Environmental Science and Pollution Research (2022) 29:24348–24361
https://doi.org/10.1007/s11356-022-18829-4

SHORT RESEARCH AND DISCUSSION ARTICLE

Synthesizing urbanization and carbon emissions in Africa: how viable is environmental sustainability amid the quest for economic growth in a globalized world?

Savaş Erdoğan[1] · Stephen Taiwo Onifade[1,2] · Mehmet Altuntaş[3] · Festus Victor Bekun[4,5]

Received: 23 November 2021 / Accepted: 20 January 2022 / Published online: 5 February 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
Global emission statistics show that Africa is among the least carbon-emitting continents. However, the rising drive for economic growth amid urbanization and globalization in recent years has continued to attract the attention of policymakers to the attendant potential environmental risks. Hence, using robust empirical techniques, this study examines the impacts of increasing urbanization alongside its interactions with energy portfolios on environmental prospects of 15 selected African countries including the most urbanized and leading oil producers in the continent of Africa. The results of the analysis produced insightful implications for achieving both environmental and economic sustainability for the understudied countries. Firstly, the trio of urbanization, economic globalization, and income levels aggravate environmental degradation among these countries as they were found to be essential drivers of carbon emission levels over the understudied period (1990–2015). Secondly, while urbanization significantly poses threat to environmental sustainability, the evidence obtained regarding its interaction with energy portfolios of the understudied countries differs. The significant detrimental environmental impacts of the interaction between urbanization and energy portfolios were only confirmed in the context of fossil energy consumption among the countries, while renewables exist as a significant decarbonization channel within the framework of the increasing level of urbanization among the countries. Thirdly, the study upholds the EKC conjecture. Hence, policymakers and authorities in Africa should capitalize on maximizing the benefits of the huge renewable resource potentials on the continent through adequate investments in green energy technologies for urban infrastructures toward the realization of sustainable development goals (SDGs 11 and 13).

Keywords Africa · Urbanization · Energy use · CO_2 emissions · Globalization · Economic growth

JEL Classification O44 · O55 · O18 · Q43 · R11

Responsible Editor: Roula Inglesi-Lotz

✉ Stephen Taiwo Onifade
stephentaiwo.onifade@lisansustu.selcuk.edu.tr

Savaş Erdoğan
serdogan@selcuk.edu.tr

Mehmet Altuntaş
mehmet.altuntas@nisantasi.edu.tr

Festus Victor Bekun
fbekun@gelisim.edu.tr

[1] Faculty of Economics and Administrative Sciences, Department of Economics, Selcuk University, Konya, Turkey

[2] Faculty of Economics and Administrative Sciences, Department of International Trade and Logistics, KTO Karatay University, Konya, Turkey

[3] Faculty of Economics, Administrative and Social Sciences, Department of Economics, Nisantasi University, Istanbul, Turkey

[4] Faculty of Economics Administrative and Social Sciences, Istanbul Gelisim University, Istanbul, Turkey

[5] Department of Economic Security, South Ural State University, 76, Lenin Aven., 454080 Chelyabinsk, Russia

Introduction

The call for decarbonization is becoming a matter of global interest among all and sundry in the international community. The reason is not far-fetched from the intensifying needs to address how the world can avert the challenges of climate change and other environmental degradations. The consequences of the failure to take urgent and important steps in this direction have been described to be tantamount to calling for a catastrophic climate disaster (UNEP 2021; IPCC 2021). While the fight for a carbon–neutral world is a global matter, the collective efforts of individual nations would be a very crucial aspect of achieving the desired success of the decarbonization campaign.

Energy use has been on the increase in Africa in the last couple of decades even as most of the nations are rapidly urbanizing amid the fast-growing population that has seen many projecting the continent to become the future most populous continent due to high birth rates with over 1.136 billion people inhabiting Sub-Saharan Africa countries alone as of 2020 (WDI 2020; Engelman 2016). Although rapid urbanization may have its advantages in Africa, there are potential environmental challenges from this development as some studies have pointed out the risks of population growth and climate change in Africa among other issues (Ahmadalipour et al. 2019). The International Energy Agency has noted that the African continent is more vulnerable to the impact of global warming, climate variability, and other environmental challenges compared to other continents despite being among the least contributors to global carbon emission (IEA 2020). Besides, it has also been estimated that there could be a shrink in Africa's gross domestic product (GDP) per capita growth to the tune of about fifteen percent as a result of undesirable environmental challenges that are related to climatic change in Africa (Baarsch et al. 2020).

While many economies in Africa continue to experience rapid urbanization in the era of globalization, the adverse environmental consequences are most likely going to cut across several aspects of the African economies, thereby exacerbating the numerous socioeconomic challenges that are currently confronting the continent. For instance, pronounce occurrence of droughts and longer duration of dry seasons stands to aggravate the problem of food insecurity in Africa considering that agricultural practices mostly depend on seasonal variations in the amount of rainfall. Aside from the food insecurity, instability in the agricultural sector will also connote a huge economic loss as the agricultural sector usually accounts for a significant proportion of the GDP, overall employment, and income generation in many African nations (Diao et al. 2010; Onifade et al. 2020a, b; Salahuddin et al. 2020).

Therefore, addressing environmental challenges in Africa by examining the potential contributing factors to pollution levels will help to position the continent on a sustainable path. As such, in the current study, we examine the impacts of increasing urbanization alongside its interactions with energy portfolios on environmental prospects of 15 selected African countries including the most urbanized and leading oil producers in the continent of Africa. While doing so, the study also factors in the roles of economic growth among the countries given the rising trends of globalization in our increasingly interconnected world. The study provides useful insights on relevant policy recommendations that are critical for enhancing environmental sustainability and sustainable economic growth, which are paramount focus points of most policymakers especially in developing economies by attempting to answer the following questions:

i. Does urbanization amid economic globalization aid environmental quality in Africa?
ii. What are the impacts of growing per capita income levels on environmental degradation in Africa?
iii. How do energy portfolios impact environmental quality in Africa given the rapid urbanization trend in recent times?
iv. Can African economies bypass detrimental economic consequences while implementing energy conservation policies for environmental sustainability?

To circumvent biased and spurious results, a combination of robust econometric approaches including quantile regression (QR), the dynamic ordinary least squares (DOLS), and fully modified ordinary least squares (FMOLS) were used in the current study. The first approach (QR) essentially makes it possible to observe the conditional distribution effects of the understudied environmental indicators (urbanization, globalization, income, and energy portfolios) on the pollution level among the countries and the method is robust for dealing with fundamental issues like cross-sectional dependence and outliers vis-à-vis error distribution. On the other hand, the other approaches make complementary and comparative analysis possible as they depend on the mean estimates, unlike the QR method. The combination of the approaches essentially helps to produce insightful results that informed useful policy directives.

The vast majority of empirical studies in the environmental literature often focus on advanced economies, especially the European Union (EU) and major emerging economies like China, Brazil, Turkey, and so on. Aside from providing crucial insights into environmental matters in Africa where the literature is relatively unsaturated compared to the rest of the world, this study also ensures that major oil-producing countries in the continent were accommodated in the analysis. Doing this makes the study worthwhile as many of the rapidly urbanizing African countries mainly rely on conventional energy use due to the continent's fossil energy potential, and this aspect has often been ignored in extant studies. Fossil energy accounts for the largest proportion of the total energy consumption in the continent as oil consumption accounts for 42%, while gas consumption accounts for 28% of the total energy consumption. Also, the consumption of other fossil energy sources like coal accounts for around 22% of total energy consumption. This is not surprising given that Africa accounts for about 9.1% and 6% of global oil and natural gas production, respectively, and about 4.2% and 3.9% of the consumption, respectively (UNEP 2017).

