Received: 2 September 2023 | Revised: 19 April 2024 | Accepted: 1 May 2024

DOI: 10.1002/sd.3040

RESEARCH ARTICLE

Sustainable Development | WILEY

Towards sustainable development in African countries: Are modern and combustible renewable energies effective?

Ugur Korkut Pata [1,2,3,4] | Selin Karlilar Pata [1,4]

[1]Department of Economics, Hatay Mustafa Kemal University, Antakya, Turkey

[2]Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon

[3]Department of Banking and Finance, European University of Lefke, Lefke, Turkey

[4]Clinic of Economics, Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan

Correspondence
Ugur Korkut Pata, Department of Economics, Hatay Mustafa Kemal University, Antakya, Turkey.
Email: ugurkorkut.pata@mku.edu.tr

Abstract

Environmental degradation and climate change problems in the African continent seriously hit country economies and human health, negatively affecting the achievement of the Sustainable Development Goals (SDGs). African countries have the potential to use economic development and renewable energy as a tool for their environmental sustainability. In this context, this study examines the effects of economic growth, modern renewable energy, and combustible renewable energy on ecological footprint (EF) in five African countries. To this end, the study uses novel regularization common correlated effects and half-panel jackknife approaches on data from 2006 to 2020. The findings of the study show that economic progress effectively reduces the EF of African countries, but renewable energy does not contribute to ecological progress. Due to their insufficient and ineffective utilization, renewable energies are not an important tool for improving ecological systems. Therefore, African countries should prioritize their economic development as a priority goal. Based on the results, African countries experiencing economic advancement should bolster for SDGs objectives through green financial incentives.

KEYWORDS

African countries, combustible renewables, ecological footprint, modern renewable energy, sustainable development

1 | INTRODUCTION

The Sustainable Development Goals (SDGs), established in 2015 with 17 targets, are important issues that provide a roadmap for economic, environmental and cultural development. The SDGs shed light on how countries can be transformed into a green economy without harming the environment and compromising economic growth. Countries have recently shaped their policy agendas in line with the SDGs. Under the SDGs, countries are trying to provide environmental benefits to their society by shaping their energy and environmental policies.

Energy is an indispensable production factor for the economy and the production process of societies (Stern, 1997). However, societies are forced to base their economic progress on fossil fuels in the first phase, which leads to heavy carbon pollution. Fossil fuels are responsible for 70% of global greenhouse gas emissions, and the intensive use of these types of energy leads to ecological degradation and habitat destruction (Ullah et al., 2024). To avoid carbon (CO_2) emissions, the use of fossil fuels must be minimized, but since fossil fuels are a major factor of production and cheap, societies are unwilling to do so. In fact, China and India were found to have weakened their coal pledges at COP26 (Rajmil et al., 2023). The fact that China and India, which have the largest populations in the world and are among the top five economies in terms of GDP (Investopedia, 2023), are not give up fossil

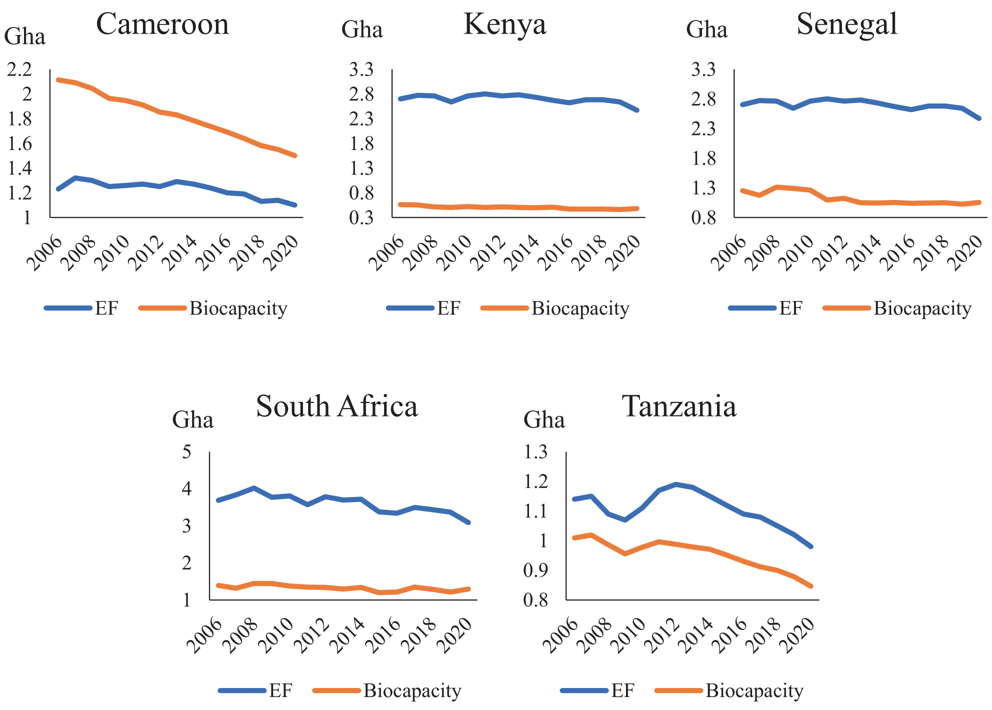

FIGURE 1 Ecological balance in five African countries. Source: Global Footprint Network (2024).

fuels also has implications for the stance of other developing countries.

African societies in the developing country category are still at the beginning of their economic development and their dependence on fossil fuels is quite high. In addition, African countries have created enormous environmental pressures in their ecological areas, which can be highlighted with the ecological footprint (EF). The progress of the EF and the biocapacity of African countries between 2006 and 2020 is presented in Figure 1.

Cameroon's EF is low in relation to its biocapacity, and the environmental conditions are sustainable. However, Cameroon's EF and biocapacity have gradually declined over the 15-year period, showing that the environmental situation is worsening. In Kenya, Senegal, South Africa and Tanzania, the EF value is significantly higher than the biocapacity. The EF as global hectare area (gha) proposed by Wackernagel and Rees (1997), reflects the pressure of humans on air and water surfaces and the carbon footprint caused by them. Biocapacity versus EF indicates the ability of natural resources to absorb man-made pollution. According to Figure 1, African countries have serious problems with ecological sustainability and solutions should be found to address these problems. To mitigate ecological issues related energy, countries can change energy mix in electricity generation on the African continent.

Figure 2 shows the share of REN and fossil fuels in the electricity generation of African countries in 2020. Cameroon and Kenya mainly produce REN electricity, while in Senegal, South Africa and Tanzania, the use of fossil fuels predominates. According to IRENA (2024) data, South Africa ranks 52nd, Kenya 71st, Cameroon 90th, Tanzania 97th and Senegal 121st among the 224 most REN producer countries in 2021. Even the total energy production and thus the energy consumption of the five African countries is not as high as that of Argentina or Peru. The low and ineffective use of REN could be one reason why African countries have not achieved the desired success in the SDGs.

