PANEL DATA ANALYSIS ON THE DETERMINANTS OF RENEWABLE ENERGY CONSUMPTION IN AFRICAN COUNTRIES

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Abstract

Africa consists of countries that are primarily dependent on fossil fuels for energy but have significant potential in many types of renewable energy. Therefore, the study investigates the factors affecting the use of renewable energy in 15 African countries in the context of panel data analysis over the period of 1980-2018. Cointegration analysis of variables is carried out using Kao, Pedroni, and Westerlund techniques, and Driscoll-Kraay and FGLS estimation methods examine long-term coefficients. The findings point out a cointegration between the variables. While economic growth, FDI, and trade openness support renewable energy use, financial development and natural resources hinder it. The findings also indicate a two-way causality between all independent variables and renewable energy use. The study will be able to put forward some policy suggestions that can improve the renewable energy sector in African countries.

Keywords: Renewable Energy, Economic Growth, Cointegration, Causality, African Countries

JEL Codes: C33, O47, F14, F41

AFRİKA ÜLKELERİNDE YENİLENEBİLİR ENERJİ TÜKETİMİNİN BELİRLEYİCİLERİ ÜZERİNE PANEL VERİ ANALİZİ

Öz

Afrika, enerji açısından büyük ölçüde fosil yakıtlara bağımlı olan ancak birçok yenilenebilir enerji türünde önemli potansiyele sahip ülkelerden oluşmaktadır. Bu nedenle çalışmada Afrika ülkelerinde yenilenebilir enerji kullanımını etkileyen faktörler panel veri analizi bağlamında araştırılmaktadır. Değişkenlerin eşbütünleşme analizi Kao, Pedroni ve Westerlund teknikleri ile yapılmakta olup, uzun dönem katsayıları Driscoll-Kraay ve FGLS tahmin yöntemleri ile incelenmektedir. Bulgular değişkenler arasında eşbütünleşme olduğuna işaret etmektedir. Ekonomik büyüme, doğrudan yabancı yatırım ve ticari açıklık yenilenebilir enerji kullanımını desteklerken, finansal gelişme ve doğal kaynaklar bunu engellemektedir. Bulgular ayrıca tüm bağımsız değişkenler ile yenilenebilir enerji kullanımı arasında iki yönlü bir nedenselliğe işaret etmektedir. Çalışma Afrika ülkelerinde yenilenebilir enerji sektörünü geliştirebilecek bazı politika önerileri ortaya koyabilecektir.

Anahtar Kelimeler: Yenilenebilir Enerji, Ekonomik Büyüme, Eşbütünleşme, Nedensellik, Afrika Ülkeleri

JEL Kodları: C33, O47, F14, F41

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1. Introduction

Renewable energy sources, such as hydropower, solar, and wind, have many important functions, such as ensuring energy efficiency, savings, and effectiveness, as well as being clean and environmentally friendly (Jaiswal et al., 2022; Strielkowski et al., 2021). Due to these features, some empirical studies today focus on renewable energy resources (Chen et al., 2021; Tu et al., 2022; Iqbal et al., 2023).

Africa is one of the country groups where the determinants of renewable energy resources are analyzed. Blessed with abundant natural resources and breathtaking landscapes, Africa is widely recognized for its untapped potential. Despite facing challenges such as poverty, underdevelopment, and limited access to basic amenities, Africa offers an excellent opportunity for sustainable development through renewable energy sources. The importance of renewable energy in African countries has gained significant traction in recent years as a critical solution to address pressing issues like energy poverty, climate change, and economic growth.

Furthermore, renewable energy provides significant economic prospects for African countries. The continent possesses abundant solar radiation, wind resources, and hydroelectric potential, making it an ideal location for renewable energy investments. Embracing renewable energy technologies can generate local employment, stimulate economic growth, attract foreign investments, and reduce the need for expensive fuel imports. Additionally, decentralized renewable energy systems can empower local communities, encourage entrepreneurship, and unlock new avenues for innovation and technological advancements. Moreover, the significance of renewable energy in Africa goes beyond individual countries. The continent's energy requirement is expected to increase considerably due to population growth, urbanization, and industrialization. By adopting renewable energy sources, African nations can sustainably fulfill their energy needs and steer clear of the challenges associated with reliance on fossil fuels faced by other areas. Furthermore, renewable energy initiatives can encourage regional collaboration, facilitating partnerships and cross-border electricity exchange to maximize resource utilization and strengthen energy security.