In Fig. 1, the transport sector is expectedly the leading sectorial demand for oil consumption on the continent, followed by industrial energy demand and residential energy consumption from oil. The United Nations Environment Program (UNEP 2017) has pointed out that economic growth, population growth, and urbanization are important factors to be considered as far as energy demand is concerned in Africa. Besides, these are among the several factors that have dominated the empirical literature vis-à-vis the major driving forces for greenhouse gas (GHG) emissions as they have a high tendency to influence energy use among nations in our rapidly urbanizing world (Dogan and Turkekul 2016; Ozturk and Acaravci 2016; Leitão and Balsalobre-Lorente 2021; Alola et al. 2021; Shahbaz et al. 2020; Onifade et al. 2021a; Al-Mulali and Ozturk 2015). Other factors include the influence of interconnectedness of economies via expanding trade volumes as nations strive to maintain an upward economic growth trajectory in our vastly globalized world (Shahbaz et al. 2017, 2019; Destek 2020; Wang et al. 2020; Adebayo et al. 2021a; Saint Akadiri et al. 2020).

A synopsis of related studies on urbanization and its environmental impacts amid economic growth and globalization is provided in Table 1. The table summarizes methods used in the studies, the sample of studies, and the overall results alongside the conclusions. Generally, there is no unanimity in terms of results in the empirical literature as most of the studies produced varying results as seen in Table 1.

Hereafter, the other aspects of the study are structured into three sections in the following order: the information on data and methodology are organized in the Methodology section, while the Discussion of Results section contains the analysis and interpretations of outcomes of the simulations. The Conclusion and Policy Recommendations section concludes the research with the study's implications and policy framework.

Methodology

An overview of the data and baseline model

To access the level of environmental sustainability in Africa amid the rapid urbanization that is being witnessed on the continent in recent times, this study essentially utilized data from the World Bank Development Indicators (WDI 2020) and the KOF Swiss Institute (Gygli et al. 2019) for a group of fifteen (15) selected African countries between 1990 and 2015, including Egypt, Nigeria, Algeria, Sudan, Tunisia, Libya, South Africa, Angola, Gabon, Congo Republic, Mozambique, Senegal, Tanzania, Kenya, and the Democratic Republic of Congo (DRC). Data sourcing is a major

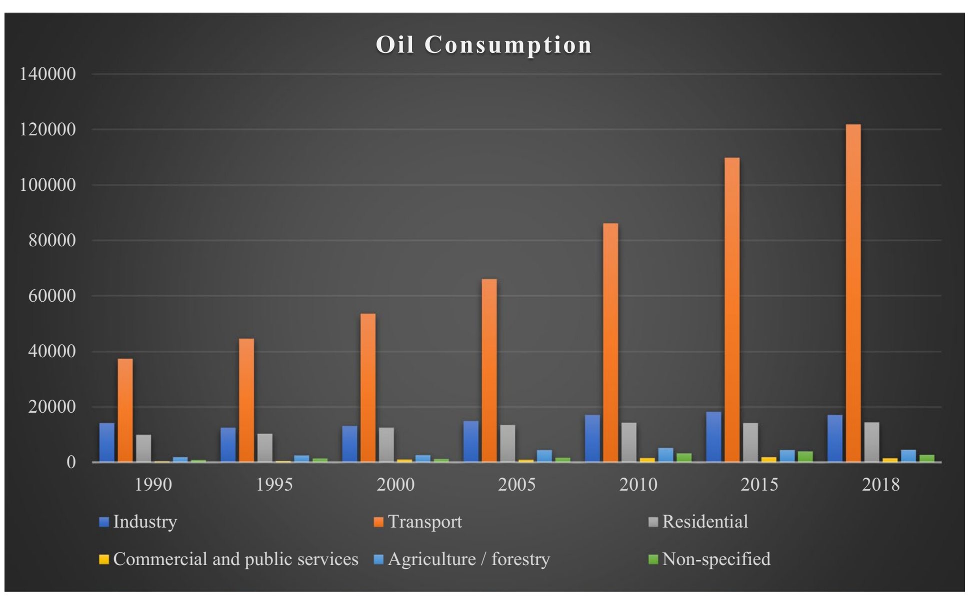

Fig. 1 Distribution of oil consumptions across selected sectors in Africa. Source: authors' computation using data from IEA 2020. Data are given in kilotons of oil equivalent (ktoe)

Table 1 Related studies summarized

Authors	The sample studied	List of countries	Method of analysis	The results and conclusions
Urbanization and environmental quality				
Dogan and Turkekul (2016)	1960 to 2010	USA	ARDL bounds test method	Urbanization induces CO_2 emissions in long run
Mahmood et al. (2020)	1968 to 2014	Saudi Arabia	ARDL methods	Urbanization induces CO_2 emissions
Anwar et al. (2021)	1990–2014	15 Asian economies	FMOLS and DOLS	Urbanization induces CO_2 emissions
Al-Mulali and Ozturk (2015)	1968–2005	MENA countries	FMOLS	Urbanization reduces environmental quality in MENA countries
Onifade et al. (2021a)	1990–2016	OPEC countries	PMG	Urbanization does not have a significant effect on CO_2 pollution
Salahuddin et al. (2019)	1980 to 2017	South Africa	ARDL method	Urbanization increases CO_2 emissions only in the short run
Anwar et al. (2021)	1990 to 2014	Asian countries	DOLS and FMOLS	Urbanization induces CO_2 emissions
Sadorsky (2014)	1971 to 2009	For 16 emerging countries	Pooled OLS	Effects of urbanization on CO_2 emission are generally insignificant
Shahbaz et al. (2016)	1970(Q1) to 2011(Q4)	Malaysia	ARDL	Urbanization has a U-shaped nexus with CO_2 emissions
Zhu et al. (2012)	1992 to 2008	For 20 emerging countries	Pooled OLS	The relation between CO_2 emissions and urbanization is nonlinear
GDP growth, energy use, and carbon emissions				
Apergis and Payne (2014)	1980 to 2011	25 OECD nations	FMOLS	GDP growth induces carbon emissions
Ozturk and Acaravci (2016)	1980–2006	For Cyprus and Malta	ARDL and Granger causality techniques	CO_2 emissions and energy use trigger economic growth
Dogan and Ozturk (2017)	1980 to 2014	The USA	ARDL method	Nonrenewable energy use induce pollution
Sarkodie and Owusu (2017)	1971–2013	Ghanian economy	Linear regression	Energy use and growth induce CO_2 emissions
Ozturk and Acaravci (2010)	1968–2005	Turkey	ARDL, Granger causality method	No significant causality between energy use, carbon emission, and GDP
Dogan and Aslan (2017)	1995 to 2011	EU countries	OLS, FMOLS, and DOLS	GDP growth reduces emissions but energy use does not
Alola (2019)	1990 (Q1) to 2018 (Q2)	The USA	Dynamic ARDL	GDP and energy use increase carbon emissions
Bekun et al. (2021a)	1995 to 2016	The E7 countries	AMG and CCEMG approach	Increase in energy use increases CO_2 emissions
Apergis and Payne (2009)	1971 to 2004	Central America countries	FMOLS	An increase in energy use increases CO_2 emissions
Shahbaz et al. (2020)	1870–2017	UK	Bootstrapping bounds test approach	Energy usage increases CO_2 emissions
Leitão and Balsalobre-Lorente (2021)	1990–2018	For 28 EU countries	DOLS and Granger causality	Renewable energy usage reduces CO_2 emissions
Gyamfi et al. (2021)	1990–2018	G7 countries	QR and AMG	Fossil energy use increases pollution levels

