study variables as highlighted at the bottom of Table 2. A strong statistically significant level ($p < 0.01$) is seen between renewable energy and CO₂. This suggests that renewable energy helps in improving environmental quality. A positive trend is obtained between the other variables (non-renewable energy, ICT, economic globalisation, and institution quality) and CO₂. However, there is a criticism of Pearson correlation analysis; thus, there is a need for more econometrics analysis, which is sorted in the next step of the section of the current study.

Subsequently, the current study advances by exploring the stationarity properties of the study variables by conducting the ADF and PP unit root test and confirmatory non-unit root test of KPSS, as presented in Table 3. Both stationarity tests and

confirmatory tests of KPSS agree with stationarity after the first difference is performed. Thus, our study dataset passes the test of I~(I) and not I~(2). Thus, the need to examine long-run properties is crucial. Prior to investigation of cointegration analysis, we explore the lag length criterion to enable the best robust model, i.e. the most parsimonious model for this study is the lag one based on the Akaike information criterion (AIC), which is in line with the study structure as reported in Table 4. For long-run analysis, our study uses the novel Bayer and Hanck (2013) combined cointegration test alongside the ARDL bounds test presented in Tables 5 and 6, respectively, for the two models. Each test confirms the long-run equilibrium relationship between study variables over the investigated period for the two models.

The next step is the baseline regression presented in Table 7 that simultaneously highlighted the short- and long-run dynamics of the relationship between renewable energy, non-renewable energy, ICT, economic globalisation, and institutional quality on the two dependent variables (CO₂ emission and ecological footprint) for Russia. The pace of adjustment is captured by the error correction term (ECT). Its calculated value is statistically significant and negative, indicating that the variables under consideration have a long-term association. The ECT-projected value of model 1 is -0.298 which indicates 29.8%, and that of model 2 is -0.820, an indication that 82% of the disequilibrium is rectified in the long run. From the baseline regression, both models 1 and 2 indicate that both renewable energy and economic globalisation have negative impact on the Russian environment for the long-run analysis, while the short run also confirms the same outcome. The only difference

Table 6 Results of Bayer-Hanck (2013) cointegration test

Estimated Model 1: $\ln\text{CO}_2 = f(\ln\text{REC}, \ln\text{NREC}, \ln\text{ICT}, \ln\text{EG}, \text{INSQ})$					
Fisher type	Test statistics	CV@1%	CV@5%	CV@10%	Decision
EG-JOH	32.866 ^a	14.804	9.223	8.040	Cointegrated
EG-J-BO-BDM	32.876 ^a	23.025	14.116	11.647	Cointegrated
Estimated Model 2: $\ln\text{ECF} = f(\ln\text{REC}, \ln\text{NREC}, \ln\text{ICT}, \ln\text{EG}, \text{INSQ})$					
Fisher Type	Test Statistics	CV@1%	CV@5%	CV@10%	Decision
EG-JOH	23.806 ^a	12.012	8.412	6.234	Cointegrated
EG-J-BO-BDM	25.176 ^a	17.567	11.234	8.567	Cointegrated

^a indicates that the results are significant at the 1% level

Table 7 Findings of ARDL model

Variables	MODEL 1	MODEL 2
Cons.	-7.242 ^a	-0.813 ^a
lnREC	-0.883 ^b	-0.555 ^c
ΔlnREC	-1.174 ^b	-0.105 ^c
lnNREC	3.931 ^b	0.614 ^c
ΔlnNREC	1.172	0.504 ^c
lnICT	-0.126 ^a	0.019 ^c
ΔlnICT	0.087 ^b	0.015 ^c
lnEG	-0.414 ^a	-0.169 ^a
ΔlnEG	0.113	-0.040
INSQ	0.229 ^a	0.136 ^a
ΔINSQ	-0.068 ^a	0.111
ECT(-1)	-0.298 ^b	-0.820 ^b

^a, ^b, and ^c denote significance at 1%, 5%, and 10% level, respectively

between the findings of the two models with regard to renewable energy is the scale of the coefficients. This is in line with the expectations of the authors, and it falls within the theoretical assertion which posits that renewable energy sources such as wind, solar, and hydro power tend to reduce high emission and favour the environmental performance of any country. This supports the findings by Gyamfi et al. (2021a), Onifade et al. (2021), Agboola et al. (2022), Gyamfi (2022), and Steve et al. (2021). It is well-known that expanding green energy intake is a powerful force for improving the health of the atmosphere, and it is also worth emphasising that economic globalisation is projected to be a significant source of this trend within the uninvestigated Russian economy. Their short-run analysis also reveals that economic globalisation has positive insignificant relation with CO₂ emission, while with ecological footprint shows negative insignificance. For non-renewable energy, the short run presents a positive significance for both models, which is similar for the long-run analysis for the Russian environment as expected by the study based on the existing literature.

Table 8 Findings of FMOLS

Variables	MODEL 1	MODEL 2
lnREC	-0.5.34 ^b	-0.445 ^c
lnNREC	0.746 ^b	0.524 ^c
lnICT	-0.456 ^a	0.317 ^c
lnEG	-0.618 ^a	-0.460 ^a
INSQ	0.227 ^a	0.331 ^a
R ²	0.667	0.38
Adjusted R ²	0.646	0.629

^a, ^b, and ^c denote significance at 1%, 5%, and 10% level, respectively

This outcome is in line with that of Bekun et al. (2021a) and Bekun et al. (2021c). It appears that the usage of fossil fuel, which includes energy derived from natural gas, coal, and oil, results in a rise in pollutant, which, in turn, adds considerably to environmental deterioration.