This paper focuses on the relationship between renewable energy and its determinants by applying panel data techniques such as CADF unit root, Kao, Pedroni, and Westerlund cointegration, Driscoll-Kraay and FGLS estimation, and Dumitrescu-Hurlin causality approaches. To be expressed more broadly, this study analyzes how economic growth, foreign direct investment, financial development, trade openness, and natural resources affect renewable energy use in 15 African countries from 1980 to 2018. The preference of these periods is based on the availability of the relevant data to perform our evaluation. Moreover, the African countries under this study are Benin, Botswana, Côte d'Ivoire, Cameroon, Congo, Algeria, Egypt, Gabon, Ghana, Kenya, Morocco, Nigeria, Senegal, Tunisia and South Africa respectively. There are fundamental reasons why these countries are the subject of research: i) they are underdeveloped economies and have a similar level of development; ii) these countries consume mainly fossil fuels in their economies; iii) they usually meet such energy demands by importing them; iv) they are faced with environmental problems caused mainly by the consumption of fossil fuels; v) finally, these countries are African countries whose data can be obtained.

The next parts of the study are determined as follows: The second part focuses on the literature. The third section covers the model and methodology. The fourth section considers the findings. The study ends with a conclusion and policy recommendations.

2. Literature

Four testable hypotheses underpin the causal relationship between energy use and economic growth. The growth hypothesis suggests that energy consumption can either directly contribute to growth or complement the efforts of capital and labor. According to conservation theory, economic development determines energy use. The feedback hypothesis is based on the interdependence of two variables. The neutrality hypothesis implies no link between these variables (Apergis & Payne, 2010; Narayan, 2016).

Sari et al. (2008), who utilized the ARDL technique to analyze the United States, demonstrate that production and employment are significant long-term energy use factors. Ocal & Aslan (2013), who explored the correlation between energy usage and economic growth, indicate that renewable energy has a detrimental influence on economic development. Furthermore, Findings suggest that energy use causes economic growth. Lean & Smyth (2013), who analyzed Malaysia, concludes that diesel is the main factor driving Malaysia's economic growth. Tugcu (2013) suggests a two-way causality between these series by applying the Granger causality approach. Bildirici (2013) reveals cointegration among the variables and a weak causal link between the variables in some countries. Lin & Moubarak (2014), who employed the ARDL methodology, show that China's economic development benefits from renewable energy. A study by Yazdi & Beygi (2018) indicates a positive link between renewable energy and growth.

Financial development influences energy consumption through three pathways. The first is connected with the improved financial sector, when customers can borrow money more quickly and at reduced rates to purchase large-ticket things that require a lot of energy. The second arises when enhanced financial development simplifies businesses' access to financial resources (Coban & Topcu, 2013). According to Sadorsky (2012), the third happens when there is an increase in confidence paired with an economic expansion.

Coban & Topcu (2013), who used the GMM model, indicate that increased financial development has a favorable impact on energy use. The influence of financial development on energy use depends on the financial sustainability of the new members. Chang’s (2015) outcomes show that energy use rises with financial development in low-income countries. Paramati et al. (2016) find that developing foreign capital and stock exchanges plays a highly significant role in improving renewable energy. Yu et al. (2018) demonstrate that the stock exchange reduces energy usage, while bank loans have an increasing effect. FDI reduces energy usage in both the region and the surrounding areas. Destek (2018) shows that bond market improvement has the greatest influence on decreasing energy use. Anton & Nucu (2020) indicate that stock markets have a positive impact on renewable energy.

Several processes, including the size effect, technical effect, and composition effect, can describe the FDI-energy consumption nexus. Because FDI often improves the output level in a host country, its energy consumption rises due to the scale effect. In other words, through the scale effect, FDI discourages using renewable energy in host countries (Tan & Uprasen, 2022). Unlike underdeveloped countries with inadequate financial systems, rich financial resource countries can use their finances to boost renewable energy development. Poor-resource countries rely on fossil fuel energy, badly impacting the environment (Akpanke et al., 2023).

Focusing on the FDI-growth link, Samour et al. (2022) analyze the UAE during the period 1989-2019. The study uses time-series techniques. According to the findings, it has been suggested that the UAE's renewable energy potential can experience significant growth through economic development and foreign direct investment. Islam et al. (2022), who applied the dynamic ARDL approach, detected that FDI stimulates all the energy resources. Khandker et al. (2018), who used time series data for Bangladesh, indicate that the relevant variables are causally related in both directions.

Numerous academic studies explore the connection between natural resources and renewable energy use. When applied to other methods, sample groups, and periods, these studies give different results. Majeed et al. (2021) present a study using the CS-ARDL estimator to analyze how natural resource abundance affected the environmental quality of GCC countries. The study reveals that abundant natural resources pollute the environment. Ma et al. (2023), who analyzed OECD nations, show that natural resources positively impact renewable energy use across all levels of society.

By analyzing data from 162 countries, Han et al. (2023), who focused on the link between natural resources and the use of renewable energy, found a significant link between these variables. Chau et al. (2022) conducted a study to investigate how the exploration and utilization of green energy impact natural resources. The researchers employed the MMQR method to indicate a positive connection between green energy and natural resources in the G7 countries. Ahmadov & Borg (2019), who conducted an extensive study of natural resources in the EU countries, revealed that abundant natural resources decrease the EU's renewable energy use.