Although some countries have achieved success in realizing the SDGs, there are specific challenges to the SDGs in African countries, and these countries are vulnerable due to conflicts (United Nations, 2015). Unlike other continents, Africa has difficulties in the socio-economic development process due to issues such as demographic problems, refugee migration, income disproportions and overconsumption (Bartniczak & Raszkowski, 2018). Indeed, the Africa Agenda 2063, which was put on the agenda in 2013 before the SDGs, reflects the African government's strategy, aspirations for sustainable development and inclusive growth (Royo et al., 2022). The seventh aim of the Agenda 2063 goals reflects environmental sustainability and climate change resilient economies, and the sixth reflects the blue ocean economy (African Union, 2024). However, African countries are lagging far behind in achieving these goals in the areas of energy and environment.

Achieving the SDGs has been at the center of many African countries' recent policies, and in this context, energy is an important indicator of sustainable development (Bugaje, 2006). Africa's energy situation needs to be supported wisely because energy is needed directly or indirectly to achieve efforts such as SDG 1.3 Social Protection and SDG 13 Climate Action (Mugagga & Nabaasa, 2016). By turning to REN resources, African communities can protect their economies from rising imported fuel prices and reduce environmental damage (Aliyu et al., 2018). The promotion of REN is important for the African continent because African countries cannot meet their own energy needs and many African countries do not have adequate access to electricity (Ibrahim et al., 2021). Since RENs are local resources that do not cause carbon emissions, are clean and do not

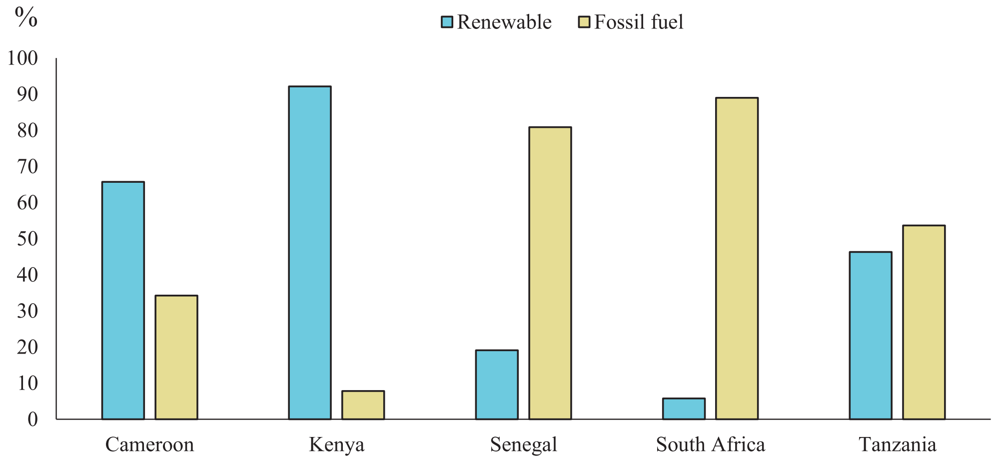

FIGURE 2 Renewable energy and fossil fuel share in African electricity generation in 2020. Source: Our World in Data (2024).

cause local damage, they contribute to the achievement of the SDGs, but countries utilization of RENs by African countries is insufficient (Schwerhoff & Sy, 2017). African countries suffer from environmental problems in the form of deforestation, overfishing and lack of clean drinking water, and the majority of African countries cannot achieve CO_2 reduction (Omisore, 2018). African countries are struggling to achieve the SDGs because 2/3 of underdeveloped countries are African countries and these countries have serious problems such as war, drought, corruption and funding shortages (Aust et al., 2020). The SDGs are universal and inclusive, but African countries have long neglected the environment in relation to development (Omisore, 2018).

Progress in the field of REN is an ecological necessity for the African continent, but Africa has not been successful in this regard. This study therefore examines whether REN in African countries contributes to the environment and whether economic progress is an eco-friendly element. Grossman and Krueger (1991) noted that economic progress can initially accelerate environmental degradation through the scale effect, but on the contrary, it can contribute to the reduction of environmental pollutants through the technique effect. The reciprocal effect of economic development on the environment has led to disagreement among researchers, and many studies have examined the relationship between economic development and ecological degradation with linear modeling (see, for example, Aytun et al., 2024), and some researchers have focused on African countries (Obuobi et al., 2022; Onifade, 2023; Saba et al., 2023). African countries continue to use large amounts of fossil fuels in their economic development processes, leading to environmental problems.

Over the last two decades, issues about environmental sustainability have changed and researchers have developed new empirical methods for analyzing the SDGs (Ramzan et al., 2023). In this regard, this study aims to analyze the impact of fossil fuel use, REN and GDP growth on EF in five South African countries using a different perspective and novel econometric methods. Following You and Kakinaka (2022), this study is the first to analyze the environmental impacts of modern (solar, wind & hydropower) and combustible (biomass) REN and waste separately for African countries. The environmental impacts of sub-types of REN can be different, and accordingly, different SDG-related environmental policies can be recommended for Africa. For this reason, the fact that the study takes a disaggregated energy approach is an important contribution to existing knowledge. Another contribution of the study to the literature is the novel panel data approaches it uses. The study applies novel regularization common correlated effects (rCCE) and half-panel jackknife (HPJ) approaches to analyze the determinants of EF in African countries. These approaches eliminate cross-sectional dependence (CSD), prediction bias and small-observation deviations. By using HPJ and rCCE, the study also makes a methodological contribution to the discussion in the field of environmental economics.

The roadmap of the five-part study is as follows: The second part provides a literature review on South Africa and the REN. The third part introduces the data and the empirical approach. The fourth part discusses the findings specifically for Africa, and the final part concludes the study.

2 | RELATED LITERATURE

2.1 | Economic progress and environment nexus

The environmental problems of African countries have long been discussed among researchers and have been the subject of empirical studies. Although those who use linear modeling in these studies generally claim that GDP growth causes environmental damage, there are other findings in the literature. Apergis et al. (2018) noted that a rise in GDP accelerates EF in 42 African countries. Nathaniel et al. (2019) found that GDP growth accelerates the EF in South Africa. Ekeocha (2021) noted the GDP growth has a U-shaped link with the EF in 47 African countries. Saint Akadiri et al. (2019) concluded that GDP growth stimulates EF in South Africa. Njoh (2021) revealed that REN mitigates CO_2, while an augment in GDP increases ecological pollution in 53 African countries. Iheonu et al. (2021) reported same finding with Njoh (2021) for 34 African nations. Obuobi et al. (2022) reported that GDP growth upsurges the EF, while REN demand mitigates ecological pollution in 11 African countries. Onifade (2023) showed that REN consumption mitigates EF, while GDP accelerates ecological issues in 10 African countries. Saba et al. (2023) reported that REN electricity output and REN consumption help to CO_2 reduction, while GDP growth upsurges ecological degradation in 51 African countries. In contrast to the general findings, Zubair et al. (2020) stated that GDP growth supports CO_2 reduction for Nigeria.

2.2 | Disaggregated renewables and environment nexus

The impact of REN on the environment (Abid et al., 2022; Adebayo & Ullah, 2024; Erdogan et al., 2020; Li et al., 2022; Ullah et al., 2023; Zhen et al., 2023) and on the economy (Berradia et al., 2023; Dabboussi & Abid, 2022; Wang et al., 2022; Zabat et al., 2022) has been analyzed by many researchers, but due to data limitations, researchers have recently focused on disaggregated REN. Ensuring the decarbonization of the energy structure is a crucial element and pivotal strategy in addressing the issue of global warming and attaining SDGs. REN assumes a significant part in the attainment of energy decarbonization, as well as enhancement of energy security, and mitigation of the environmental consequences associated with fossil fuels. Karlilar Pata and Balcilar (2024) provide evidence that a progressive transition away from dependence on fossil fuels can be attained by the widespread implementation of clean energy technologies, including hydropower, solar power, and wind power.