Moreover, institution quality has a favourable effect on the environment of Russia as it has positive impact on the environment. The present outcomes of this investigation add to the conclusions of other studies on the potential alleviating influence institution quality on carbon emissions in Russia (Bekun et al. 2021a; Godil et al. 2020; Gyamfi et al. 2021b; Gyamfi et al. 2022a). But the short run reveals that it has negative significance with CO₂ emission but is positively insignificant with ecological footprint. In a nutshell, this finding argues for more focus on the critical roles of integrity, responsibility, and the combat against fraud in the government domain in order to achieve a desired and healthy ecology. To move for an ecologically responsible action plan while simultaneously increasing greener income, which can encourage clean energy consumption within the Russian economy, it would be necessary not only for economic globalisation to start happening, but also for a greater standard of institutional quality to be achieved.

Furthermore, there is a negatively significant connection between ICT and CO₂ emission. This implies that ICT is

Table 9 Residual diagnostic test

	Chi-square (<i>P</i> -value)	Findings
Diagnostic test		
MODEL 1		
Breusch-Godfrey Serial Correlation LM	0.429	No serial correlations
Breusch-Pagan-Godfrey	0.429	No heteroscedasticity
ARCH test	0.296	No heteroscedasticity
Ramsey RESET test	0.406	Model correctly specified
Diagnostic test		
MODEL 2		
Breusch-Godfrey Serial Correlation LM	0.521	No correlations
Breusch-Pagan-Godfrey	0.427	No heteroscedasticity
ARCH test	0.493	No heteroscedasticity
Ramsey RESET test	0.614	Model correctly specified

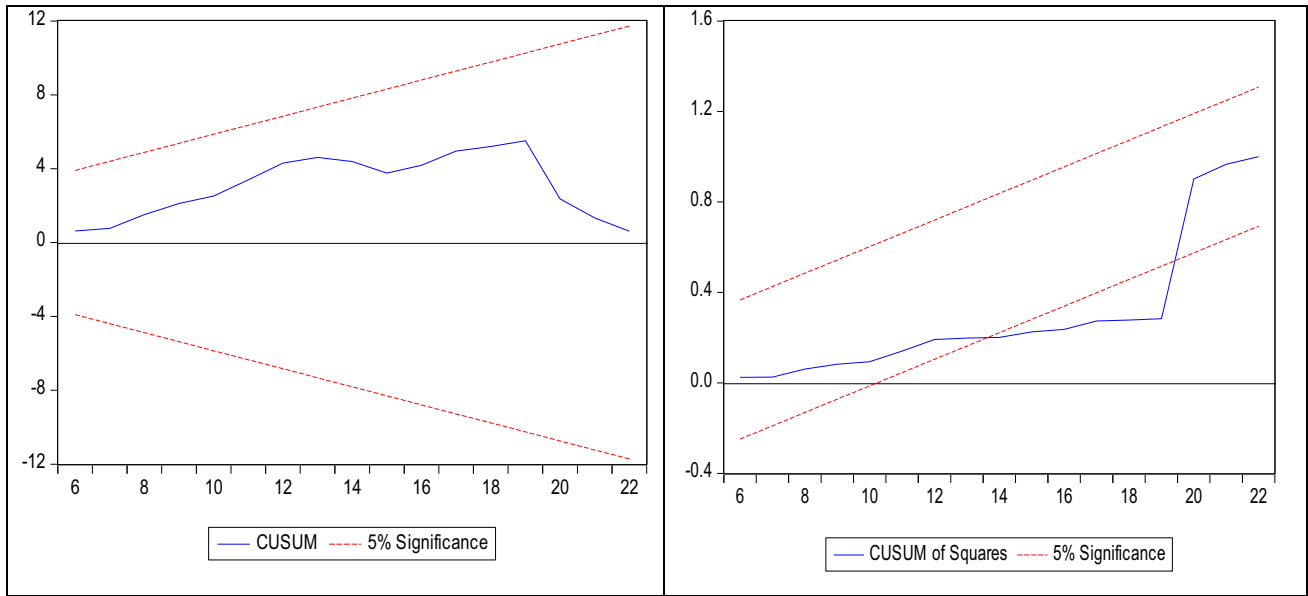


Fig. 3 Model 1: CUSUM and CUSUM square test

vital in decreasing environmental degradation for Russia with respect to CO₂ emission and is in line with Gyamfi et al. (2022b), Bekun et al. (2021b), Al-mulali et al. (2015), and Nguyen et al. (2020). This result suggests that, as duration progresses and the usage of mobile customers in Russia increases, the atmospheric integrity (CO₂) in this nation is deteriorating. As Zhang and Liu (2015) argue, a continual rise in the expansion of the ICT industry is favourably associated with the higher energy usage, which, in turn, results in increased carbon pollution. On the other hand, for model

2, it is observed that there is a positive connection regarding ICT and ecological footprint. This assumption can be supported by an understanding of the positive role played by the supply curve, which is strongly connected to the operations of cutting emissions, demobilisation, and digitalisation, among other things. The significant improvement in ICT in the Russian Federation increases in the operations of inherent commodities, such as e-banking, electronic mail, e-books, e-commerce, and mutually beneficial gatherings (conferences); decreases energy intake; and, as a result,