Trade openness is a crucial factor in economic growth because it leads to the growth of the internal market, the development of industries that focus on exports, the acquisition of technologies that save energy, and the improvement of trade between two countries. Most importantly, embracing trade leads to increased economic activity, resulting in higher energy consumption (Sadorsky, 2012). Shahbaz et al. (2014) state that trade openness leads to energy consumption through various channels. For example, to meet the growing global demand for increased production, we fulfill international orders, importing additional machinery and equipment, resulting in a rise in energy consumption. Furthermore, for smooth import and export operations, it is imperative to maintain a consistent flow of energy in the transportation system.

Sadorsky (2011) uses the FMOLS technique for Middle Eastern nations. In the short and long terms, the findings show that trade openness expands energy use. The study also reveals that this increase affects trade, leading to more people using more energy. Using time series analysis, Houssain (2011) shows a direct correlation between trade openness and energy use. Cole (2006) explores how trade liberalization affects the energy used in 32 industrialized and developing economies. The study notes that trade openness has a favorable effect on energy use. Sbia et al. (2014) analyze the association between trade openness and energy use in the UAE. They perform this by using ARDL and VECM approaches. The study finds that trade liberalization reduces energy consumption.

Hoa et al. (2023) test the factors affecting renewable energy use for Asian countries. The authors find that energy use, FDI and growth hinder the use of renewable energy. Alexiou (2023) analyzes the patent systems-renewable energy use relationship for 47 countries and provides evidence that R&D and growth reduce renewable energy use. Wang et al. (2022a) empirically investigate the institutional quality-renewable energy relationship for OECD countries, revealing that growth and institutional quality support renewable energy sources.

Hassan et al. (2024) focus on the environmental policy-renewable energy relationship for 32 OECD countries. System GMM estimation findings indicate that environmental policy increases the use of renewable energy. Although Nchofoung et al. (2023) focus on the green taxation-renewable energy relationship, they include many macroeconomic variables in their empirical model. Driscoll-Kraay estimates reveal that the coefficients of environmental tax, trade openness and growth are positive and significant. These findings are not supported by the GMM estimates. As can be seen in these recent studies, the empirical literature focusing on renewable energy also models R&D, corporate quality and environmental taxes variables in its empirical analyses.

Empirical studies on energy economics include econometric models as well as studies that include input-output analysis (Miller & Blair, 2009; Ünal et al., 2023: Akdeniz et al., 2024). These studies reach different results from other econometric studies due to a different analysis method.

Based on the empirical literature, it is seen that studies on the analysis of factors affecting renewable energy consumption in African countries are limited (Akpanke et al., 2023; Dingru et al., 2023). While the first study considers financial development, economic growth, inflation and FDI as explanatory variables in its empirical model, the second study determines trade openness, FDI, natural resources, economic growth and urbanization as independent variables. The difference between our study and these studies is that it establishes a broader model than the models of both studies and models FDI, trade openness, financial development, growth and natural resources. Additionally, our study includes panel estimators such as Driscoll-Kraay and FGLS estimators, which are not applied in either study. Yazdi & Beygi (2018), on the other hand, analyze African countries and focus on the determinants of environmental pollution, and in this respect they differ from our study.

3. Model and Methodology

3.1. Model and Data Description

Based on the research conducted by Zhao et al. (2020), Vural (2021), and Shahbaz et al. (2022), and taking into account the theoretical background, the empirical models used in the study have been developed as follows:

$$lnRNE_{it} = \gamma_0 + \gamma_1 lnGDP_{it} + \gamma_2 FIN_{it} + \gamma_3 FDI_{it} + \gamma_4 NR_{it} + \varepsilon_{it} \quad \textbf{(1)}$$

$$lnREN_{it} = \gamma_0 + \gamma_1 lnGDP_{it} + \gamma_2 FIN_{it} + \gamma_3 FDI_{it} + \gamma_4 NR_{it} + \gamma_5 TR_{it} + \varepsilon_{it} \quad \textbf{(2)}$$

where t is the time period, i is the cross-section units (or countries), and ε is the residual term. γ_0 is the constant term. Here, RNE stands for renewable energy consumption; GDP is economic growth; FIN denotes financial development; FDI is foreign direct investment; NR is natural resources; TR denotes trade openness. $\gamma_0, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5$ are the parameters of variables. In this study, which has a balanced panel feature, l is the natural logarithm notation. The variables are described in Table 1. In other words, the table indicates the variables' names, symbols, measures, and logarithms. The course of the series over time is seen in Fig. 1.