Tiba and Belaid (2021) find that REN increases ecological sustainability in 25 African economies. Namahoro et al. (2021) observe that REN usage contributes to the mitigation of emissions in African countries. Djellouli et al. (2022) show that REN technologies reduces the climate change risk in 20 African countries. Guo et al. (2023) demonstrate that the utilization of REN is ineffective in attaining sustainable development in 28 sub-Sahara African countries. Likewise, Nathaniel and Iheonu (2019) find the same result for 19 African countries. In the Nigerian economy, Somoye et al. (2024) show that lower quantiles of REN have an inhibitory effect on CO_2 emissions, whereas higher quantiles of REN have a favorable effect.

2.2.1 | Modern renewables

Modern renewables, such as solar, wind, and hydropower, are characterized by their lack of GhG emissions and minimal environmental impact. Further, they play a crucial role in the reversal of environmental degradation and the mitigation of potential environmental hazards. For instance, Hussain et al. (2023) observe that wind and solar energy generation reduces ecosystem by decreasing EF in 43 countries. Namahoro et al. (2023) point out that wind power has a significant role in promoting ecological sustainability in 41 countries. Xiaosan et al. (2021) find that hydropower helps improve China's ecological system. Emir and Karlilar (2023) show that hydropower is ineffective in attaining environmental sustainability in Turkey. Pata, Yurtkuran, et al. (2023) also obtain the similar findings for Turkey. Long et al. (2023) prove that wind power has a direct impact on lowering global warming levels. Wang et al. (2023) analyze comparative effectiveness of wind, solar, and hydro energy in emitting reductions. Wind power demonstrates the highest efficacy, followed by solar and hydropower. Waris et al. (2023) reveal that solar and biofuel help maintain natural ecosystem. In their study of the top five oil-importing countries, Pata and Kartal (2024) find that wind power has an increasing effect on environmental health, whereas solar power has an ineffective function.

2.2.2 | Combustible renewables and environment

Combustible renewables and waste materials function as viable alternatives to fossil fuels, hence mitigating reliance on such resources. In addition, it is important to note that these alternatives also contribute to alleviating the burden on natural resources. Recently, there is a growing body of literature regarding the environmental impact of combustible renewable energy sources and waste materials. However, the ongoing discussion regarding their potential benefits and drawbacks remains unresolved.

Jebli and Belloumi (2017) note that the use of combustible renewables and waste materials (CRW) leads to a substantial increase in emissions in Tunisia. Ali et al. (2021) reveal a bidirectional causal linkage of CRW and CO_2 emissions in 13 selected EU countries. Eweade et al. (2024) demonstrate the effectiveness of CRW in mitigating environmental contamination through the reduction of EF in the United Kingdom. Kim et al. (2020) show that biomass energy (BIO) is an effective instrument for improving natural systems in the United States (US). Zafar et al. (2021) show that BIO causes ecological problems in APEC countries. In the case of 10 biomass consuming economies, Liu et al. (2022) discover that biomass-based renewables contribute to enhancing ecological quality. Xin et al. (2023) highlight the ecological degradation caused by BIO in the top 10 biomass-consuming economies. Nguea and Fotio (2024) demonstrate the role of BIO in exacerbating environmental degradation in 31 African countries. Pata et al. (2024) find a bidirectional causal connection of BIO and load capacity factor in the US.

2.3 | Fossil fuels and environment

Despite there has been a gradual rise in the adoption of clean energy, the majority of the world's energy demands are still fulfilled by fossil fuel technologies. Numerous nations rely on conventional fossil energy technologies to enhance their economies owing to its cost-effectiveness, widespread availability, and capacity to rapidly bolster economic expansion (Wang et al., 2023). Nevertheless, the burning fossil fuels results in the release of CO_2, which is a prominent component of GhG, hence disrupting the stability of the climate system. Extensive research has been conducted in this domain (Adebayo et al., 2023; Ali & Seraj, 2022; Aslan et al., 2024; Eweade et al., 2023; Pata, Erdogan, & Ozkan, 2023; Usman et al., 2023) and the overall consensus from these studies is that fossil fuel technologies have a detrimental impact on the environment due to their emission of GhG. With regard to African countries context, Khan et al. (2023) observe that fossil fuels contribute to ecological pollution in 41 sub-Saharan countries. In the context of Kenya, Voumik et al. (2023) show the harmful impact of fossil fuels on environmental contamination but its impact is insignificant. Bekun (2024) document that fossil fuels are a significant source of ecological contamination in South Africa.

2.4 | The literature gaps

Upon conducting a comprehensive evaluation of the related literature, it is shown that numerous studies have been conducted to investigate the impact of RE sources on the environment across various African nations. However, prior research on modern and combustible renewable energy sources has hardly focused their attention towards African countries. Furthermore, the extent of available data regarding renewables in these nations was restricted to specific energy categories and a restricted range of industries, hence lacking a comprehensive examination of the environmental footprint trends. Accordingly, this study is a first pioneering effort in examining the impact of disaggregated RE on the ecological footprint within selected African countries. In particular, this study categorizes renewables as modern and combustible, and then analyzes the impact of each category on emissions separately. From this standpoint, the empirical results of the research provide valuable policy implications for African countries in accordance with the SDG-7, which emphasizes the significance of modern renewables.

3 | DATA, MODEL AND METHODOLOGY

3.1 | Data and model

The study examines the impact of fossil fuels, modern REN and combustible REN on EF for five African countries for the period 1980–2018. The study includes 75 observations on a panel basis for each variable due to limited REN data for African countries. REN resources theoretically have the potential to minimize environmental degradation (Abid et al., 2022). Previous studies have used REN as a factor in the EF for African countries, including net electricity generation (Shen et al., 2024), consumption (Njoh, 2021; Onifade, 2023), demand (Obuobi et al., 2022) and share in the total energy mix (Espoir et al., 2024). In other words, previous studies conducted in Africa considered different types of the total REN. You and Kakinaka (2022) suggested analyzing the environmental impacts of modern and traditional REN separately. In this study, the effects of modern and combustible REN on EF for Africa are examined using Equation (1).

$$\ln EF_t = \varphi_0 + \varphi_1 \ln GDP_t + \varphi_2 \ln FOS_t + \varphi_3 \ln MREN_t + \varphi_4 \ln CREN_t + u_t. \tag{1}$$

In the study, all variables are used in logarithmic form to calculate the elasticities. Table 1 shows the symbols, measures and source definitions of these variables.

Before analyzing the impact of the explanatory variables collected from two different sources on EF, the descriptive statistics are examined in Table 2.

GDP is the variable with the highest mean and maximum value. All variables comprise a total of 75 observations, with time = 15 and cross-section = 5. Skewness values close to 0 and kurtosis values close to 2 indicate that the series has a normal distribution. Fossil fuels are the most volatile variable.