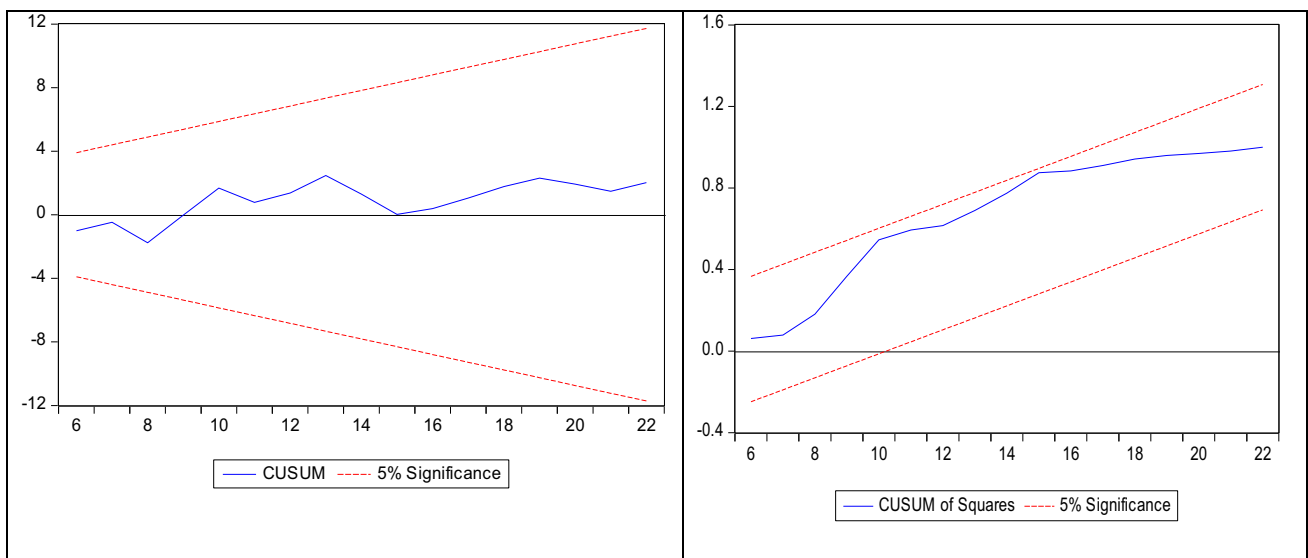


Fig. 4 Model 2: CUSUM and CUSUM square test

lessens air degradation. Initially, the positive alternative impact of reducing ecological footprint outweighed the impending negative impact of the expense and intake impact of reducing ecological footprint. Many academicians agree with this finding, recommending that the ICT-based displacement impact reduces pollution levels considerably by boosting energy savings and effectiveness, as well as stimulating technical growth and resource competency in their respective manufacturing industries (Apergis 2016; Dogan and Seker 2016; Özokcu and Özdemir 2017). However, the short-run connection reveals that both models have a positive connection with emissions.

Moreover, by utilizing fully modified ordinal least square (FMOLS) as robustness check in Table 8. It was observed that all the outcome are in line with the already ARDL technique used indication that, a percentage change in non-renewable energy and institutional quality positively increases both ecological footprint and CO₂ emission whiles renewable energy, ICT and economic globalization decreases both dependent variables in the long run.

Table 9 outlines the study diagnostic tests where all test satisfactorily pass all model tests, such as serial correlation, heteroscedasticity, and ARCH test and Ramsey model specification test. The stability of the fitted model is presented by the CUSUM and CUSUMsq plots that satisfactorily pass the 5% boundary, suggesting that the model is stable and fit for policy crafting (Figs. 3 and 4).

Conclusion and policy implications

The perpetual need for economic growth driven by energy consumption driven from fossil fuel has its implication on environment. This study focuses on the mitigating role of renewables and institutional quality for the case of the Russian Federation in a carbon-income environment with two fitted models on two key pollutants, namely carbon dioxide emission and ecological footprint. The current study leverages on novel combined Bayer and Hanck and Pesaran ARDL bound testing approach to explore the dynamic relationship between economic growth, economic globalisation, access to technological innovation, and the pertinent role of institutional quality. Empirical evidence traces equilibrium relationship between the study's investigated variables, suggesting a long-run bond between the highlighted variables. Key findings from the study include the validation of the economic growth energy-induced emission for the Russian Federation. This suggest that energy mix in Russia stems from fossil fuel which is a root cause of emission levels, while increased anthropogenic human economic activities that are not green worsen environmental quality, as revealed by our study. To this

end, from a policy perspective, there is urgent need for decision-makers in Russia to intensify policy strategies that decouple economic growth from emission increase. Strategies such as adoption of clean technologies will help achieve this position and the need for shift to cleaner energy alternatives for cleaner ecological and blue skies of Russia. Investments in renewable energy infrastructure and research and development (R&D) will foster sustainable economic growth without compromise for the quality of the environment. Feedback from interaction of access to technological innovation and institutional apparatus shows strong strength to improve the quality of the environment. Thus, government administrators are encouraged to tighten institutional apparatus in terms of environmental regulations to attain the adverse effect of weak institutional laws and strategies.

Authorities and environmentalists should use a phase-by-phase approach to solve their problems. As a starting point, the centralised government must make it simple for small- and medium-sized industrial enterprises to obtain financial resources, with the goal of encouraging them to use ICT-based outlines in their readily available production methods. At this time, the borrowing costs on funds loaned will vary depending on the amount of borrowed capital and the level of environmental damage caused by the economic firm. Organisations with high levels of ecological pollution will be compelled to pay a high rate of credit, while enterprises with low levels of carbon pollution will be obliged to pay a lower rate of return. As a result, this strategy approach will encourage cleaner and more contemporary businesses to expand their new innovative possibilities, while simultaneously discouraging polluting institutions from consuming non-renewable energy inputs.