Table 1 (continued)

Authors	The sample studied	List of countries	Method of analysis	The results and conclusions
Globalization and carbon emissions				
Shahbaz et al. (2017)	1970–2012	China	ARDL, VECM	CO_2 emission is reduced by rising globalization in China
Sharif et al. (2020)	1978 Q1–2017 Q4	China	QARDL	Globalization largely has a negative impact on environmental quality
Shahbaz et al. (2019)	From 1970 to 2012	87 countries based on income levels	Cross-correlation approach	Emissions are reduced by globalization just in high and middle-income states
Balsalobre-Lorente et al. (2020)	1994–2014	OECD countries	FMOLS	Globalization lowers carbon emissions from the angle of international tourism
Adebayo et al. (2021a)	1980–2018	For South Korea	ARDL	A positive link between globalization and CO_2 emission levels
Onifade et al. (2021b)	1990–2016	E7 economies	AMG, FMOLS, and DOLS	Globalization helps to lower CO_2 pollution
Saint Akadiri et al. (2020)	1970–2014	Turkey	ARDL, Bayer, and Hanck cointegration	Globalization does not influence CO_2 emissions
Destek (2020)	1995–2015	Central and Eastern European states	AMG, causality test	CO_2 emissions levels in the CEECs are induced by globalization
Wang et al. (2020)	1996–2017	For G7 economies	CS-ARDL	CO_2 emissions are induced by globalization in the G7

Note: see Appendix for the list of abbreviations

challenge with African countries, and the scope of the present study is limited to the extent of data available from those organizations. The country selection was carried out based on two important yardsticks vis-à-vis the aim of the study. First is the consideration for the level of urbanization in terms of the proportion of the population living in the urban settlements to the total population, and the second is the energy portfolios of countries. For the latter condition, the study prioritized the case of nations that are generally known to be rich in conventional energy sources due to their vast fossil energy resources deposits such as is the case for oil and gas-rich countries like Nigeria, Libya, Angola, Algeria, and Egypt and also the case of South Africa when considering coal resources. Notably, some of these countries apart from being rich in conventional energy resources are still among the most urbanized on the continent including others on the list. The study's baseline model is provided in Eq. 1.

$$\begin{aligned} \mathrm{LnCO}_{2it} = \alpha_0 + \alpha_1 \mathrm{LnIC}_{it} + \alpha_2 \mathrm{LnIC}^2{}_{it} \\ + \alpha_2 \mathrm{LnUB}_{it} + \alpha_4 \mathrm{LnUBFF}_{it} \\ + \alpha_3 \mathrm{LnUBRW}_{it} + \alpha_5 \mathrm{LnEGZ}_{it} + \varepsilon_{it} \end{aligned} \tag{1}$$

In Eq. 1, the measure of environmental quality is the level of carbon emission (LnCO_2) in the countries, while the number of populations in the urban as a fraction of the total population was used to capture the level of urbanization (LnUB). Two main interaction terms were incorporated into the model to factor in the impact of energy portfolios within the urbanization context, and priority was given to both fossil and renewable energy aspects. The interaction between the level of urbanization and fossil energy resources, namely the amount of electricity production from oil, gas, and coal sources as a % of total electricity generation was represented by LnUBFF. On the other hand, the interaction between the level of urbanization and the level of renewable energy use as a proportion of total energy consumption was denoted by LnUBRW. Given the growing quest to sustain economic growth in our increasingly globalized world, the proxies for both economic growth and globalization as captured by real per capita income (LnIC) and the economic globalization (LnEGZ), respectively, were incorporated into the model. LnCO_2 is given in metric tons, while the income levels are in the current US$. Lastly, the variable LnIC^2 represents the square of real per capita income level. The introduction of this variable helps to simultaneously assess whether the well-known environmental Kuznets curve (EKC) hypothesis is valid for this group of countries within the context of their urbanization experience. Introducing the square value of income level aligns with existing approaches in some

Table 2 An overview of the summary statistics and correlation matrix

Variables	$LnCO_2$	*LnIC*	$LnIC^2$	*LnUB*	*LnUBFF*	*LnUBRW*	*LnEGZ*
Mean	−0.141386	1.570374	4.268979	1.646281	2.352424	2.335164	1.673377
Median	−0.197040	1.426994	2.036368	1.634230	2.895997	2.744913	1.674091
Maximum	0.999893	12.00415	144.0995	1.945065	3.798218	3.752186	1.849995
Minimum	−1.788352	−0.000834	6.95E−07	1.223963	−2.008828	−2.274889	1.432423
Std. dev	0.706953	1.344447	13.60433	0.177720	1.458749	1.150347	0.092289
Observations	390	390	390	390	390	390	390
Correlation matrix							
$LnCO_2$	1						
p-value	—						
LnIC	0.1130**	1					
p-value	(0.0256)	—-					
$LnIC^2$	−0.0734	0.9377***	1				
p-value	(0.1476)	(0.0000)	—-				
LnUB	0.7624***	0.0864*	−0.0470	1			
p-value	(0.0000)	(0.0884)	(0.3541)	—-			
LnUBFF	0.7795***	−0.0256	−0.1645**	0.5123***	1		
p-value	(0.0000)	(0.6129)	(0.0011)	(0.0000)	—-		
LnUBRW	−0.5081***	−0.0686	0.0468	−0.2805***	−0.4389***	1	
p-value	(0.0000)	(0.1760)	(0.3561)	(0.0000)	(0.0000)	—-	
LnEGZ	0.5470***	−0.2074***	−0.2813***	0.3682***	0.5067***	−0.2436***	1
p-value	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	—-

Source: computed by the author. Single, double, and triple asterisks (*) stand for estimates' statistical significance at 10%, 5%, and 1% levels, respectively

empirical studies (Apergis and Ozturk 2015; Bekun et al. 2021b). All of the variables were taken in the natural logarithm for ease of analysis in elasticity form and the basic statistical properties of the variables are given in the result section.