Table 1. Descriptions of Variables

Variables	Symbol	Measure	Source	Logarithm
Renewable energy consumption	lnRNE	Renewable energy consumption (Million tonnes)	BP	Yes
Economic growth	lnGDP	Total GDP	WB	Yes
Financial development	FIN	Broad money (% of GDP)	WB	No
Foreign direct investment	FDI	Foreign direct investment, net inflows (% of GDP)	WB	No
Natural resources	NR	Total natural resources rents (% of GDP)	WB	No
Trade openness	TR	Total exports and imports (% of GDP)	WB	No

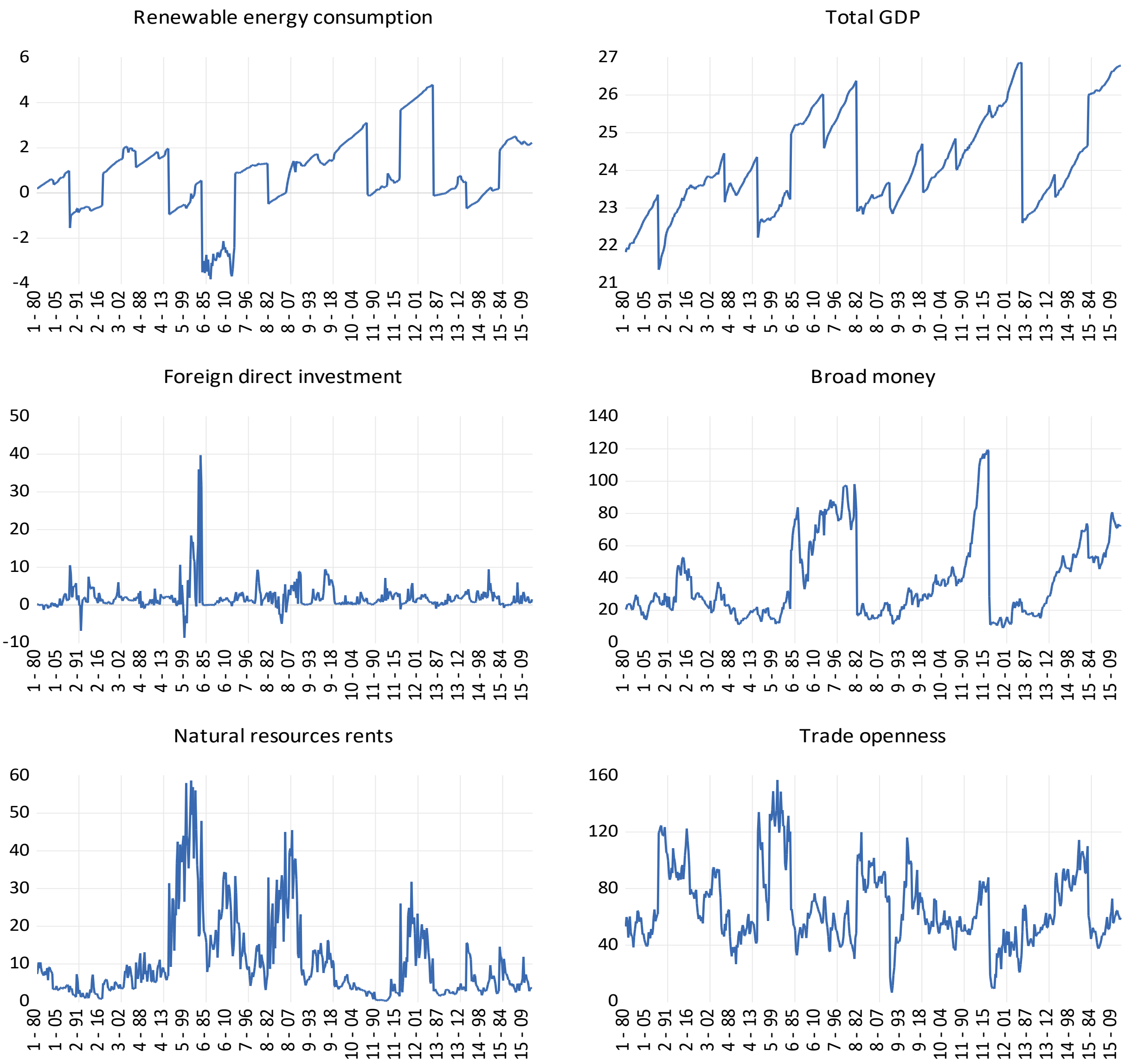

Fig. 1. Trends of the Variables for African Countries (1980-2018)

3.2. Methodology

This study applies several panel data techniques as follows: (i) The cross-sectional dependence (CSD) tests suggested by Breush & Pagan (1980) and Pesaran (2004), (i) The panel unit-root test known as the cross-sectionally augmented ADF (CADF) developed by Pesaran (2007), (iii) The panel cointegration tests presented by Kao (1999), Pedroni (2004) and Westerlund (2005), (iv) The panel estimation methods developed by Driscoll & Kraay (1998) and Parks (1967) and (v) The panel causality test suggested by Dumitrescu & Hurlin (2012). Firstly, the Breusch-Pagan LM test is applied to explore the presence of CSD. Later, we employed the Pesaran CD test in this context. All the tests are estimated as follows:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \qquad \textbf{(3)}$$

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

Here, the null hypothesis indicates no dependence between cross-sectional units. These tests are highly recommended for both balanced and unbalanced panels.