The present study is limited by scope for the Russian Federation; thus, there is a need to explore the variables highlighted in this study for other economies using disaggregated data to either refute or agree with the current findings.

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Author contribution Festus Victor Bekun was responsible for the conceptualization, methodology, and writing of the “Result and interpretation” section. Bright Akwasi Gyamfi was responsible for formal analysis and writing of the “Literature review” section. Divine Q. Agozie managed the data curation and preliminary analysis. Phillips O. Agboola was responsible for proofreading and manuscript editing. The author(s) read and approved the final manuscript.

Data availability The data for this present study are sourced from World Development Indicators (WDI) available at www.data.worldbank.org.

Declarations

Ethical approval The authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and gave consent for submission and subsequent publication of the manuscript.

Consent to participate Not applicable.

Consent to publish Applicable.

Competing interests The authors declare no competing interests.

References

- Abbas S, Kousar S, Pervaiz A (2021) Effects of energy consumption and ecological footprint on CO₂ emissions: empirical evidence from Pakistan. *Environ Dev Sustain* 23(9):13364–13381
- Adedoyin FF, Gumede MI, Bekun FV, Etokakpan MU, Balsalobre-Lorente D (2020) Modelling coal rent, economic growth and CO₂ emissions: does regulatory quality matter in BRICS economies? *Sci Total Environ* 710:136284
- Adedoyin FF, Agboola PO, Ozturk I, Bekun FV, Agboola MO (2021b) Environmental consequences of economic complexities in the EU amidst a booming tourism industry: accounting for the role of brexit and other crisis events. *J Clean Prod* 305:127117
- Adedoyin FF, Ozturk I, Bekun FV, Agboola PO, Agboola MO (2021c) Renewable and non-renewable energy policy simulations for abating emissions in a complex economy: evidence from the novel dynamic ARDL. *Renew Energy* 177:1408–1420
- Agboola PO, Hossain M, Gyamfi BA, Bekun FV (2022) Environmental consequences of foreign direct investment influx and conventional energy consumption: evidence from dynamic ARDL simulation for Turkey. *Environ Sci Pollut Res*, 1–14
- Aimer NM (2020) Renewable energy consumption, financial development and economic growth: evidence from panel data for the Middle East and North African countries. *Econ Bull* 40:2058–2072 <http://www.accessecon.com/Pubs/EB/2020/Volume40/EB20-V40-I3-P180.pdf>
- Akadiri SS, Alola AA, Usman O (2021) Energy mix outlook and the EKC hypothesis in BRICS countries: a perspective of economic freedom vs. economic growth. *Environ Sci Pollut Res* 28(7):8922–8926
- Ali Q, Ali R, Saadia N, Sahrish S, Iqbal MTK (2020) Potential of renewable energy, agriculture, and financial sector for the economic growth: evidence from politically free, partly free and not free countries *Renew Energy*, 162:934–947. [10.1016/j.renene.2020.08.055](https://doi.org/10.1016/j.renene.2020.08.055)
- Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. *Energy* 84:382–389. <https://doi.org/10.1016/j.energy.2015.03.004>
- Al-Mulali U, Weng-Wai C, Sheau-Ting L, Mohammed AH (2015) Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. *Ecol Ind* 48:315–323
- Alola AA, Nwulu N (2021) Income vs. economic freedom threshold and energy utilities in Russia: an environmental quality variability? *Environ Sci Pollut Res* 28(26):35297–35304
- Alola AA, Bekun FV, Sarkodie SA (2019) Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *Sci Total Environ* 685:702–770
- Amri F (2017) Intercourse across economic growth, trade, and renewable energy consumption in developing and developed countries. *Renew Sustain Energy Rev* 69:527–534. <https://doi.org/10.1016/j.rser.2016.11.230>
- Ansari M, Haider S, Khan N (2020) Does trade openness affects global carbon dioxide emissions: evidence from the top CO₂ emitters. *Manage Environ Qual* 31(1):32–53. <https://doi.org/10.1108/MEQ-12-2018-0205>
- Apergis N (2016) Environmental Kuznets curves: new evidence on both panel and country-level CO₂ emissions. *Energy Econ* 54:263–271
- Appiah M, Gyamfi BA, Adebayo TS, Bekun FV (2022) Do financial development, foreign direct investment, and economic growth enhance industrial development? Fresh evidence from Sub-Saharan African countries. *Portuguese Econ J*, 1–25
- Balsalobre-Lorente D, Shahbaz M, Roubaud D, Farhani S (2018) How economic growth, renewable electricity, and natural resources contribute to CO₂ emissions? *Energy Policy* 113:356–367. <https://doi.org/10.1016/j.enpol.2017.10.050>
- Banerjee A, Dolado J, Mestre R (1998) Error-correction mechanism tests for cointegration single-equation framework. *J Time Ser Anal* 19(3):267–283
- Bayer C, Hanck C (2013) Combining non-cointegration tests. *J Time Ser Anal* 34(1):83–95. <https://doi.org/10.1111/j.1467-9892.2012.00814.x>
- Bekun FV (2022) Mitigating emissions in India: accounting for the role of real income, renewable energy consumption and investment in energy. *Intl J Energy Econ Policy* 12(1):188–192
- Bekun FV, Gyamfi BA, Onifade ST, Agboola MO (2021a) Beyond the environmental Kuznets curve in E7 economies: accounting for the combined impacts of institutional quality and renewables. *J Clean Prod* 314:127924
- Bekun FV, Alola AA, Gyamfi BA, Ampomah AB (2021b) The environmental aspects of conventional and clean energy policy in sub-Saharan Africa: is N-shaped hypothesis valid? *Environ Sci Pollut Res* 28(47):66695–66708
- Bekun FV, Alola AA, Gyamfi BA, Yaw SS (2021c) The relevance of EKC hypothesis in energy intensity real-output trade-off for sustainable environment in EU-27. *Environ Sci Pollut Res* 28(37):51137–51148
- Belaïd F, Youssef M (2017) Environmental degradation, renewable and non-renewable electricity consumption, and economic growth: assessing the evidence from Algeria. *Energy Policy* 102:277–287. <https://doi.org/10.1016/j.enpol.2016.12.012>
- Bello, M. O., Solarin, S.A. and Yen, Y.Y. (2018). The impact of electricity consumption on CO₂ emissions, carbon footprint, water footprint and ecological footprint: the role of hydropower in an emerging economy, *J Environ Manage*, Vol. 219, pp. 218–230, doi: [10.1016/j.jenvman.2018.04.101](https://doi.org/10.1016/j.jenvman.2018.04.101)
- Boswijk HP (1995) Efficient inference on cointegration parameters in structural error correction models. *J Econometr* 69(1):133–158
- BP, (2020). BP Statistical Review of World Energy 2020. <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energyeconomics/statistical-review/bp-stats-review-2020-full-report.pdf>.
- Caglar AE, Zafar MW, Bekun FV, Mert M (2022) Determinants of CO₂ emissions in the BRICS economies: The role of partnerships investment in energy and economic complexity. *Sustainable Energy Technol Assess* 51:101907
- Charfeddine L (2017) The impact of energy consumption and economic development on ecological footprint and CO₂ emissions: evidence from a Markov switching equilibrium correction model. *Energy Econ* 65:355–374. <https://doi.org/10.1016/j.eneco.2017.05.009>
- Charfeddine L, Mrabet Z (2017) The impact of economic development and social-political factors on ecological footprint: a panel data