Procedures for estimation

Analysis in the empirical stage begins with conducting a combination of necessary pre-estimation tests. It is highly imperative to examine the statistical features of the panel data set as a guide for the proper choice of estimation techniques. Considering the level of interconnectedness of nations especially in our globalized world, a cross-sectional dependence (CD) test, therefore, heralds the pre-estimation tests. This action is necessary to guide the choice of proper panel unit root test as well as method selection for the cointegration test as seen in contemporary empirical studies (Chudik et al. 2016; Bekun et al. 2021a, b; Sinha and Sengupta 2019; Gyamfi et al. 2021).

$$Y_{it} = \delta_i + \alpha_i X_{it} + \mu_{it} \tag{2}$$

Following a simplified panel expression between variable Y and X in Eq. 2, a cross-sectional dimension denoted by (i) is given for the panel observations ranging from 1 to N in period (t) spanning from 1 to T as shown in Eq. 3. Subsequently, a null hypothesis that supports the absence of cross-sectional dependence (correlation) in residuals, whereby $\mathrm{Cov}(\mu_{it},\mu_{jt})=0$ is formulated in contrast to an alternative hypothesis that supports cross-section dependence in residuals at least in a pair of the given cross-sections whereby $\mathrm{Cov}(\mu_{it},\mu_{jt})\neq 0$.

$$LM = T\sum_{i=1}^{N-1}\sum_{J=i+1}^{N}\rho\hat{\ }_{ij}^{2}\chi^{2}_{N(N-1)/2} \tag{3}$$

The pairwise correlation of the estimated residuals ($\rho\hat{\ }_{ij}$) obtained from the OLS results of Eq. 2 following the

Table 3 Results for the CD test

Methods	Breusch and Pagan (1980) LM test	Pesaran (2007) CD test	Pesaran (2015) LM test
Model (1)	1181.23***	4.08***	74.26***
Probability value	(0.0000)	(0.0000)	(0.0000)

Source: computed by the author. Single, double, and triple asterisks (*) stand for estimates' statistical significance at 10%, 5%, and 1% levels, respectively

Lagrange multiplier (LM) approach of Breusch and Pagan (1980) is denoted by ($\hat{\rho}_{ij}$), while the LM test for cross-sectional dependence of Pesaran (2015) was used in line with Eq. 4 and Eq. 5. The method offers an advantage as it accounts for matters of cross-sectional dependence and slope heterogeneity, especially in not too big or relatively small sample observations.

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{J=i+1}^{N}\hat{\rho}_{ij}\right) \quad (4)$$

$$\hat{\rho}_{ji} = \hat{\rho}_{ij} = \frac{\sum_{t-1}^{T}\hat{\mu}_{i,t}\hat{\mu}_{j,t}}{\left(\sum_{t=1}^{T}\hat{\mu}_{it}^{2}\right)^{\frac{1}{2}}\left(\sum_{t=1}^{T}\hat{\mu}_{jt}^{2}\right)^{\frac{1}{2}}} \quad (5)$$

It is assumed that the obtained residuals (μ) should be asymptomatically distributed vis-à-vis their test statistics such that CD ~ N (0, 1). Thereafter, to evaluate the long-run relationship between the panel variables of interest in the study, the study adopted a unit root analysis that can account for CD pitfalls, since the test result came out positive as fully detailed in the discussion section. As a result, the CIPS panel unit root test (Pesaran 2007) and the IPS test (Im et al. 2003) were jointly utilized in the study. Subsequently, Westerlund's (2007) cointegration technique was applied to confirm a long-run relationship between the understudied panel variables. The Westerlund (2007) approach depends on the mechanism of error correction in Eq. 6, and this approach is also compatible for long-run tests under analysis that is marred by the CD shortfalls (Sinha and Sengupta 2019).

$$\Delta Y_{it} = \alpha_i D_t + \varnothing_i Y_{it-1} + \lambda_i X_{it-1} + \sum_{j=1}^{pi}\varnothing_{ij}\Delta Y_{i,t-j} + \sum_{j=0}^{pi}\gamma_{ij}\Delta X_{i,t-j} + \varepsilon_{it} \quad (6)$$

While α_t stands for the vector of the individual parameters, the D_t represents the model's deterministic arrangement in Eq. 6, and the deterministic pattern can be designed to reflect an interactive arrangement among variables without deterministic components $\{D_t=(0)\}$, or with a constant only component $\{D_t=(1)\}$, and sometimes as a model with the combination of both trend and constant $\{D_t=(1, t)\}$. The Westerlund approach produces both group statistics (Gt, Gα) and panel statistics (Pt, Pα), which assists in the assessment of the cointegration relationship based on the estimation of the error adjustment process ($\varnothing_i$).

Table 4 Outputs for the unit root test

Variables	*CIPS* $D_t=(1, t)$ Levels	*CIPS* $D_t=(1, t)$ 1st difference	*IPS* $D_t=(1, t)$ Levels	*IPS* $D_t=(1, t)$ 1st difference
LnCO2	−2.121	−5.337***	−2.2522	−3.7385***
LnIC	−2.910*	−4.677***	−2.1022	−3.0056***
LnIC²	−2.453**	−4.641***	−2.3442	−2.9250***
LnUB	−2.111	−1.935	−1.1697	−3.0375***
LnUBFF	−2.114	−4.619***	−1.6286	−3.5657***
LnUBRW	−2.267	−4.426***	−1.9909	−3.3941***
LnEGZ	−2.546	−4.461***	−1.7618	−3.3771***

Source: computed by the author. Single, double, and triple asterisks (*) stand for estimates' statistical significance at 10%, 5%, and 1% levels, respectively

Long-run analysis

As for the long-run analysis, a combination of robust econometric approaches including quantile regression (QR), the DOLS of Pedroni (2001a, b), and FMOLS of Pedroni (2001a, b) were used in the current study. The QR is in line with the foundational work of Koenker and Bassett (1978) as further advanced by Koenker (2004) and Powell (2016). The first approach (QR) essentially makes it possible to observe the conditional distribution effects of the understudied environmental indicators (urbanization, globalization, income, and energy portfolios) on the pollution level

Table 5 Estimates for Westerlund (2007) cointegration

Model 1 $LnCO_2$ = f (LnIC, $LnIC^2$, LnUB, LnUBFF, LnUBRW, LnEGZ)	Group Gτ	Group Gα	Panel Pτ	Panel Pα
Statistics	−3.288***	−0.731	−6.460***	−0.492
p-value	0.0000	1.0000	0.0000	1.0000

Source: computed by the author. Single, double, and triple asterisks (*) stand for estimates' statistical significance at 10%, 5%, and 1% levels, respectively

among the countries, and the method is robust for dealing with fundamental issues like cross-sectional dependence and outliers vis-à-vis error distribution (Nwaka et al. 2020). On the other hand, the other approaches make complementary and comparative analysis possible as they depend on the mean estimates, unlike the QR method.

$$\begin{aligned} \mathrm{QLnCO}_{2it}(\tau/\chi_{it}) = \beta_i^{(\tau)} + \beta_1^{(\tau)}\mathrm{LnIC}_{it} + \beta_2^{(\tau)}\mathrm{LnIC}_{it}^2 \\ + \beta_3^{(\tau)}\mathrm{LnUB}_{it} + \beta_4^{(\tau)}\mathrm{LnUBFF}_{it} \\ + \beta_5^{(\tau)}\mathrm{LnUBRW}_{it} + \beta_6^{(\tau)}\mathrm{LnEGZ}_{it} + \varphi_{it} \end{aligned} \quad (7)$$

The representations in Eq. (7) follow the interaction among variables in the baseline Eq. 1 such that τ^{th} represent the conditional quantile of carbon emission levels as the measure of environmental pollution in the expression $\mathrm{QLnCO2}_{it}(\tau/\chi_{it})$ given that the vector of individual independent variables is represented by χ_{it}. On the other hand, tau (τ) represents the selected quantiles for the panel countries i in time t, while the slope parameters for the individual independent variables and the error term for the corresponding vector are denoted by β and φ_{it} accordingly. In a nutshell, the combination of the approaches essentially helps to circumvent biased and spurious results and produce insightful results that informed useful policy directives. Finally, the analysis procedure closes with an evaluation of the direction of causality among the underlining variables of the study using the Granger causality method of Dumitrescu and Hurlin (Dumitrescu and Hurlin 2012). The findings from the empirical procedures have been structured out in the results discussion section.