After investigating the existence of CSD, the cointegration among the respective variables is examined. If the CSD exists within the data, then the first-generation unit root techniques may provide misleading effects (Dogan & Seker, 2016). In addition, Khan et al. (2020) state that the findings obtained from these tests will be biased. Therefore, this study uses the unit root test known as CADF by Pesaran (2007), a popular second-generation approach. Pesaran (2007) uses the following equation to investigate the stationarity properties of the variables:

$$\Delta y_{it} = \alpha_i + \beta_i y_{it-1} + \gamma_i \hat{y}_{t-1} + \theta_i \Delta\hat{y}_t + \varepsilon_{it} \qquad \textbf{(5)}$$

where, $i = 1, \dots, N, t = 1, \dots, T$ and $\hat{y}_t$ is cross-section means estimated from $\hat{y}_t = N^{-1}\sum_{i=1}^{N} y_{it}$. In this approach, the hypotheses are as follows:

$$H_0: \beta_i = 0\ for\ all\ i;\ H_1: \beta_i < 0\ for\ some\ i \qquad \textbf{(6)}$$

Before estimating the long-run parameters, the study examines whether cointegration exists in the underlying variables. In this context, the current research first considers Kao's (1999) approach. Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) type tests are offered by Kao (1999). Kao (1999) starts the cointegration analysis based on the following regression equation:

$$y_{it} = \alpha_i + \beta x_{it} + e_{it}, i = 1, \dots\dots, N; t = 1, \dots\dots, T \qquad \textbf{(7)}$$

where α_i denotes the fixed effect changing among the cross-sectional units, β shows the slope coefficient common across the cross-sectional units, uit indicates the error terms. The DF and ADF-type panel statistics suggested by Kao (1999) can be formulated as follows:

$$DF_t^* = \frac{\dfrac{(\hat{\rho}-1)\sqrt{\sum_{i=1}^{N}\sum_{t=2}^{T}\hat{e}_{i,t-1}^{*2}}}{S_e} + \dfrac{\sqrt{6N}\hat{\sigma}_{0v}^2}{2\hat{\sigma}_{0u}}}{\sqrt{\dfrac{\hat{\sigma}_{0v}^2}{2\hat{\sigma}_v^2} + \dfrac{3\hat{\sigma}_v^2}{10\hat{\sigma}_{0v}^2}}} \qquad \textbf{(8)}$$

$$ADF = \frac{\frac{\sum_{i=1}^{N}(e_i' Q_i v_i)}{sv\sqrt{\sum_{i=1}^{N}(e_i' Q_i e_i)}} + \frac{\sqrt{6N\hat{\sigma}_v}}{2\hat{\sigma}_v^2} +}{\sqrt{\frac{\hat{\sigma}_{0v}^2}{2\hat{\sigma}_v^2} + \frac{3\hat{\sigma}_v^2}{10\hat{\sigma}_{0v}^2}}} \quad (9)$$

Secondly, the study applies Pedroni's (2004) cointegration technique. Pedroni (2004) presents seven alternative tests to analyze the cointegration between the variables for dynamic panels. Such panels allow heterogeneity among cross-sectional units. Pedroni tests are divided into two parts. They are the panel techniques encompassing the within and between-dimension procedures. In Pedroni's tests, the hypotheses are established as follows:

$$H_o: \rho_i = 0 \; and \; H_A: \rho_i < 0 \quad (10)$$

where ρ_i is the autoregressive term of the estimated residuals and considers the following specification:

$$\hat{\varsigma}_{it} = \rho_i \hat{\varsigma}_{it-1} + u_{it} \quad (11)$$

All tests introduced in the literature by Pedroni (2004) show an asymptotic distribution as follows:

$$\frac{Z - \mu\sqrt{N}}{\sqrt{V}} \to N(0,1) \quad (12)$$

The present study also uses Westerlund's (2005) cointegration approach. The most important property of all the cointegration tests is that these approaches are residual-based techniques. The null hypothesis tested in these cointegration procedures is that no cointegration exists among the variables. Westerlund (2005) bases on the following regression equations in cointegration analysis:

$$y_{it} = d_t' \hat{\delta}_i + x_{it}' \hat{\beta}_i + \hat{e}_{it} \quad (13)$$