3.2 | Methodology

This study follows a five-stage empirical strategy, which is illustrated in Figure 3. In the first stage, the study uses the weak CD test by Pesaran (2015) and the CDw + test by Fan et al. (2015) to test CSD. The null hypothesis of these tests shows that there is no pass-through of shocks among the countries in the analyzed panel, and the alternative hypothesis implies that CSD is present in the panel data.

In the second stage, the study applies the cross sectionally augmented Dickey-Fuller (CADF) unit root test by Pesaran (2007). The CADF approach takes into account the CSD and can be modeled by Equation (2).

$$\Delta MREN_{it} = \alpha_i + \rho_i MREN_{it-1} + \mu_i \overline{MREN}_{t-1} + \sum_{j=0}^{h} \vartheta_{ij} \Delta \overline{MREN}_{it-1} + \sum_{j=0}^{h} \theta_{ij} MREN_{it-1} + W_{it}, \tag{2}$$

where ρ_i is the coefficient from which the t statistics are measured to investigate the stationarity. If the calculated CADF test statistic is greater than the Pesaran (2007) table value in absolute value, it implies the rejection of the null hypothesis and the stationarity of the series.

The third stage is the cointegration analysis and the study uses Westerlund's (2008) Durbin-Hausman (DH) approach for this. The DH cointegration test considers the CSD and includes two test statistics: DH_{group} and DH_{panel}. Equations (3) and (4) show the modeling for the DH_{group} and DH_{panel} test statistics.

$$DH_{group} = \sum_{i=1}^{N} \hat{s}_i (\vartheta_{1i} - \vartheta_{2i})^2 \sum_{t=2}^{T} \hat{u}_{i(t-1)}^2, \tag{3}$$

$$DH_{panel} = \hat{s}_n (\vartheta_1 - \vartheta_2)^2 \sum_{i=1}^{N} \sum_{t=2}^{T} \hat{u}_{i(t-1)}^2, \tag{4}$$

where ϑ_1 and ϑ_{1i} show individual and pooled instrumental variable coefficients, respectively. The absence of cointegration is analyzed as $\vartheta_i = 1$ for all $I = 1, \ldots 5$.

The fourth stage comprises the application of the rCCE approach by Juodis (2022). The rCCE approach is derived from the CCE method of Pesaran (2006) by eliminating the deviations caused by too many cross sections. Equation (5) models the CCE approach.

TABLE 1 Definitions of the series.

Series	Symbol	Measurements	Source
Ecological footprint	EF	Global hectares per capita	GFN
Gross domestic product	GDP	Per capita, constant 2015 US$	WDI
Non-renewable energy	FOS	Electricity generation from oil, gas, and coal sources (percentage of total)	WDI
Modern renewable energy	MREN	Electricity generation from hydro, geothermal, solar, wind, tide and wave (billion kWh)	EIA
Combustible renewables and waste	CREN	Combustible renewables and waste (percentage of total energy)	WDI

Abbreviations: EIA, US Energy Information Agency database; GFN, Global Footprint Network; WDI: World Development Indicators.

TABLE 2 Descriptive statistics.

	lnEF	lnGDP	lnFOS	lnMREN	lnCREN
Mean	0.713	7.413	1.763	1.530	4.652
Std. Dev.	0.477	0.682	1.872	1.205	0.806
Maximum	−0.020	6.550	−0.693	−2.120	1.945
Minimum	1.391	8.742	5.451	2.965	6.466
Skewness	−0.261	1.189	1.307	−0.705	−0.145
Kurtosis	1.363	2.937	3.030	3.509	3.105
Observations	75	75	75	75	75

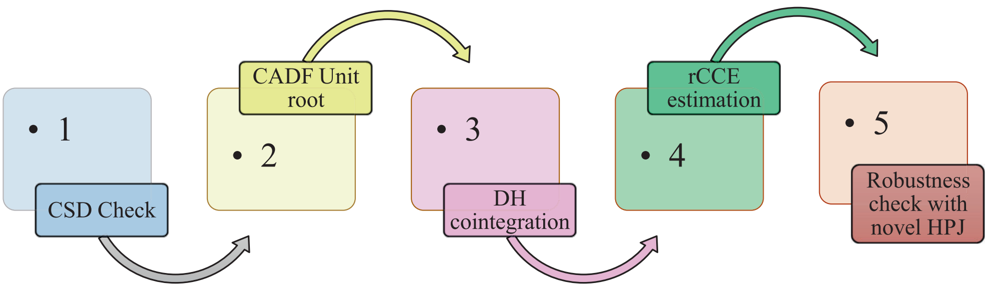

FIGURE 3 Empirical flowchart.

$$\ln y_{it} = \beta_{it} + \vartheta_i \ln x_{it} + \theta_i \ln \overline{y}_{it} + \mu_i \ln \overline{x}_{it} + c_i f_t + z_{it}, \tag{5}$$

where ϑ_i illustrates the measured parameter coefficients and f_t shows the unobserved common factor. Juodis (2022) modifies the CCE to include unproximated factors using singular value decomposition and thus provides robust elasticity estimates with rCCE.

In the fifth step, the HPJ estimator and the causality approach of Juodis et al. (2021) is employed for robustness check. The HPJ approach provides strong size and power characteristics by applying a bias correction to the estimators (Nwani et al., 2023). Equation (6) is used in the application of the HPJ test.

$$y_{i,t} = \phi_{0,i} + \sum_{p=1}^{P} \phi_{p,i}, y_{i,t-p} + \sum_{q=1}^{Q} \delta_{q,i} x_{i,t-q} + v_{i,t}, \tag{6}$$

Juodis et al. (2021) revise the causality parameter δ as in Equation (7) to avoid the Nickel bias problem.

$$\widehat{\delta} \equiv 2\widehat{\delta} - \frac{1}{2}\left(\widehat{\delta}_{\frac{1}{2}} + \widehat{\delta}_{\frac{2}{1}}\right) = \widehat{\delta} + \left(\widehat{\delta} - \frac{1}{2}\left(\widehat{\delta}_{\frac{1}{2}} + \widehat{\delta}_{\frac{2}{1}}\right)\right). \tag{7}$$

HPJ approach tests the null hypothesis that there is no causality from $x_{i,t}$ to $y_{i,t}$ as $H_0: \delta_{q,i} = 0$, and also estimates the interaction between x and y by calculating elasticities in the last stage.

4 | EMPIRICAL RESULTS

The study first reports the results of the CSD analysis in Table 3. When the CD and CDw + test statistics are analyzed as a whole, the null hypothesis that there is no CSD in the panel data is rejected. In other words, the negative impact of a political crisis, conflict, economic depression or natural disaster in one African country may affect another African country.

In a second step, the results of the unit root test are presented in Table 4. The results of the CADF test show that all series are $I(1)$ and

TABLE 3 Cross-sectional dependence check.

Variable	CD	p value	CDw+	p value
lnEF	10.03	.000	33.28	.000
lnGDP	8.67	.000	−2.13	.033
lnFOS	−0.63	.526	25.45	.000
lnMREN	0.95	.345	25.93	.000
lnCREN	0.58	.564	11.29	.000

TABLE 4 CADF unit root.

Variable	Test statistics	p value	Decision
lnEF	−1.496	.670	I(1)
lnΔEF	−3.037*	.003	
lnGDP	−2.075	.227	I(1)
lnΔGDP	−2.601**	.034	
lnFOS	−1.966	.300	I(1)
lnΔFOS	−3.703*	.000	
lnMREN	−1.513	.657	I(1)
lnΔMREN	−2.864*	.009	
lnCREN	−1.368	.758	I(1)
lnΔCREN	−4.271*	.000	

Note: * and ** denote significance at 1% and 5% levels, respectively.