Discussion of results

The preliminary tests

In the discussion section, an overview of the summary statistics for the panel variables is presented in Table 2 to include the mean values, the median, the maximum and minimum values, and the standard deviations of the samples. Furthermore, Table 2 also presents the correlation matrix for the sample. The correlation matrix reveals that the panel variables positively correlate with carbon emission except for the interaction between urbanization and renewable energy consumption. However, simple correlation analysis would be insufficient without accounting for the statistical properties of the panel variables through an in-depth examination. Besides, the results for the combined CD tests also validate the existence of CD among the variables for the sample countries as the null hypothesis of no cross-sectional dependency can be conveniently rejected following the significance of the probability value of the individual test statistics in Table 3. As such, the adopted unit root test approaches took into cognizance of this development in the subsequent analysis. The results in Table 4 reveal that the understudied panel variables are essentially first-order stationary variables. The IPS approach specifically rejects the evidence of stationarity at a level point for all variables, thereby corroborating the CIPS evidence of stationarity for the panel variables at first difference.

The cointegration results from the Westerlund (2007) approach as shown in Table 5 reveal that the null of no cointegration among variables can be rejected following the significance of the estimates with evidence from at least each of the group and panel statistics, hence, signifying the existence of a long-run connection among the understudied panel variables. This result, therefore, precedes the need to explore the underlying long-run coefficients for the study.

The long-run estimates and causality analysis

The results from the long-run analysis are detailed in Table 6. The findings from the QR approach in the table show the effects of the conditional distribution of the understudied environmental indicators (urbanization, globalization, income, and the interaction of urbanization with energy portfolios) on carbon emission as a measure for environmental pollution level among the African economies. To begin with the environmental impacts of urbanization and globalization, the QR coefficients for these indicators show that the rapid urbanization among the countries as well as the level of economic globalization are significantly detrimental to environmental quality as the effects of these variables are positive and very significant across all the distribution of pollution level throughout the given quantiles ranging from the lower to the mid, and upper quantiles (τ = 0.10 to τ = 0.30), (τ = 0.40 to τ = 0.60), and (τ = 0.70 to τ = 0.90), respectively. The results of the median observations of the QR are also in agreement with the observed findings from the mean estimate approaches of both the DOLS and FMOLS, thereby corroborating many studies where there is evidence of detrimental effects of both urbanization and globalization in the empirical literature (Anwar et al. 2021; Dogan and Turkekul 2016; Onifade et al. 2021c; Destek 2020; Wang et al. 2020).

While urbanization significantly poses threat to environmental sustainability, the evidence obtained regarding its interaction with energy portfolios of the understudied countries differs. The significant detrimental environmental impacts of the interaction between urbanization and energy portfolios were only confirmed in the context of fossil energy consumption among the countries as seen in the positive coefficients across the quantiles of CO_2 emissions. Contrarily, the interaction with renewables exists as a significant decarbonization channel within the framework of the

Table 6 Long-run coefficients

Technique(s)	*QR coefficients*									*FMOLS*	*DOLS*
Explained (var): $LnCO_2$	τ= 0.10	τ= 0.20	τ= 0.30	τ= 0.40	τ= 0.50	τ= 0.60	τ= 0.70	τ= 0.80	τ= 0.90		
LnIC	0.2113***	0.1808***	0.1636***	0.1557**	0.1455***	0.1581***	0.1745***	0.2989***	0.4978***	0.1545***	0.1685***
p-value	(0.0000)	(0.0001)	(0.0003)	(0.0106)	(0.0066)	(0.0003)	(0.0001)	(0.0052)	(0.0000)	(0.0000)	(0.0000)
$LnIC^2$	−0.0131***	−0.0119**	−0.0110**	−0.0106*	−0.0105**	−0.0122**	−0.0135***	−0.0256**	−0.0385***	−0.0071***	−0.0075
p-value	(0.0010)	(0.0102)	(0.0176)	(0.0711)	(0.0436)	(0.0051)	(0.0017)	(0.0103)	(0.0000)	(0.0039)	(0.1382)
LnUB	1.1172***	1.4772***	1.4760***	1.6812***	1.7641***	2.0001***	2.0744***	1.9171***	1.3286***	5.0705***	1.7832***
p-value	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0014)	(0.0004)
LnUBFF	0.2623***	0.2326***	0.2195***	0.1655***	0.1344***	0.1367***	0.1320***	0.1516***	0.1842***	0.0442***	0.0105
p-value	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0021)	(0.4642)
LnUBRW	−0.0861***	−0.0924***	−0.0934***	−0.1048***	−0.1061***	−0.0877***	−0.0675***	−0.0722**	−0.0253	−0.0756	−0.3682***
p-value	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0005)	(0.0439)	(0.4651)	(0.2375)	(0.0007)
LnEGZ	1.2792***	1.0075***	0.9755***	1.3301***	1.7777***	1.6131***	1.5825***	1.4555***	0.9254***	1.1412***	0.5156**
p-value	(0.0003)	(0.0033)	(0.0063)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0002)	(0.0016)	(0.0005)	(0.0133)
Observation	405	405	405	405	405	405	405	405	405	405	
No. of regressors	6	6	6	6	6	6	6	6	6	6	
No. of groups	15	15	15	15	15	15	15	15	15	15	

Source: computed by the author. Single, double, and triple asterisks (*) stand for estimates' statistical significance at 10%, 5%, and 1% levels, respectively

increasing level of urbanization among the countries. These results were also backed up by the mean estimate of the DOLS and FMOLS as a percent rise in the interaction with renewable energy consumption corresponds with a 0.368% fall in carbon emissions, while a percent rise in the interaction with fossil energy aggravates emission levels by 0.044% accordingly. The current results uphold the position of some studies regarding the exacerbating and cushioning effects of fossil energy use and renewable energy use on environmental pollution, respectively (Shahbaz et al. 2020; Bekun et al. 2021a, b; Adebayo et al. 2021b; Kirikkaleli et al. 2021; Gyamfi et al. 2022; Leitão and Balsalobre-Lorente 2021; Adebayo and Rjoub 2021).

In addition, the countries also witnessed environmentally detrimental economic growth for the understudied period as resonated by the positive and significant coefficients of the income level across all the distribution of carbon levels among the countries for all the quantiles. The results of the median observations of the QR are also in agreement with the observed findings from the mean estimate approaches of both the DOLS and FMOLS as a percent rise in per capita income level is expected to trigger carbon emissions by about 0.168% and 0.154%, respectively. This observation upholds some empirical evidence in the literature about pollution-triggering effects of growth (Su et al. 2021). On the other hand, the significant negative coefficients of the impacts of the square income across all quantiles confirm the EKC conjecture for the study, and this is also upheld in the mean estimate of the FMOLS. The implication of the EKC conjecture is that the rising income level is aggravating pollution among the country in the meantime, but this pollution aggravation is expected to reach a peak level after which income expansion is expected to start cushioning carbon emission levels among the understudied African economies.

Lastly, following the causality evidence among urbanization, economic growth, carbon emission, and globalization in Table 7, a one-way causality flows from per capita income level to carbon emission levels and urbanization among the countries and not the reverse direction. This further buttresses the long-run results that economic growth is the driver of emission among the countries. On the other hand, there is a two-way causality flow between urbanization, emission, and globalization. The causality channel, therefore, implies that carefully orchestrated emission reduction schemes will have little or no detrimental effects on sustainable economic growth. This is a welcome result; however, the matters of the detrimental pollution effects of urbanization must be carefully addressed to ensure environmental sustainability, since urbanization granger causes carbon emission.