$$\hat{e}_{it} = \rho_i \hat{e}_{it-1} + u_{it} \quad (14)$$

y_{it} is a scalar variate, x_{it} is a *K*-dimensional vector of regressors, and d_t is a vector of deterministic components. $\hat{E}_{it} = \sum_{j=1}^{t} \hat{e}_{ij}$ and $\hat{R}_{it} = \sum_{t=1}^{T} \hat{e}_{it}^2$. Westerlund (2005) develops two statistics with straightforward applications. These tests, well known as VR_p and VR_G statistics suggested by Westerlund (2005), can be calculated as follows:

$$VR_p = \sum_{i=1}^{N}\sum_{t=1}^{T} \hat{E}_{it}^2 \left(\sum_{i=1}^{N} \hat{R}_i\right)^{-1} \quad (15)$$

$$VR_G = \sum_{i=1}^{N}\sum_{t=1}^{T} \hat{E}_{it}^2 \, \hat{R}_i^{-1} \quad (16)$$

We detect the long-run estimates by utilizing the Driscoll-Kraay standard errors approach. This estimation method presents robust findings when heteroscedasticity, serial correlation, and CSD problems exist in the panel data (Alssadek & Benhin, 2021). This procedure is used for both balanced and unbalanced series, and it can also be employed for missing values (Wang et al., 2022b). This procedure encompasses a two-step estimation technique. Firstly, the dependent and independent variables, $Z_{it} \in \{y_{it}, x_{it}\}$ are converted as follows:

$$\tilde{Z}_{it} = z_{it} - \bar{z}_i + \bar{Z} \text{ where } \bar{Z}_i \sum_{t=ti1}^{Ti} z_{it} \text{ and } \bar{Z} = (\sum T_i)^{-1} \sum\sum z_{it} \quad (17)$$

In the second step, the following model is estimated:

$$\tilde{y}_{it} = \tilde{x}_{it}\beta + \tilde{\varepsilon}_{it} \quad (18)$$

The study also utilizes the Feasible Generalized Least Squares (FGLS) estimation techniques to obtain robust findings from analyses. This estimator, suggested by Parks (1967), employs the general formulae for $\hat{\beta}$and $Var(\hat{\beta})$ as follows:

$$\hat{\beta} = \left(X'\hat{\Omega}^{-1}X\right)^{-1}X'\hat{\Omega}^{-1}y \quad \mathbf{(19)}$$

$$Var(\hat{\beta}) = \left(X'\hat{\Omega}^{-1}X\right)^{-1} \quad \mathbf{(20)}$$

where $\hat{\Omega}$ includes implicit assumptions about error heteroscedasticity, serial correlation, and CSD.

One of the most important reasons for using panel causality tests in empirical studies is that the causality findings obtained help develop policy recommendations. Therefore, this study utilizes a classical panel causality approach offered by Dumitrescu & Hurlin (2012) to investigate the relationships between the variables. In this test, the model can be described as follows:

$$y_{it} = \delta_i + \sum_{i=1}^{K} \gamma_i^k y_{i,t-k} + \sum_{i=1}^{K} \theta_i^k x_{i,t-k} + \varepsilon_{i,t} \quad \mathbf{(21)}$$

Here, classical critical values offered by Dumitrescu & Hurlin (2012) are applied for causality analysis. In this procedure, the $\bar{Z}$ and $\bar{W}$ statistics presented by Dumitrescu & Hurlin (2012) are formulated as follows:

$$\bar{W} = \frac{1}{N}\sum_{i=1}^{N} W_i \quad \mathbf{(22)}$$

$$\bar{Z} = \sqrt{\frac{N}{2K}}(\bar{W} - K) \quad \mathbf{(23)}$$

4. Findings

This study is essential since it provides a clearer picture of the data in Table 2. According to the findings, the mean value of renewable energy consumption is 5.06. The other variables' mean values are 7.69, 38.10, 1.93, 10.73 and 66.32, respectively. The maximum and minimum values of renewable energy consumption are 7.83 and -0.45, respectively. The selected countries' average GDP is 7.69, with a standard deviation 0.74. Financial development has a mean value of 38.10. Also, FDI has a mean value of 1.93 and a standard deviation of 3.53. Furthermore, the average value of natural resources is 10.73 percent of the countries considered, with a standard deviation of 11.02 across the selected countries. The maximum and minimum values of the natural resources of these countries are 58.65 and 0.19, respectively. Given the average mean of 66.32 with a standard deviation of 25.97, trade openness's maximum and minimum values are 156.86 and 6.32, respectively. Renewable energy and trade openness are the series with the lowest and highest mean concerning the maximum and standard deviation. In this study, the total number of observations for 15 African countries is 585.

The correlation matrix considered variables indicate a positive correlation between FDI and renewable energy and trade openness and renewable energy. In addition, the correlation between renewable energy and other regressors is negative.