- analysis for 15 MENA countries. *Renew Sustain Energy Rev* 76:138–154. <https://doi.org/10.1016/j.rser.2017.03.031>
- Chen Y, Wang Z, Zhong Z (2018) CO₂ emissions, economic growth, renewable and nonrenewable energy production and foreign trade in China. *Renew Energy* 131:208–216. <https://doi.org/10.1016/j.renene.2018.07.047>
- Cheng CY, Chien MS, Lee CC (2020) ICT diffusion, financial development, and economic growth: an international cross-country analysis. *Econ Model* 94(C):662–671. <https://doi.org/10.1016/j.econmod.2020.02.008>
- Destek MA, Aslan A (2017) Renewable and non-renewable energy consumption and economic growth in emerging economies: evidence from bootstrap panel causality. *Renew Energy* 111:757–763. <https://doi.org/10.1016/j.renene.2017.05.008>
- Destek MA, Sarkodie SA (2019) Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. *Sci Total Environ* 650:2483–2489
- Dogan E, Seker F (2016) Determinants of CO₂ emissions in the European Union: the role of renewable and non-renewable energy. *Renew Energy* 94:429–439
- Dong K, Hochman G, Zhang Y, Sun R, Li H, Liao H (2018) CO₂ emissions, economic and population growth, and renewable energy: empirical evidence across regions. *Energy Econ* 75:180–192. <https://doi.org/10.1016/j.eneco.2018.08.017>
- Egbetokun S, Osabuohien E, Akinbobola T, Onanuga O, Gershon O, Okafor V (2020) Environmental pollution, economic growth and institutional quality: exploring the nexus in Nigeria. *Manage Environ Qual* 31(1):18–31. <https://doi.org/10.1108/MEQ-02-2019-0050>
- Engle RF, Granger CW (1987) Co-integration and error correction: representation, estimation, and testing. *Econometrica: J Econometr Soc*:251–276
- Fakher HA (2019) Investigating the determinant factors of environmental quality (based on ecological carbon footprint index). *Environ Sci Pollut Res* 26(10):10276–10291
- Galli A, Giampietro M, Goldfinger S, Lazarus E, Lin D, Saltelli A, Muller F (2016) Questioning the ecological footprint. *Ecological Indicators* 69:224–232. <https://doi.org/10.1016/j.ecolind.2016.04.014>
- Global Footprint Network (2012). Ecological footprint”, available at: <https://www.footprintnetwork.org/our-work/ecological-footprint>
- Global Footprint Network (2020). Global Footprint Network. <https://www.footprintnetwork.org/our-work/ecological-footprint>
- Godil DI, Sharif A, Agha H, Jermisittiparsert K (2020) The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO₂ emission in Pakistan: new insights from QARDL approach. *Environ Sci Pollut Res* 27(19):24190–24200
- Gyamfi BA (2022) Consumption-based carbon emission and foreign direct investment in oil-producing Sub-Saharan African countries: the role of natural resources and urbanization. *Environ Sci Pollut Res* 29(9):13154–13166
- Gyamfi BA, Adedoyin FF, Bein MA, Bekun FV, Agozie DQ (2021a) The anthropogenic consequences of energy consumption in E7 economies: juxtaposing roles of renewable, coal, nuclear, oil and gas energy: evidence from panel quantile method. *J Clean Prod* 295:126373
- Gyamfi BA, Adedoyin FF, Bein MA, Bekun FV (2021b) Environmental implications of N-shaped environmental Kuznets curve for E7 countries. *Environ Sci Pollut Res* 28(25):33072–33082
- Gyamfi BA, Bein MA, Adedoyin FF, Bekun FV (2022a) How does energy investment affect the energy utilization-growth-tourism nexus? Evidence from E7 Countries. *Energy Environ* 33(2):354–376
- Gyamfi BA, Onifade ST, Nwani C, Bekun FV (2022b) Accounting for the combined impacts of natural resources rent, income level, and energy consumption on environmental quality of G7 economies: a panel quantile regression approach. *Environ Sci Pollut Res* 29(2):2806–2818
- Gygli S, Haelg F, Potrafke N, Sturm JE (2019) The KOF globalisation index—revisited. *Rev Intl Org* 14(3):543–574
- Haseeb A, Xia E, Saud S, Ahmad A, Khurshid H (2019) Does information and communication technologies improve environmental quality in the era of globalization. *Empirical Anal Environ Sci Pollut Res* 26(9):8594–8608. <https://doi.org/10.1007/s11356-019-04296-x>
- Hassan ST, Xia E, Khan NH, Shah SMA (2019) Economic growth, natural resources and ecological footprints: evidence from Pakistan. *Environ Sci Pollut Res* 26(3):2929–2938. <https://doi.org/10.1007/s11356-018-3803-3>
- Ibrahiem DM (2015) Evaluating cost of air pollution from using fossil fuels in some industries in Egypt. *Advances in Management and Applied Economics*, No. 1, pp. 27–39
- Ibrahiem DM (2018) Road energy consumption, economic growth, population and urbanization in Egypt: cointegration and causality analysis. *Environ Dev Sustain* 20(3):1053–1066. <https://doi.org/10.1007/s10668-017-9922-z>
- Ibrahiem DM (2020) Do technological innovations and financial development improve environmental quality in Egypt? *Environ Sci Pollut Res* 27(10):10869–10881. <https://doi.org/10.1007/s11356-019-07585-7>
- Ibrahiem DM, Hanafy SA (2020) Dynamic linkages amongst ecological footprints, fossil fuel energy consumption and globalization: an empirical analysis. *Management of Environmental Quality: An International Journal* Vol. 31 No. 6, 2020 pp. 1549–1568 © Emerald Publishing Limited 1477-7835 10.1108/MEQ-02-2020-0029
- IEA (2021). CO₂ emissions – Global Energy Review 2021 – Analysis . Available at <https://www.iea.org/reports/global-energy-review-2021/co2-emissions>
- IRENA (International Renewable Energy Agency) (2018), *Renewable Energy Outlook: Egypt*, Abu Dhabi.
- Islam R, Ghani ABA, Mahyudin E (2017) Carbon dioxide emission, energy consumption, economic growth, population, poverty and forest area: evidence from panel data analysis. *Intl J Energy Econ Policy* 7(4):99–106
- Jebli MB, Youssef SB, Ozturk I (2016) Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. *Ecol Ind* 60:824–831. <https://doi.org/10.1016/j.ecolind.2015.08.031>
- Johansen S (1991) Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica: J Econometr Soc*, 1551–1580
- Kahia M, Aissa MSB, Lanouar C (2017) Renewable and non-renewable energy use-economic growth nexus: the case of MENA net oil importing countries. *Renew Sustain Energy Rev* 71:127–140. <https://doi.org/10.1016/j.rser.2017.01.010>
- Kamel S, Agyekum EB, Adebayo TS, Taha IB, Gyamfi BA, Yaqoob SJ (2022) Comparative analysis of Rankine cycle linear Fresnel reflector and solar tower plant technologies: techno-economic analysis for Ethiopia. *Sustainability* 14(3):1677
- Karasoy A, Akçay S (2019) Effects of renewable energy consumption and trade on environmental pollution: the Turkish case. *Manage Environ Qual* 30(2):437–455. <https://doi.org/10.1108/MEQ-04-2018-0081>
- Karhan G (2019) Does renewable energy increase growth? Evidence from EU-19 countries. *Int J Energy Econ Policy* 9(2):341–346. 10.32479/ijeep.7589
- Khan H, Itbar K, Truong TB (2020) The heterogeneity of renewable energy consumption, carbon emission and financial development in the globe: a panel quantile regression approach. *Energy Rep* 6:859–867. <https://doi.org/10.1016/j.egy.2020.04.002>
- Khan I, Han L, Khan H, Oanh L (2021) Analyzing renewable and nonrenewable energy sources for environmental quality:

- dynamic investigation in developing countries. *Math Probl Eng* 3399049:1–12. <https://doi.org/10.1155/2021/3399049>
- Lahiani A, Meftteh-Wali S, Shahbaz M, Vo XV (2021) Does financial development influence renewable energy consumption to achieve carbon neutrality in the USA? *Energy Policy* 158:112524. <https://doi.org/10.1016/j.enpol.2021.112524>
- Laurent A, Olsen SI, Hauschild MZ (2012) Limitations of carbon footprint as indicator of environmental sustainability. *Environ Sci Technol* 46(7):4100–4108
- Ling CH, Ahmed K, Muhamad RB, Shahbaz M (2015) Decomposing the trade-environment nexus for Malaysia: what do the technique, scale, composition, and comparative advantage effect indicate? *Environ Sci Pollut Res* 22(24):20131–20142
- Liu X, Zhang S, Bae J (2017) The impact of renewable energy and agriculture on carbon dioxide emissions: investigating the environmental Kuznets curve in four selected ASEAN countries. *J Clean Prod* 164:1239–1247. <https://doi.org/10.1016/j.jclepro.2017.07.086>
- Lu J, Imran M, Haseeb A, Saud S, Wu M, Siddiqui F, Khan MJ (2021a) Nexus between financial development, FDI, globalization, energy consumption and environment: evidence from BRI countries. *Front Energy Res* 9:707590. <https://doi.org/10.3389/fenrg.2021.707590>
- Lu J, Imran M, Haseeb A, Saud S, Wu M, Siddiqui F, Khan MJ (2021b) Nexus between financial development, FDI, globalization, energy consumption and environment: evidence from BRI countries. *Front Energy Res* 9:707590. <https://doi.org/10.3389/fenrg.2021.707590>
- Mehmood U, Tariq S (2020) Globalization and CO₂ emissions nexus: evidence from the EKC hypothesis in South Asian countries. *Environ Sci Pollut Res* 27:37044–37056. <https://doi.org/10.1007/s11356-020-09774-1/Published>
- Munir K, Ameer A (2020) Nonlinear effect of FDI, economic growth, and industrialization on environmental quality: evidence from Pakistan. *Manage Environ Qual* 31(1):223–234. <https://doi.org/10.1108/MEQ-10-2018-0186>
- Najan A, Runnalls D, Halle M (2007) Environment and globalization: five propositions. International Institute for Sustainable Development
- Nguyen TT, Pham TAT, Tram HTX (2020) Role of information and communication technologies and innovation in driving carbon emissions and economic growth in selected G-20 countries. *J Environ Manage* 261:110162
- OECD I et al (2020). Revenue statistics in Latin America and the Caribbean 2020, OECD Publishing, Paris. the OECD Centre for Tax Policy and Administration, the OECD Development Centre, the Inter-American Center of Tax Administrations (CIAT), the Economic Commission for Latin America and the Caribbean (ECLAC) and the Inter-American Development Bank (IDB)
- Ohajionu UC, Gyamfi BA, Haseki MI, Bekun FV (2022) Assessing the linkage between energy consumption, financial development, tourism and environment: evidence from method of moments quantile regression. *Environ Sci Pollut Res*, 1-15
- Onifade ST, Gyamfi BA, Haouas I, Bekun FV (2021) Re-examining the roles of economic globalization and natural resources consequences on environmental degradation in E7 economies: are human capital and urbanization essential components? *Resour Policy* 74:102435
- Özokcu S, Özdemir Ö (2017) Economic growth, energy, and environmental Kuznets curve. *Renew Sustain Energy Rev* 72:639–647
- Ozturk I, Al-Mulali U, Saboori B (2016) Investigating the environmental Kuznets curve hypothesis: the role of tourism and ecological footprint. *Environ Sci Pollut Res* 23(2):1916–1928. <https://doi.org/10.1007/s11356-015-5447-x>
- Pata UK, Caglar AE (2021) Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: evidence from augmented ARDL approach with a structural break. *Energy* 216:119220