TABLE 5 DH cointegration.

Variable	Test statistic	p value	Cointegration
DH_{panel}	−1.864**	0.031	✓
DH_{group}	−1.787**	0.039	✓

Note: ** denotes significance at 5% level.

TABLE 6 Regularization common correlated effects estimation.

Variable	Coefficient	Standard error	p value
lnGDP	−0.640***	0.377	.090
lnFOS	0.227**	0.099	.022
lnMREN	0.033	0.109	.760
lnCREN	0.001	0.0320	.981

Note: ** and *** denote significance at 5% and 10% levels, respectively.

therefore the cointegration relationships between EF, GDP, FOS, MREN and CREN can be examined using a second-generation panel data approach.

To analyze the long-term relationships, the study applies the DH panel cointegration approach and reports the results in Table 5. The DH test statistics indicate the existence of a strong long-term interaction between the series.

After confirming the existence of cointegration, the study calculates long-term elasticities using the novel rCCE approach and reports them in Table 6. A 1% increase in GDP reduces EF by 0.64. Conversely, a 1% increase in FOS increases EF by 0.22. MREN and CREN have no statistically significant effect on EF.

The study checks the reliability of the rCCE results with the HPJ approach and presents the results in Table 7. The HPJ results indicate a unidirectional causality from GDP and FOS to EF. However, there is no causal relationship between MREN and CREN and EF. The results of the elasticity calculation are consistent with rCCE. A 1% upsurge in GDP reduces EF by 0.28. In contrast, a 1% augment in fossil fuels increases EF by 0.21.

The main findings of the study are summarized in Figure 4. The findings suggest that the harmful effects of fossil fuels for the African continent can be minimized by GDP growth, but the REN is not yet sufficient to reduce the EF.

The view that GDP brings environmental benefits contrasts with the findings of Apergis et al. (2018), Saint Akadiri et al. (2019), Obuobi et al. (2022), and Saba et al. (2023). The green role of GDP for Africa supports the outcomes of Zubair et al. (2020). African countries need financial resources to invest in REN energy, disseminate environmental awareness programs, develop eco-friendly technologies and minimize water pollution through purification. In order to better transfer financial resources to African countries, the development of the countries' economies and financial infrastructures is essential. To achieve this, GDP growth must be at the top of the African political agenda. Africa's GDP growth can help achieve the SDGs by bringing economic and environmental benefits at the same time.

The results of HPJ and rCCE indicate that MREN and CREN did not reduce EF in five African countries. These findings are inconsistent with Njoh (2021), and Iheonu et al. (2021) who noted that REN provides environmental benefits for Africa, Onifade (2023), and Saba et al. (2023). The reason why disaggregated REN does not reduce EF in Africa could be the ineffective and underutilization of REN resources. Pata (2018), Pata and Caglar (2021), and Pata and

TABLE 7 Half-panel jackknife estimation and causality.

	Lag	Wald test	p value	Coefficient	p value
lnGDP ↛ lnEF	1	4.026**	.048	−0.281**	.045
lnFOS ↛ lnEF	1	3.108***	.077	0.214***	.078
lnMREN ↛ lnEF	1	1.692	.192	0.018	.193
lnCREN ↛ lnEF	1	0.652	.419	0.007	.419

Note: ** and *** denote significance at 5% and 10% levels, respectively.

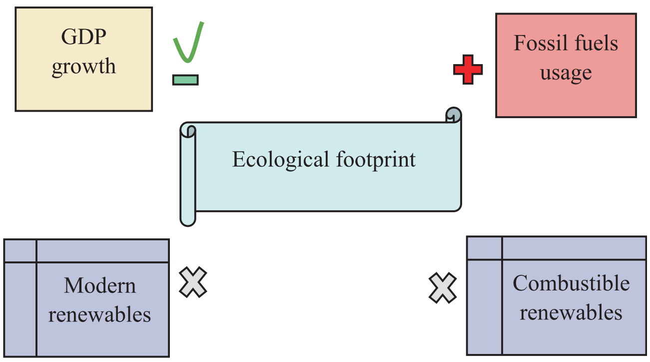

FIGURE 4 Visual summary of the outcomes.

Samour (2022) stated that REN energy does not reduce CO_2 due to ineffective utilization in Turkey, China and France, respectively. Modern REN usage, especially in African countries, is much lower than in these three countries. Moreover, the development of REN technologies in Africa is far behind other continents. Based on this discussion, Africa must first complete its economic development and then make a breakthrough in the REN field.

5 | CONCLUSION AND POLICY CAVEATS

5.1 | Conclusion

This study analyzes the comparative impact of fossil fuels, modern REN, and combustible REN on EF using the rCCE and HPJ approaches. To this end, the study uses panel data from five African countries. The empirical results obtained from the from the rCCE method show that GDP has a favorable impact on environmental damage, while fossil fuels have a destructive impact on the EF. The empirical results further reveal that modern REN and combustible REN have no impact on the ecological system. Based on these findings, the study offers REN and GDP-based environmental policy recommendations for the achievement of the SDGs in the African region.

5.2 | Policy caveats

The positive impact of the GDP suggests that when the economic levels of African nations increase, they may have a greater understanding of the significance of clean energy technology and strategically allocate resources towards their investment. Hence, it is important for African nations to prioritize the attainment of sustainable development through the enhancement of their financial stability.

The negative impact of FOS suggests that the energy structures of the African countries under investigation are predominantly reliant on fossil fuel, and the extensive usage of these resources is associated with adverse environmental consequences. The use of fossil fuel in electrical energy production is over 50% in three of the five African countries analyzed (Our World in Data, 2024). However, a significant part of the African continent does not have easy access to electricity and the risk to energy security is greatest in this region. In this context, the African community should channel the income gains from its economic expansion into alternative sources of energy and ensure technological and efficient advances to utilize these resources cheaply and effectively.

The results also suggest that REN sources are not effective in mitigating environmental degradation. This implies that the current level of modern REN and combustible REN in African countries is not sufficient to improve ecological conditions. It can be inferred that the current level of income in African countries is not sufficient to support investments in REN due to their substantial initial costs. African countries should therefore give priority to raising their level of economic development first. They can achieve both development and environmental sustainability by investing in clean energy resources while increasing their income levels and working towards this goal.

Despite the benefits of REN in promoting sustainable development in African countries, most governments have failed to attract the necessary investments and lack a solid political commitment to promoting REN sources. Moreover, the deployment of REN in African countries is hindered by various problems, such as lack of financial resources, inadequate institutional frameworks and infrastructure, insufficient REN legislation, and a shortage of skilled labor. Therefore, first, the establishment and implementation of stable economic policies should be the top priority of African governments in order to achieve long-term economic stability. Second, cooperation between the public and private sectors can effectively combat climate change by creating financial incentives for investment in REN initiatives. Third, the governments of African countries can promote collaboration among stakeholders to drive the advancement of REN. This can be achieved by creating the necessary infrastructure, technologies, and an enabling environment that encourages investors in the energy sector to actively drive the development of REN sources. Fourth, governments can facilitate investment in clean energy by introducing tax exemptions and providing tax incentives. Finally, governments can implement disincentive policies by imposing stringent taxation on companies that rely heavily on fossil fuels as their main source of energy.