Table 2. Summary Statistics and Correlation Matrix

	LNRNE	LNGDP	FIN	FDI	NR	TR
Mean	5.066	7.699	38.108	1.939	10.730	66.321
Median	5.486	7.549	28.398	1.242	6.599	59.470
Std. dev.	1.473	0.744	24.602	3.532	11.028	25.978
Min.	-0.459	6.542	9.063	-8.703	0.192	6.320
Max.	7.839	9.451	119.383	39.760	58.650	156.861
Skewness	-1.741	0.575	1.192	5.420	1.833	0.705
Kurtosis	6.494	2.312	3.733	49.378	6.216	3.334
Obs.	585	585	585	585	585	585
Jarque-Bera	593.381	43.843	151.808	55295.79	580.046	51.269

Prob.	0.000	0.000	0.000	0.000	0.000	0.000
LNRNE	1	-0.049	-0.589	0.079	-0.012	0.111
LNGDP	-0.049	1	0.260	0.095	0.3283	0.409
FIN	-0.589	0.260	1	0.017	-0.185	0.409
FDI	0.079	0.095	0.017	1	0.273	-0.038
NR	-0.012	0.328	-0.185	0.273	1	0.391
TR	0.111	0.409	-0.038	0.334	0.391	1

Table 4 shows the findings obtained from the Pesaran (2004) CD test. The findings reveal a dependency between cross-section units. In this study, we prefer Pesaran's (2007) CADF test for unit root analysis. Table 5 indicates that the variables are stationary in the first difference, implying that the order of integration is 1. Thus, it is possible to test cointegration between variables.

Table 3. CSD and Unit Root Analysis

Variables	LNRNE	LNGDP	FIN	FDI	NR	TR
Breush-Pagan LM	1524.925***	1866.675***	1094.900***	403.588***	616.843***	522.037***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Pesaran CD	-3.168***	20.439***	25.387***	13.370***	10.537***	10.251***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CADF (Level)	3.032	0.127	-0.367	-0.641	-0.245	-0.028
CADF (First difference)	-8625***	-6.497***	-8.673***	-6.909***	-7.524***	-10.365***

Note: *** shows significance at 1% level.

The study uses Kao's (1999) cointegration test to examine the cointegration relationship between the variables. Table 6 reports the findings of the Kao cointegration test. The findings show a cointegration between the series. The findings are valid for both Model 1 and Model 2. So, we conclude that the long-run relationship between economic growth, financial development, foreign direct investment, natural resources, trade openness, and renewable energy is found. The cointegration results for both models are confirmed by the findings of Pedroni and Westerlund.

Table 4. Cointegration Analysis

Variables	Model 1	Model 2
Panel A. Kao		
Modified DF t	-3.041***	-1.991**
DF t	-2.184**	-1.691**
ADF t	-0.910	-0.328
Unadjusted Modified DF t	-3.373***	-3.716***
Unadjusted DF t	-2.320**	-2.496***
Panel B. Pedroni		
Modified variance ratio	-2.089**	-2.592***
Modified PP t	1.306	2.221**
PP t	-0.228	0.492
ADF t	0.947	1.737**
Panel C. Westerlund		
Variance ratio	2.161**	3.185***

Note: ***and ** shows significance at 1% and 5% level, respectively.

The existence of cointegration between the variables in both models allows the estimation of the coefficients of these variables in the next step. Here, The Driscoll-Kraay and FGLS estimation methods are applied to investigate the coefficients of related explanatory variables. The estimation findings are described in Table 5. The results for Model (1) and Model (2) suggest that economic growth is positively linked with renewable energy use. This means that economic growth stimulates renewable energy use in these countries. Our finding is supported by Yi et al. (2022), who applied several panel econometric approaches. The long-term elasticity coefficients suggest that economic growth and economic globalization positively influence renewable energy consumption.

The results report that renewable energy use is negatively affected by financial development. This indicates that financial development decreases renewable energy use. This is not in line with the findings of Pata et al. (2022), who examined the financial development-renewable energy link for the USA. Using the Fourier-wavelet quantile causality test, the growth of the financial sector promotes the use of renewable energy. The most important finding is that the depth of financial instruments encourages the use of renewable energies. The study suggests that the US government should take measures to improve the depth and access to financial markets.

FDI encourages renewable energy use. Tan & Uprasen (2022) do not support this finding. They explored the FDI-renewable energy link for BRICS countries using the GMM models. This study suggests that FDI reduces renewable energy consumption.

According to the findings, natural resources will negatively affect renewable energy use. This is not confirmed by Chau et al. (2023), who focused on the links between natural resources, green finance, and renewable energy in Asian countries. The study revealed a positive link between the variables.