- Pao HT, Chen CC (2019) Decoupling strategies: CO₂ emissions, energy resources, and economic growth in the Group of Twenty. *J Clean Prod* 206:907–919. <https://doi.org/10.1016/j.jclepro.2018.09.190>
- Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. *J Appl Econometr* 16(3):289–326
- Phong LH (2019) Globalization, Financial development, and environmental degradation in the presence of environmental Kuznets curve: evidence from ASEAN 5 countries. *Intl J Energy Econ Policy* 9(2):40–45. <https://doi.org/10.32479/ijeeep.7290>
- Rashid A, Irum A, Ali Malik I, Ashraf A, Liu R, Liu G, Yousaf B (2018) Ecological footprint of Rawalpindi: Pakistan's first footprint analysis from urbanization perspective. *J Clean Prod* 170:362–368. <https://doi.org/10.1016/j.jclepro.2017.09.186>
- Rehman A, Ma H, Ahmad M, Ozturk I, İşık C (2021) Estimating the connection of information technology, foreign direct investment, trade, renewable energy and economic progress in Pakistan: evidence from ARDL approach and cointegrating regression analysis. *Environ Sci Pollut Res*:1–13. [10.1007/s11356-021-14303-9](https://doi.org/10.1007/s11356-021-14303-9)
- Rudolph A, Figge L (2017) Determinants of ecological footprints: what is the role of globalization? *Ecol Ind* 81:348–361. <https://doi.org/10.1016/j.ecoliind.2017.04.060>
- Salahuddin M, Ali I, Vink N, Gow J (2019) The effects of urbanization and globalization on CO₂ emissions: evidence from the Sub-Saharan Africa (SSA) countries. *Environ Sci Pollut Res* 26:2699–2709. <https://doi.org/10.1007/s11356-018-3790-4>
- Sapkota P, Bastola U (2017) Foreign direct investment, income, and environmental pollution in developing countries: panel data analysis of Latin America. *Energy Economics* 64:206–212. <https://doi.org/10.1016/j.eneco.2017.04.001>
- Sasana H, Ghozali I (2017) The impact of fossil and renewable energy consumption on the economic growth in Brazil, Russia, India, China, and South Africa. *Int J Energy Econ Policy* 7(3):194–200. <https://www.econjournals.com/index.php/ijeeep/article/view/4926>
- Saud S, Chen S, Haseeb A (2020) The role of financial development and globalization in the environment: accounting ecological footprint indicators for selected one-belt-one-road initiative countries. *J Clean Prod* 250:119518
- Shahbaz M, Bhattacharya M, Ahmed K (2015) Growth-globalization-emissions nexus: the role of population in Australia, Department of Economics Discussion Paper Series (Discussion Paper 23-15), Monash University
- Shahbaz M, Khan S, Ali A, Bhattacharya M (2017) The impact of globalization on CO₂ emissions in China. *Singapore Econ Rev* 62(4):929–957
- Shahbaz M, Mahalik M, Shahzad J, Hammoudeh S (2019) Testing the globalization driven carbon emissions hypothesis: international evidence”, *Intl Econ*, Vol. 158, pp. 25-38, doi: <https://doi.org/10.1016/j.inteco.2019.02.002>.
- Shahbaz M, Topcu BA, Sarigül SS, Vo XV (2021) The effect of financial development on renewable energy demand: the case of developing countries. *Renew Energy* 178:1370–1380. <https://doi.org/10.1016/j.renene.2021.06.121>
- Shittu W, Adedoyin FF, Shah MI, Musibau HO (2021) An investigation of the nexus between natural resources, environmental performance, energy security and environmental degradation: evidence from Asia. *Resour Policy* 73:102227
- Sinha A, Shahbaz M, Sengupta T (2018a) Renewable energy policies and contradictions in causality: a case of Next 11 countries. *J Clean Prod* 197:73–84. <https://doi.org/10.1016/j.jclepro.2018.06.219>
- Sinha A, Shahbaz M, Sengupta T (2018b) Renewable energy policies and contradictions in causality: a case of Next 11 countries. *J*