5.3 | Limitations and future directions

This study has some limitations. The primary limitation of this study was the difficulty in collecting data on modern REN and combustible REN within the African context. Future research can therefore examine modern REN and combustible REN for developing countries, industrialized countries, or different sets of countries, including European countries, the OECD, and BRICS. Second, future research can expand the scope of this study by incorporating more African economies. Third, future research can examine the ecological consequences of various factors, such as institutional quality, financial development, and digitalization, in African nations. Fourth, the study considers environmental assessment only in terms of human demand for natural resources, taking EF into account. Future studies can analyze the ecological effects of MREN and CREN by examining the load capacity factor. In this way, the environmental impacts of MREN and CREN for Africa and other continents can be assessed simultaneously in terms of supply and demand for natural resources.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

Abid, M., Gheraia, Z., & Abdelli, H. (2022). Does renewable energy consumption affect ecological footprints in Saudi Arabia? A bootstrap causality test. *Renewable Energy*, *189*, 813–821.

Adebayo, T. S., Kartal, M. T., & Ullah, S. (2023). Role of hydroelectricity and natural gas consumption on environmental sustainability in the United States: Evidence from novel time-frequency approaches. *Journal of Environmental Management*, *328*, 116987.

Adebayo, T. S., & Ullah, S. (2024). Towards a sustainable future: The role of energy efficiency, renewable energy, and urbanization in limiting CO_2 emissions in Sweden. *Sustainable Development*, *32*(1), 244–259.

African Union. (2024). Agenda 2063: The Africa We Want. https://au.int/agenda2063/goals

Ali, M., & Seraj, M. (2022). Nexus between energy consumption and carbon dioxide emission: Evidence from 10 highest fossil fuel and 10 highest renewable energy-using economies. *Environmental Science and Pollution Research*, *29*(58), 87901–87922. https://doi.org/10.1007/s11356-022-21900-9

Ali, S., Akter, S., & Fogarassy, C. (2021). The role of the key components of renewable energy (combustible renewables and waste) in the context of CO_2 emissions and economic growth of selected countries in Europe. *Energies*, *14*(8), 2034. https://doi.org/10.3390/en14082034

Aliyu, A. K., Modu, B., & Tan, C. W. (2018). A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, *81*, 2502–2518.

Apergis, N., Jebli, M. B., & Youssef, S. B. (2018). Does renewable energy consumption and health expenditures decrease carbon dioxide emissions? Evidence for sub-Saharan Africa countries. *Renewable Energy*, *127*, 1011–1016.

Aslan, A., Ilhan, O., Usama, A. M., Savranlar, B., Polat, M. A., Metawa, N., & Raboshuk, A. (2024). Effect of economic policy uncertainty on CO_2 with the discrimination of renewable and non renewable energy consumption. *Energy*, *291*, 130382. https://doi.org/10.1016/j.energy.2024.130382

Aust, V., Morais, A. I., & Pinto, I. (2020). How does foreign direct investment contribute to sustainable development goals? Evidence from African countries. *Journal of Cleaner Production*, *245*, 118823.

Aytun, C., Erdogan, S., Pata, U. K., & Cengiz, O. (2024). Associating environmental quality, human capital, financial development and technological innovation in 19 middle-income countries: A disaggregated ecological footprint approach. *Technology in Society*, *76*, 102445.

Bartniczak, B., & Raszkowski, A. (2018). Sustainable development in African countries: An indicator-based approach and recommendations for the future. *Sustainability*, *11*(1), 22.

Bekun, F. V. (2024). Race to carbon neutrality in South Africa: What role does environmental technological innovation play? *Applied Energy*, *354*, 122212. https://doi.org/10.1016/j.apenergy.2023.122212

Berradia, H., Abid, M., Sakrafi, H., Gheraia, Z., & Abdelli, H. (2023). The effect of renewable energy consumption on economic growth in KSA: A bootstrap causality test. *Energy & Environment*, *34*(6), 1787–1804.

Bugaje, I. M. (2006). Renewable energy for sustainable development in Africa: A review. *Renewable and Sustainable Energy Reviews*, *10*(6), 603–612.

Dabboussi, M., & Abid, M. (2022). A comparative study of sectoral renewable energy consumption and GDP in the US: Evidence from a threshold approach. *Renewable Energy*, *192*, 705–715.

Djellouli, N., Abdelli, L., Elheddad, M., Ahmed, R., & Mahmood, H. (2022). The effects of non-renewable energy, renewable energy, economic growth, and foreign direct investment on the sustainability of African countries. *Renewable Energy*, *183*, 676–686. https://doi.org/10.1016/j.renene.2021.10.066

Ekeocha, D. O. (2021). Urbanization, inequality, economic development and ecological footprint: Searching for turning points and regional homogeneity in Africa. *Journal of Cleaner Production*, *291*, 125244.

Emir, F., & Karlilar, S. (2023). Application of RALS cointegration test assessing the role of natural resources and hydropower energy on ecological footprint in emerging economy. *Energy & Environment*, *34*(4), 764–779. https://doi.org/10.1177/0958305X211073807

Erdogan, S., Okumus, I., & Guzel, A. E. (2020). Revisiting the environmental Kuznets curve hypothesis in OECD countries: The role of renewable, non-renewable energy, and oil prices. *Environmental Science and Pollution Research*, *27*, 23655–23663.

Espoir, D. K., Sunge, R., Nchofoung, T., & Alola, A. A. (2024). Analysing the drivers of ecological footprint in Africa with machine learning algorithm. *Environmental Impact Assessment Review*, *104*, 107332.

Eweade, B. S., Akadiri, A. C., Olusoga, K. O., & Bamidele, R. O. (2024). The symbiotic effects of energy consumption, globalization, and combustible renewables and waste on ecological footprint in the United Kingdom. In *Natural resources forum* (Vol. 48, pp. 274–291). Blackwell Publishing Ltd. https://doi.org/10.1111/1477-8947.12392

Eweade, B. S., Karlilar, S., Pata, U. K., Adeshola, I., & Olaifa, J. O. (2023). Examining the asymmetric effects of fossil fuel consumption, foreign direct investment, and globalization on ecological footprint in Mexico. *Sustainable Development*. https://doi.org/10.1002/sd.2825

Fan, J., Liao, Y., & Yao, J. (2015). Power enhancement in high-dimensional cross-sectional tests. *Econometrica*, *83*(4), 1497–1541.

Global Footprint Network (2024). https://data.footprintnetwork.org/#/

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement. Working paper No: 3914.

Guo, Q., Abbas, S., AbdulKareem, H. K., Shuaibu, M. S., Khudoykulov, K., & Saha, T. (2023). Devising strategies for sustainable development in sub-Saharan Africa: The roles of renewable, non-renewable energy, and natural resources. *Energy*, *284*, 128713. https://doi.org/10.1016/j.energy.2023.128713

Hussain, B., Naqvi, S. A. A., Anwar, S., & Usman, M. (2023). Effect of wind and solar energy production, and economic development on the environmental quality: Is this the solution to climate change? *Gondwana Research*, *119*, 27–44. https://doi.org/10.1016/j.gr.2023.01.012

Ibrahim, I. D., Hamam, Y., Alayli, Y., Jamiru, T., Sadiku, E. R., Kupolati, W. K., Ndambuki, J. M., & Eze, A. A. (2021). A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study. *Energy Strategy Reviews*, *38*, 100740.