In a nutshell, from the study, urbanization plays a significant role in the environmental pollution dynamics of Africa as evidenced in the understudied African countries, and this calls for authorities and policymakers to be proactive in addressing urbanization issues as a crucial matter not just for economic gains but also for environmental sustainability.

Conclusion and policy recommendations

This study focuses on assessing the environmental implications of the rapid urbanization being witnessed among African states amid the dynamics of energy use in our increasingly globalized world. To this end, the study applies a combination of approaches for empirical data analysis for a sample scope ranging from 1990 to 2015 for a total of fifteen African countries. The evidence obtained from the empirical analysis shows that the duo of urbanization and economic globalization reduces the quality of the environment by inducing CO_2 emissions. The countries also witnessed environmentally detrimental economic growth for the understudied period. The evidence obtained regarding the effects of the interaction between urbanization and energy portfolios differs as it supports a favorable environmental effect when considering interaction with renewable energy use but a detrimental effect concerning fossil energy production. Furthermore, a one-way causality flows from per capita income level to carbon emission levels and urbanization among the countries and not the reverse direction, while a two-way causality flow between urbanization, emission, and globalization.

The causality channel, therefore, implies that carefully orchestrated emission reduction schemes will have little or no detrimental effects on sustainable economic growth. While this is a welcome result, however, the matters of the detrimental pollution effects of urbanization must be

Table 7 Granger causality

	W-stat				
Variables	***LnCO$_2$***	***LnIC***	***LnUB***	***LnEGZ***	***Direction of causality***
LnCO$_2$	_	1.3218	15.5675***	2.8042***	*LnCO2* → *LnUB*, *LnEGZ*
LnIC	1.9003*	_	9.4312***	2.0637**	*LnIC* → *LnCO2*, *LnUB*, *LnEGZ*
LnUB	3.8850***	1.5423	_	3.4063***	*LnUB* → *LnCO2*, *LnEGZ*
LnEGZ	3.7570***	1.3124	8.5612***	_	*LnEGZ* → *LnCO2*, *LnUB*

Source: computed by the author. Single, double, and triple asterisks (*) stand for estimates' statistical significance at 10%, 5%, and 1% levels, respectively

carefully addressed to ensure environmental sustainability, since urbanization granger causes carbon emission. As such, to mitigate environmental pollution and attendant climate crisis that can be exacerbated by urbanization amid economic globalization among the African countries, it is recommended that authorities in these nations should promote investments in green energy resources. Renewables significantly mitigate carbon emissions in these nations, and supporting advancements of energy production and consumption from renewable resources would therefore foster decarbonization and ultimately facilitate environmental sustainability on the African continent.

Africa has a huge natural advantage of benefitting from renewable resources ranging from hydro resources potential to solar energy, wind energy, and even geothermal. For example, the continent's vast renewable potential in solar and wind energy as shown in Fig. 2 in the Appendix can be tapped into and fully maximized especially for energy production rather than focusing on energy generation from fossil resources, which have been confirmed to be enhancing carbon emission growth and ultimately detrimental to environmental sustainability.

Furthermore, the selected African countries also need to pursue green infrastructural development plans for crucial sectors of the economy where energy demands are pronounced such as the transportation sector and the industrial sector among others as seen in Fig. 1. Such plans would bring two advantages for the understudied countries if implemented in both urban and rural settlements. Firstly, green infrastructural investments would trigger environmental benefits by ensuring a cleaner and quality environment from reduced greenhouse gas emissions, and secondly, it would further assist the African countries in combatting the growing pressure on urban infrastructure due to rural–urban migration, thereby enhancing the overall quality of life in the urban settlements toward fostering the realization of SDG 11 that emphasizes the need for sustainable cities and communities.

Limitation of the study and future recommendation

The current study is mainly constrained in terms of the scope since not all African countries were accommodated in the empirical analysis. Future studies can therefore expand on the current framework to cover more African economies, and

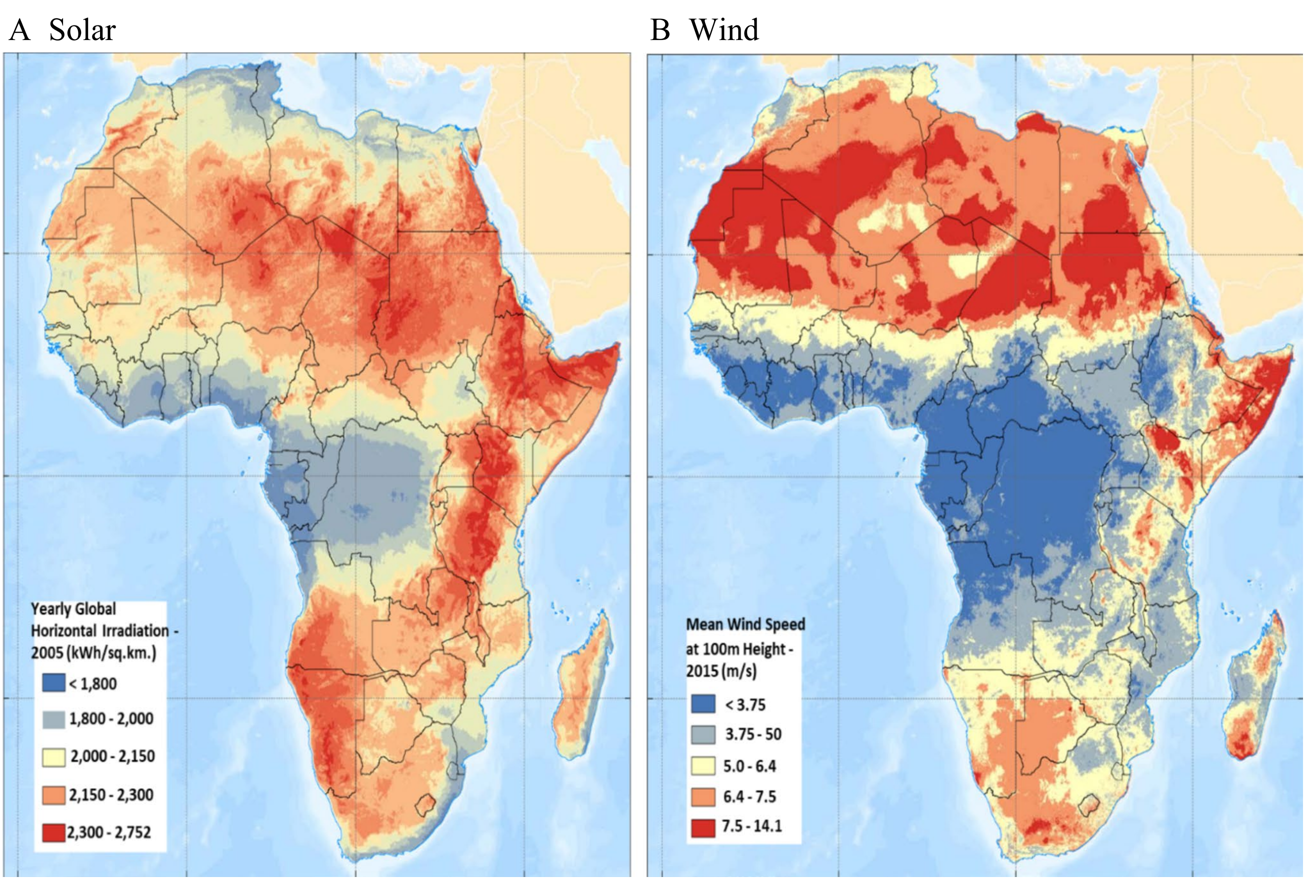

Fig. 2 A map of Africa showing solar and wind energy potential. Source: African Development Bank (AfDB 2014)