Finally, trade openness is positively correlated with renewable energy use. This is not proved by the results of Dingru et al. (2022), who examined the trade-renewable energy use in SSA countries. According to the study, Mexico's renewable energy use is positively linked with exports and total trade, while the United States' renewable energy consumption minimally affects these factors.

Table 5. Long-run Estimates

Variables	Model 1	Model 2
Panel A. Driscoll-Kraay	Coefficients	Coefficients
LNGDP	0.387***	0.334***
FIN	0.041***	-0.040***
FDI	0.057***	0.049***
NR	-0.032***	-0.034***
TR	-	0.004***
Constant	3.885***	4.025***
Panel B. FGLS		
LNGDP	0.379***	0.322***
FIN	-0.040***	-0.039***
FDI	0.040***	0.031***
NR	-0.030***	-0.032***
TR	-	0.004***
Constant	3.917***	4.055***

Note: *** shows significance at 1% level.

The findings of the Dumitrescu-Hurlin causality approach used for causality analysis are reported in Table 6. A two-way causality between economic growth and renewable energy use is detected. Our result is not proved by Chen et al. (2022), who focused on renewable energies and economic growth using the MS-VAR model. The study detects that economic growth causes renewable energy for Ontario and Alberta.

In addition, a two-way causal link between financial development and renewable energy use is determined. This finding is not supported by Qamruzzaman & Jianguo (2020), who investigated the asymmetric relationship between several variables using a panel NARDL approach. They find that financial development causes renewable energy use.

A two-way causality is detected between FDI and renewable energy use. The results of Lin & Benjamin (2018), who analyzed the links between energy consumption, FDI, and economic growth using the panel DOLS technique, are inconsistent with our results. The study detects that FDI causes energy consumption in Nigeria.

Our causality results detect that natural resources and renewable energy consumption cause each other. Dingru et al. (2023), who analyzed SSA countries with ARDL models, don’t present similar findings. They reveal no causal link between the variables.

According to the causality findings, trade openness and renewable energy use cause each other. Liu et al.’s (2018) findings, which utilized a VECM approach for 15 Asia-Pacific countries to examine how trade and renewable energy affect output, do not confirm our findings. They discover a causality from trade openness to renewable energy use.

Table 6. Causality Analysis

Variables	W-Stat.	Z-bar Stat.	p-value	Causality
lnREN ≠> LNGDP	14.262	2.693	0.007***	lnGDP ↔ lnREN
lnGDP ≠> lnREN	21.926	9.022	0.007***	
lnREN ≠> FIN	16.508	5.244	0.000***	FIN ↔ lnREN
FIN ≠> lnREN	17.351	0.548	0.000***	
lnREN ≠> FDI	35.876	3.933	0.000***	FDI ↔ lnREN
FDI ≠> lnREN	15.763	20.540	0.000***	
lnREN ≠> NR	19.256	22.183	0.000***	NR ↔ lnREN
NR ≠> lnREN	37.865	6.817	0.000***	
lnREN ≠> TR	19.001	19.887	0.000***	TR ↔ lnREN
TR ≠> lnREN	35.084	6.607	0.000***	

Note: *** shows significance at 1% level.

5. Conclusion

This empirical study analyzes the factors affecting the use of renewable energy in African countries from an econometric perspective. Pedroni, Kao, and Westerlund techniques are used for cointegration analysis, while Driscoll-Kraay and FGLS estimators are used for long-term forecasts. The Dumitrescu-Hurlin causality approach is applied in the causality research of variables.

The study finds a cointegration among the variables. According to empirical findings, economic growth, FDI, and trade openness increase renewable energy consumption, while financial development and natural resources have a decreasing effect. Empirical findings indicate a two-way causal linkage between all explanatory variables and renewable energy use.

In the context of policy recommendations, it may be recommended to accelerate economic growth, as well as FDI and trade openness policies. Natural resources use need to be restructured to encourage the renewable energy sector. In addition, Financial sector funds should be directed to renewable energy investments rather than fossil energy resources. Apart from the empirical findings of the study, some general steps can be taken to develop the renewable energy sector in these countries:

• To set ambitious and quantifiable goals for embracing renewable energy. These goals will provide valuable direction and aid in prioritizing investments and policies that facilitate a faster transition.

• Governments should create favorable and attractive policies and regulations to encourage private investment in renewable energy projects. This can be done by simplifying administrative processes, offering feed-in tariffs and tax incentives, and setting clear guidelines for integrating renewable energy into the grid.

• To prioritize the advancement of renewable energy infrastructure. By doing so, they can establish a solid basis for expanding their renewable energy capabilities and decreasing their dependence on fossil fuels.

• To promote collaboration and cooperation among regions to foster the development of renewable energy projects across borders. By connecting grids and working together on joint initiatives, we can effectively allocate resources, cut down on expenses, and improve energy security.

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