Iheonu, C. O., Anyanwu, O. C., Odo, O. K., & Nathaniel, S. P. (2021). Does economic growth, international trade, and urbanization uphold environmental sustainability in sub-Saharan Africa? Insights from quantile and causality procedures. *Environmental Science and Pollution Research*, *28*, 28222–28233.

Investopedia. (2023). The Top 25 Economies in the World. https://www.investopedia.com/insights/worlds-top-economies/

IRENA. (2024). IRENASTAT Online Data Query Tool. https://pxweb.irena.org/pxweb/en/IRENASTAT

Jebli, M. B., & Belloumi, M. (2017). Investigation of the causal relationships between combustible renewables and waste consumption and CO_2 emissions in the case of Tunisian maritime and rail transport. *Renewable and Sustainable Energy Reviews*, *71*, 820–829. https://doi.org/10.1016/j.rser.2016.12.108

Juodis, A. (2022). A regularization approach to common correlated effects estimation. *Journal of Applied Econometrics*, *37*(4), 788–810.

Juodis, A., Karavias, Y., & Sarafidis, V. (2021). A homogeneous approach to testing for granger non-causality in heterogeneous panels. *Empirical Economics*, *60*(1), 93–112.

Karlilar Pata, S., & Balcilar, M. (2024). Decarbonizing energy: Evaluating fossil fuel displacement by renewables in OECD countries. *Environmental Science and Pollution Research*, *2024*. https://doi.org/10.1007/s11356-024-33324-8

Khan, S. A. R., Zia-Ul-Haq, H. M., Ponce, P., & Janjua, L. (2023). Re-investigating the impact of non-renewable and renewable energy on environmental quality: A roadmap towards sustainable development. *Resources Policy*, *81*, 103411. https://doi.org/10.1016/j.resourpol.2023.103411

Kim, G., Choi, S. K., & Seok, J. H. (2020). Does biomass energy consumption reduce total energy CO2 emissions in the US? *Journal of Policy Modeling*, *42*(5), 953–967. https://doi.org/10.1016/j.jpolmod.2020.02.009

Li, R., Wang, X., & Wang, Q. (2022). Does renewable energy reduce ecological footprint at the expense of economic growth? An empirical analysis of 120 countries. *Journal of Cleaner Production*, *346*, 131207.

Liu, Z., Saydaliev, H. B., Lan, J., Ali, S., & Anser, M. K. (2022). Assessing the effectiveness of biomass energy in mitigating CO_2 emissions: Evidence from top-10 biomass energy consumer countries. *Renewable Energy*, *191*, 842–851. https://doi.org/10.1016/j.renene.2022.03.053

Long, Y., Chen, Y., Xu, C., Li, Z., Liu, Y., & Wang, H. (2023). The role of global installed wind energy in mitigating CO_2 emission and temperature rising. *Journal of Cleaner Production*, *423*, 138778. https://doi.org/10.1016/j.jclepro.2023.138778

Mugagga, F., & Nabaasa, B. B. (2016). The centrality of water resources to the realization of sustainable development goals (SDG). A review of potentials and constraints on the African continent. *International Soil and Water Conservation Research*, *4*(3), 215–223.

Namahoro, J. P., Wu, Q., & Su, H. (2023). Wind energy, industrial-economic development and CO2 emissions nexus: Do droughts matter? *Energy*, *278*, 127869. https://doi.org/10.1016/j.energy.2023.127869

Namahoro, J. P., Wu, Q., Zhou, N., & Xue, S. (2021). Impact of energy intensity, renewable energy, and economic growth on CO_2 emissions: Evidence from Africa across regions and income levels. *Renewable and Sustainable Energy Reviews*, *147*, 111233. https://doi.org/10.1016/j.rser.2021.111233

Nathaniel, S., Nwodo, O., Adediran, A., Sharma, G., Shah, M., & Adeleye, N. (2019). Ecological footprint, urbanization, and energy consumption in South Africa: Including the excluded. *Environmental Science and Pollution Research*, *26*, 27168–27179.

Nathaniel, S. P., & Iheonu, C. O. (2019). Carbon dioxide abatement in Africa: The role of renewable and non-renewable energy consumption. *Science of the Total Environment*, *679*, 337–345. https://doi.org/10.1016/j.scitotenv.2019.05.011

Nguea, S. M., & Fotio, H. K. (2024). Synthesizing the role of biomass energy consumption and human development in achieving environmental sustainability. *Energy*, *293*, 130500. https://doi.org/10.1016/j.energy.2024.130500

Njoh, A. J. (2021). Renewable energy as a determinant of inter-country differentials in CO_2 emissions in Africa. *Renewable Energy*, *172*, 1225–1232.

Nwani, C., Usman, O., Okere, K. I., & Bekun, F. V. (2023). Technological pathways to decarbonisation and the role of renewable energy: A study of European countries using consumption-based metrics. *Resources Policy*, *83*, 103738.

Obuobi, B., Zhang, Y., Nketiah, E., Adu-Gyamfi, G., & Cudjoe, D. (2022). Renewable energy demand, financial reforms, and environmental quality in West Africa. *Environmental Science and Pollution Research*, *29*(46), 69540–69554.

Omisore, A. G. (2018). Attaining sustainable development goals in sub-Saharan Africa; the need to address environmental challenges. *Environmental Development*, *25*, 138–145.

Onifade, S. T. (2023). Environmental impacts of energy indicators on ecological footprints of oil-exporting African countries: Perspectives on fossil resources abundance amidst sustainable development quests. *Resources Policy*, *82*, 103481.

Our World in Data. (2024). Share of primary energy consumption from fossil fuels, 2022. https://ourworldindata.org/fossil-fuels

Pata, U. K. (2018). Renewable energy consumption, urbanization, financial development, income and CO_2 emissions in Turkey: Testing EKC hypothesis with structural breaks. *Journal of Cleaner Production*, *187*, 770–779.

Pata, U. K., & Caglar, A. E. (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.

Pata, U. K., Erdogan, S., & Ozkan, O. (2023). Is reducing fossil fuel intensity important for environmental management and ensuring ecological efficiency in China? *Journal of Environmental Management*, *329*, 117080. https://doi.org/10.1016/j.jenvman.2022.117080

Pata, U. K., & Kartal, M. T. (2024). Testing the ecological effect of wind and solar energy consumption: A novel regularized common correlated effect approach for top oil-importing countries. In *Natural resources forum*. Blackwell Publishing Ltd. https://doi.org/10.1111/1477-8947.12455

Pata, U. K., & Samour, A. (2022). Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor. *Progress in Nuclear Energy*, *149*, 104249.

Pata, U. K., Wang, Q., Kartal, M. T., & Sharif, A. (2024). The role of disaggregated renewable energy consumption on income and load capacity factor: A novel inclusive sustainable growth approach. *Geoscience Frontiers*, *15*(1), 101693. https://doi.org/10.1016/j.gsf.2023.101693

Pata, U. K., Yurtkuran, S., Ahmed, Z., & Kartal, M. T. (2023). Do life expectancy and hydropower consumption affect ecological footprint? Evidence from novel augmented and dynamic ARDL approaches. *Heliyon*, *9*(9), e19567. https://doi.org/10.1016/j.heliyon.2023.e19567

Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, *74*(4), 967–1012.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312.