Table 8 Full meanings of abbreviations

Methods	Full meanings
AMG	Augmented mean group
ARDL	Autoregressive distribution lag
CS-ARDL	Cross-sectional augmented autoregressive distributed lag
CCEMG	Common correlated effects mean group
OLS	Ordinary least squares
DOLS	Dynamic OLS
FMOLS	Fully modified OLS
PMG	Pooled mean group
VECM	Vector error correction model
QARDL	Quantile ARDL

attention can also be paid to the exploration of the roles of the understudied variables on a country-specific basis. Doing this may yield more advantages in addressing environmental pollution challenges beyond a group analysis considering some possible influence of country-specific differences.

Acknowledgements The author's gratitude is extended to Prof Dr. Mehmet Alagöz and Prof. Dr. Baki Yilmaz of Selçuk University for the numerous supports, encouragement, and constructive comments/criticism toward improving the current draft of this study.

Author contribution The first author (Savaş Erdoğan) alongside the second author (Stephen Taiwo Onifade) were responsible for the conceptual construction of the study's idea and handling the introduction and literature sections. They also managed the data gathering, preliminary analysis, simulation, and interpretation of the simulated results alongside the third author (Mehmet Altuntaş). Finally, both the third author and the fourth author (Festus Victor Bekun) were responsible for proofreading and general manuscript editing.

Availability of data and materials The data for this present study are sourced from the database of the World Development Indicators (WDI 2020) Available at https://data.worldbank.org and the KOF Swiss Economic Institute (https://kof.ethz.ch/en/).

Declarations

Ethics approval and consent to participate NA.

Consent for publication NA.

Competing interests The authors declare no competing interests.

Appendix Fig. 2 and Table 8

References

Adebayo TS, Coelho MF, Onbaşıoğlu DÇ, Rjoub H, Mata MN, Carvalho PV, ..., Adeshola I (2021a) Modeling the dynamic linkage between renewable energy consumption, globalization, and environmental degradation in South Korea: does technological innovation matter?. Energies 14(14):4265

Adebayo TS, Oladipupo SD, Adeshola I, Rjoub H (2021b) Wavelet analysis of impact of renewable energy consumption and technological innovation on CO2 emissions: evidence from Portugal. Environmental Science and Pollution Research, 1–18

Adebayo TS, Rjoub H (2021) A new perspective into the impact of renewable and nonrenewable energy consumption on environmental degradation in Argentina: a time–frequency analysis. Environmental Science and Pollution Research, 1–17

Ahmadalipour A, Moradkhani H, Castelletti A, Magliocca N (2019) Future drought risk in Africa: integrating vulnerability, climate change, and population growth. Sci Total Environ 662:672–686. https://doi.org/10.1016/j.scitotenv.2019.01.278

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

Alola AA (2019) Carbon emissions and the trilemma of trade policy, migration policy and health care in the US. Carbon Management 10(2):209–218

Alola AA, Adebayo TS, Onifade ST (2021) Examining the dynamics of ecological footprint in China with spectral Granger causality and quantile-on-quantile approaches. Int J Sustain Dev World Ecol 1-14. https://doi.org/10.1080/13504509.2021.1990158

Anwar A, Sinha A, Sharif A, Siddique M, Irshad S, Anwar W, Malik S (2021) The nexus between urbanization, renewable energy consumption, financial development, and CO2 emissions: evidence from selected Asian countries. Environment, Development and Sustainability, 1–21

Apergis N, Payne JE (2009) CO2 emissions, energy usage, and output in Central America. Energy Policy 37(8):3282–3286

Apergis N, Ozturk I (2015) Testing environmental Kuznets curve hypothesis in Asian countries. Ecol Ind 52:16–22

Apergis N, Payne JE (2014) The causal dynamics between renewable energy, real GDP, emissions and oil prices: evidence from OECD countries. Appl Econ 46(36):4519–4525

AfDB (2014) Africa Energy Sector: Outlook 2040. African Development Bank, PIDA. Abidjan: AfDB. Available at: https://www.afdb.org Accessed 11 Nov 2021

Baarsch F, Granadillos JR, Hare W, Knaus M, Krapp M, Schaeffer M, Lotze-Campen H (2020) The impact of climate change on incomes and convergence in Africa. World Development 126:104699

Balsalobre-Lorente D, Driha OM, Shahbaz M, Sinha A (2020) The effects of tourism and globalization over environmental degradation in developed countries. Environ Sci Pollut Res 27(7):7130–7144

Bekun, F. V., Gyamfi, B. A., Onifade, S. T., & Agboola, M. O. (2021a). Beyond the environmental Kuznets Curve in E7 economies: accounting for the combined impacts of institutional quality and renewables. J Clean Prod 127924. https://doi.org/10.1016/j.jclepro.2021.127924

Bekun FV, Alola AA, Gyamfi BA, Yaw SS (2021b) The relevance of EKC hypothesis in energy intensity real-output trade-off for sustainable environment in EU-27. Environmental Science and Pollution Research, 1–12

Breusch TS, Pagan AR (1980) The Lagrange multiplier test and its applications to model specification in econometrics. Rev Econ Stud 47(1):239–253

Chudik A, Mohaddes K, Pesaran MH, Raissi M (2016) Long-run effects in large heterogeneous panel data models with cross-sectionally correlated errors. Emerald Group Publishing Limited. https://doi.org/10.1108/S0731-905320160000036013

Destek MA (2020) Investigation on the role of economic, social, and political globalization on environment: evidence from CEECs. Environ Sci Pollut Res 27(27):33601–33614

Kirikkaleli D, Güngör H, Adebayo TS (2021) Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in Chile. Bus Strateg Environ. https://doi.org/10.1002/bse.2945

Diao X, Hazell P, Thurlow J (2010) The role of agriculture in African development. World Dev 38(10):1375–1383. https://doi.org/10.1016/j.worlddev.2009.06.011

Dogan E, Turkekul B (2016) CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23(2):1203–1213

Dogan E, Ozturk I (2017) The influence of renewable and non-renewable energy consumption and real income on CO2 emissions in the USA: evidence from structural break tests. Environ Sci Pollut Res 24(11):10846–10854

Dogan E, Aslan A (2017) Exploring the relationship among CO2 emissions, real GDP, energy consumption and tourism in the EU and candidate countries: evidence from panel models robust to heterogeneity and cross-sectional dependence. Renew Sustain Energy Rev 77:239–245

Dumitrescu E, Hurlin C (2012) Testing for granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Engelman, R. (2016). Six billion in Africa. Scientific American, 314(2), 56–63. https://www.jstor.org/stable/26046844

Gyamfi, B. A., Onifade, S. T., Nwani, C., & Bekun, F. V. (2021). 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 1-13. https://doi.org/10.1007/s11356-021-15756-8

Gyamfi BA, Bekun FV, Balsalobre-Lorente O, S. T., Ampomah, A. B., (2022) Beyond the environmental Kuznets curve: do combined impacts of air transport and rail transport matter for environmental sustainability amidst energy use in E7 economies? Environ Dev Sustain. https://doi.org/10.1007/s10668-021-01944-6

Gygli, Savina, Florian Haelg, Niklas Potrafke and Jan-Egbert Sturm (2019): The KOF Globalisation Index – revisited, review of international organizations. 14(3): 543–574 https://doi.org/10.1007/s11558-019-09344-2

IEA (2020). International Energy Agency: Data and Statistics. Available at: https://www.iea.org/data-and statistics Accessed January 2021.

Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. Journal of Econometrics 115(1):53–74

IPCC (2021) Summary for policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press

Koenker R (2004) Quantile regression for longitudinal data. J Multivar Anal 91(1):74–89

Koenker R, Bassett G (1978) Quantile regression. Econometrica 46:33–50

Leitão, N. C., & Balsalobre-Lorente, D. (2021). The effects of tourism, economic growth and renewable energy on carbon dioxide emissions. In Strategies in Sustainable Tourism, Economic Growth and Clean Energy (pp. 67–87). Springer, Cham.

Mahmood H, Alkhateeb TTY, Furqan M (2020) Industrialization, urbanization and CO2 emissions in Saudi Arabia: asymmetry analysis. Energy Rep 6:1553–1560

Nwaka ID, Nwogu MU, Uma KE, Ike GN (2020) Agricultural production and CO2 emissions from two sources in the ECOWAS region: new insights from quantile regression and decomposition analysis. Sci Total Environment 748:141329

Onifade ST, Çevik S, Erdoğan S, Asongu S, Bekun FV (2020a) An empirical retrospect of the impacts of government expenditures on economic growth: new evidence from the Nigerian economy. Journal of Economic Structures 9(1):6. https://doi.org/10.1186/s40008-020-0186-7

Onifade ST, Ay A, Asongu S, Bekun FV (2020b) Revisiting the trade and unemployment nexus: empirical evidence from the Nigerian economy. J Public Aff 20(3):e2053. https://doi.org/10.1002/pa.2053

Onifade ST, Alola AA, Erdoğan S, Acet H (2021a) Environmental aspect of energy transition and urbanization in the OPEC member states. Environ Sci Pollut Res 28(14):17158–17169. https://doi.org/10.1007/s11356-020-12181-1

Onifade ST, Gyamfi BA, Ilham H, Bekun FV (2021b) Re-examining the roles of economic globalization on environmental degradation in the E7 economies: are human capital, urbanization, and total natural resources essential components? Resour Policy. https://doi.org/10.1016/j.resourpol.2021.102435

Onifade, S. T., Erdoğan, S., Alagöz, M., & Bekun, F. V. (2021c). Renewables as a pathway to environmental sustainability targets in the era of trade liberalization: empirical evidence from Turkey and the Caspian countries. Environ Sci Pollut Res 1-12. https://doi.org/10.1007/s11356-021-13684-1

Ozturk I, Acaravci A (2010) CO2 emissions, energy consumption and economic growth in Turkey. Renew Sustain Energy Rev 14(9):3220–3225

Ozturk I, Acaravci A (2016) Energy consumption, CO2 emissions, economic growth, and foreign trade relationship in Cyprus and Malta. Energy Sources Part B 11(4):321–327

Pedroni, P. (2001) Fully modified OLS for heterogeneous cointegrated panels, nonstationary panels, panel cointegration, and dynamic panels. 15: 93–130. https://doi.org/10.1016/S0731-9053(00)15004-2

Pedroni P (2001b) Purchasing power parity tests in cointegrated panels. Rev Econ Stat 83(4):727–731. https://doi.org/10.1162/003465301753237803

Pesaran MH (2007) A simple panel unit root test in the presence of cross section dependence. J Appl Economet 22(2):265–312

Pesaran MH (2015) Testing weak cross-sectional dependence in large panels. Econom Rev 34(6–10):1089–1117

Powell, D. (2016). Quantile regression with nonadditive fixed effects. Quantile Treatment Effects, 1–28.

Sadorsky P (2014) The effect of urbanization on CO2 emissions in emerging economies. Energy Economics 41:147–153

Sarkodie S, Owusu PA (2017) Recent evidence of the relationship between carbon dioxide emissions, energy use, GDP, and population in Ghana: a linear regression approach. Energy Sources Part B 12(6):495–503

Salahuddin M, Gow J, Ali MI, Hossain MR, Al-Azami KS, Akbar D, Gedikli A (2019) Urbanization-globalization-CO2 emissions nexus revisited: empirical evidence from South Africa. Heliyon 5(6):e01974

Salahuddin M, Gow J, Vink N (2020) Effects of environmental quality on agricultural productivity in Sub-Saharan African countries: a second generation panel based empirical assessment. Sci Total Environ 741:140520

Saint Akadiri S, Alola AA, Olasehinde-Williams G, Etokakpan MU (2020) The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. Science of The Total Environment 708:134653

Sinha A, Sengupta T (2019) Impact of natural resource rents on human development: what is the role of globalization in Asia Pacific countries? Resources Policy 63:101413

Shahbaz M, Loganathan N, Muzaffar AT, Ahmed K, Jabran MA (2016) How urbanization affects CO2 emissions in Malaysia?

The application of STIRPAT model. Renew Sustain Energy Rev 57:83–93

Shahbaz M, Khan S, Ali A, Bhattacharya M (2017) The impact of globalization on CO2 emissions in China. The Singapore Economic Review 62(04):929–957

Shahbaz M, Mahalik MK, Shahzad SJH, Hammoudeh S (2019) Testing the globalization-driven carbon emissions hypothesis: international evidence. International Economics 158:25–38

Shahbaz M, Nasir MA, Hille E, Mahalik MK (2020) UK's net-zero carbon emissions target: investigating the potential role of economic growth, financial development, and R&D expenditures based on historical data (1870–2017). Technological Forecasting and Social Change 161:120255

Sharif A, Godil DI, Xu B, Sinha A, Khan SAR, Jermsittiparsert K (2020) Revisiting the role of tourism and globalization in environmental degradation in China: fresh insights from the quantile ARDL approach. Journal of Cleaner Production 272:122906

Su ZW, Umar M, Kirikkaleli D, Adebayo TS (2021) Role of political risk to achieve carbon neutrality: evidence from Brazil. Journal of Environmental Management 298:113463

United Nation Environment Program, UNEP (2017). Atlas of Africa Energy Resources. United Nations Environment Programme. PO Box 30552, Nairobi 00100, Kenya

UNEP (2021). United Nations Environment Program: Emissions Gap Report. The heat is on – a world of climate promises not yet delivered. Nairobi. Available at www.unep.org/resources/emissions-gap-report-2021 Accessed 1st of November 2021.

Wang L, Vo XV, Shahbaz M, Ak A (2020) Globalization and carbon emissions: is there any role of agriculture value-added, financial development, and natural resource rent in the aftermath of COP21? J Environ Manag 268:110712

Westerlund J (2007) Testing for error correction in panel data. Oxford Bull Econ Stat 69:709–748

World Development Indictors, WDI (2020). https://data.worldbank.org/ Accessed April 2021

Zhu HM, You WH, Zeng ZF (2012) Urbanization and CO2 emissions: a semi-parametric panel data analysis. Econ Lett 117(3):848–850

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.