- Clean Prod 197:73–84. <https://doi.org/10.1016/j.jclepro.2018.06.219>
- Steve YS, Murad AB, Gyamfi BA, Bekun FV, Uzuner G (2021) Renewable energy consumption a panacea for sustainable economic growth: panel causality analysis for African blocs. *Intl J Green Energy*, 1–10
- Taghvaei VM, Shirazi JK, Boutabba MA, Aloo AS (2017) Economic growth and renewable energy in Iran. *Econ Rev* 21(4):789–808. <https://doi.org/10.22059/ier.2017.64081>
- Tinta AA (2021) Financial development, ecological transition, and economic growth in Sub-Saharan African countries: the performing role of the quality of institutions and human capital. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-021-18104-y>
- Tinta AA (2022) Financial development, ecological transition, and economic growth in Sub-Saharan African countries: the performing role of the quality of institutions and human capital. *Environ Sci Pollut Res* 29:37617–37632. <https://doi.org/10.1007/s11356-021-18104-y>
- Tinta AA, Ouedraogo S, Thiombiano N (2021) Nexus between economic growth, financial development, and energy consumption in Sub-Saharan African countries: a dynamic approach. *Nat Res Forum*:1–14. <https://doi.org/10.1111/1477-8947.12240>
- Torrás M, Moskalev S, Hazy J, Ashley A (2011) An econometric analysis of ecological footprint determinants: implications for sustainability. *Intl J Sustain Soc* 3(3):258–275. <https://doi.org/10.1504/IJSSOC.2011.041267>
- Uddin GA, Alam K, Gow J (2019) Ecological and economic growth interdependency in the Asian economies: an empirical analysis. *Environ Sci Pollut Res* 26:13159–13172. <https://doi.org/10.1007/s11356-019-04791-1>
- Wandeda DO, Masai W, Myandemo SM (2021) Institutional quality and economic growth: evidence from Sub-Saharan Africa countries. *Afr J Econ Rev* 9(4):106–112
- Wang Q, Dong Z (2021a) Does financial development promote renewable energy? Evidence of G20 economies. *Environ Sci Pollut Res Int*. <https://doi.org/10.1007/s11356-021-15597-5>
- Wang Q, Dong Z (2021b) Does financial development promote renewable energy? Evidence of G20 economies. *Environ Sci Pollut Res Int*. <https://doi.org/10.1007/s11356-021-15597-5>
- World Bank (2020) World Bank. *World Dev. Indic.* (<http://databank.worldbank.org/data/reports.aspx?Source=World%20Development%20Indicators#>)
- WWF (2018) Living Planet Report 2018: Aiming Higher, in Grooten, M. and Almond, R.E.A. (Eds), WWF, Gland.
- WWF Report (2018) Russia's biocapacity and ecological footprint: nowcasting and forecasting from the National Footprint Accounts
- Xu Z, Baloch MA, Danish, Meng F, Zhang J, Mahmood Z (2018) Nexus between financial development and CO2 emissions in Saudi Arabia: analyzing the role of globalization. *Environ Sci Pollut Res* 25:28378–28390. <https://doi.org/10.1007/s11356-018-2876-3>
- Yin Y, Xiong X, Hussain J (2021) The role of physical and human capital in FDI-pollution-growth nexus in countries with different income groups: a simultaneity modeling analysis. *Environ Impact Assess Rev* 91:106664. <https://doi.org/10.1016/j.eiar.2021.106664>
- Zhang C, Liu C (2015) The impact of ICT industry on CO2 emissions: a regional analysis in China. *Renew Sustain Energy Rev* 44:12–19
- Zoundi Z (2017) CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renew Sustain Energy Rev* 72:1067–1075. <https://doi.org/10.1016/j.rser.2016.10.018>

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