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, *34*(6–10), 1089–1117.

Rajmil, D., Morales, L., & Andreosso-O'Callaghan, B. (2023). The onus on coal consumption and the 'beautiful China initiative': Economic and policy implications. *China Report*, *59*(4), 349–368.

Royo, M. G., Diep, L., Mulligan, J., Mukanga, P., & Parikh, P. (2022). Linking the UN sustainable development goals and African agenda 2063: Understanding overlaps and gaps between the global goals and continental priorities for Africa. *World Development Sustainability*, *1*, 100010.

Saba, C. S., Djemo, C. R. T., Eita, J. H., & Ngepah, N. (2023). Towards environmental sustainability path in Africa: The critical role of ICT, renewable energy sources, agriculturalization, industrialization and institutional quality. *Energy Reports*, *10*, 4025–4050.

Saint Akadiri, S., Bekun, F. V., & Sarkodie, S. A. (2019). Contemporaneous interaction between energy consumption, economic growth and environmental sustainability in South Africa: What drives what? *Science of the Total Environment*, *686*, 468–475.

Schwerhoff, G., & Sy, M. (2017). Financing renewable energy in Africa—Key challenge of the sustainable development goals. *Renewable and Sustainable Energy Reviews*, *75*, 393–401.

Shen, J., Ibrahim, R. L., Ajide, K. B., & Al-Faryan, M. A. S. (2024). Tracking environmental sustainability pathways in Africa: Do natural resource dependence, renewable energy, and technological innovations amplify or reduce the pollution noises? *Energy & Environment*, *35*(1), 88–112.

Somoye, O. A., Seraj, M., Ozdeser, H., & Mar'I, M. (2024). Modelling the connection between energy intensity, renewable energy, globalization, technological innovation and CO_2 emissions: A quantile–on–quantile technique. *Geological Journal*, *59*, 1322–1336. https://doi.org/10.1002/gj.4930

Stern, D. I. (1997). Limits to substitution and irreversibility in production and consumption: A neoclassical interpretation of ecological economics. *Ecological Economics*, *21*(3), 197–215.

Tiba, S., & Belaid, F. (2021). Modeling the nexus between sustainable development and renewable energy: The African perspectives. *Journal of Economic Surveys*, *35*(1), 307–329. https://doi.org/10.1111/joes.12401

Ullah, S., Luo, R., Sunday Adebayo, T., & Balsalobre-Lorente, D. (2023). Green perspectives of finance, technology innovations, and energy consumption in restraining carbon emissions in China: Fresh insights from wavelet approach. *Energy Sources, Part B: Economics, Planning, and Policy*, *18*(1), 2255584.

Ullah, S., Niu, B., & Meo, M. S. (2024). Digital inclusion and environmental taxes: A dynamic duo for energy transition in green economies. *Applied Energy*, *361*, 122911.

United Nations. (2015). Transforming our world: the 2030 Agenda for Sustainable Development. https://sdgs.un.org/2030agenda

Usman, O., Alola, A. A., Usman, M., & Uzuner, G. (2023). Asymmetric effect of environmental cost of forest rents in the Guinean forest-savanna mosaic: The Nigerian experience. *Environmental Science and Pollution Research*, *30*(17), 50549–50566. https://doi.org/10.1007/s11356-023-25653-x

Voumik, L. C., Ridwan, M., Rahman, M. H., & Raihan, A. (2023). An investigation into the primary causes of carbon dioxide releases in Kenya: Does renewable energy matter to reduce carbon emission? *Renewable Energy Focus*, *47*, 100491. https://doi.org/10.1016/j.ref.2023.100491

Wackernagel, M., & Rees, W. E. (1997). Perceptual and structural barriers to investing in natural capital: Economics from an ecological footprint perspective. *Ecological Economics*, *20*(1), 3–24.

Wang, Q., Guo, J., & Li, R. (2023). Better renewable with economic growth without carbon growth: A comparative study of impact of turbine, photovoltaics, and hydropower on economy and carbon emission. *Journal of Cleaner Production*, *426*, 139046. https://doi.org/10.1016/j.jclepro.2023.139046

Wang, Q., Zhang, F., Li, R., & Li, L. (2022). The impact of renewable energy on decoupling economic growth from ecological footprint–an empirical analysis of 166 countries. *Journal of Cleaner Production*, *354*, 131706.

Waris, A., Khan, S., Hronec, M., & Suplata, M. (2023). The impact of hydro-biofuel-wind-solar energy consumption and coal consumption on carbon emission in G20 countries. *Environmental Science and Pollution Research*, *30*(28), 72503–72513. https://doi.org/10.1007/s11356-023-27442-y

Westerlund, J. (2008). Panel cointegration tests of the fisher effect. *Journal of Applied Econometrics*, *23*(2), 193–233.

Xiaosan, Z., Qingquan, J., Iqbal, K. S., Manzoor, A., & Ur, R. Z. (2021). Achieving sustainability and energy efficiency goals: Assessing the impact of hydroelectric and renewable electricity generation on carbon dioxide emission in China. *Energy Policy*, *155*, 112332. https://doi.org/10.1016/j.enpol.2021.112332

Xin, Y., Li, H., Sunday Adebayo, T., & Ayobamiji Awosusi, A. (2023). Asymmetric linkage between biomass energy consumption and ecological footprints in top ten biomass-consuming nations. *Economic Research-Ekonomska istraživanja*, *36*(3), 2147567. https://doi.org/10.1080/1331677X.2022.2147567

You, V., & Kakinaka, M. (2022). Modern and traditional renewable energy sources and CO_2 emissions in emerging countries. *Environmental Science and Pollution Research*, *29*(12), 17695–17708.

Zabat, L. H., Sadaoui, N. A., Abid, M., & Sekrafi, H. (2022). Threshold effects of renewable energy consumption by source in US economy. *Electric Power Systems Research*, *213*, 108669.

Zafar, M. W., Sinha, A., Ahmed, Z., Qin, Q., & Zaidi, S. A. H. (2021). Effects of biomass energy consumption on environmental quality: The role of education and technology in Asia-Pacific economic cooperation countries. *Renewable and Sustainable Energy Reviews*, *142*, 110868. https://doi.org/10.1016/j.rser.2021.110868

Zhen, Z., Ullah, S., Shaowen, Z., & Irfan, M. (2023). How do renewable energy consumption, financial development, and technical efficiency change cause ecological sustainability in European Union countries? *Energy & Environment*, *34*(7), 2478–2496.

Zubair, A. O., Samad, A. R. A., & Dankumo, A. M. (2020). Does gross domestic income, trade integration, FDI inflows, GDP, and capital reduces CO_2 emissions? An empirical evidence from Nigeria. *Current Research in Environmental Sustainability*, *2*, 100009.

How to cite this article: Pata, U. K., & Karlilar Pata, S. (2024). Towards sustainable development in African countries: Are modern and combustible renewable energies effective? *Sustainable Development*, 1–11. https://doi.org/10.1002/sd.3040