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The rise and fall of the energy-carbon Kuznets curve: Evidence from Africa

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Abstract

Purpose – This paper provides an analysis of the energy-carbon Kuznets curve hypothesis (CKC) using a second-generation panel methodology.

Design/methodology/approach – Specifically, we investigate whether energy consumption, natural resources, and governance explain the CKC proposition. Our empirical strategy is based on the Westerlund panel cointegration test, augmented mean group (AMG), and vector autoregressive (VAR) panel Granger-causality tests.

Findings – The results suggest that the CKC hypothesis is incomplete without these mechanisms, as they play a critical role in reducing carbon emissions in Africa. We recommend improving the environmental standards and proper regulatory and monitoring systems to reduce carbon emissions and promote sustainable development in the continent.

Originality/value –The study revisits the CKC hypothesis with particular emphasis on governance and more robust empirical estimation techniques.

Keyword*: carbon cuts; Energy consumption; Governance; Climate crisis; Panel analysis; Africa.*

1. Introduction

For decades, research has been conducted to empirically assess the relevance of the carbon Kuznets curve (CKC) hypothesis, which theorises an inverted U-shaped relationship between economic growth and carbon emissions. The hypothesis is credited to Grossman and Krueger (1993) in their quest to design a policy towards environmental sustainability. Some of this research has relied on the intuition underpinning time series, panel, and advanced econometrics applications, without much progress. To date, efforts to validate the relevance of the CKC hypothesis have remained unclear. This is because conflicting views among scholars and policymakers make it difficult to generalise the hypothesis (Cole et al., 1997; Hu et al., 2018; Shobande & Asongu, 2021; Liu et al., 2019; Asongu & Odhiambo, 2021a). Some studies have reported empirical evidence to support this proposition. For example, Cole et al. (2004) for the Organisation for Economic Co-operation and Development (OECD) countries, Fodha and Zaghdoud (2010) for Tunisia, Jalil and Mahmud (2009) for China, Apergis and Payne (2009) for Central American countries, Lean and Smyth (2010) for Asian countries, Saboori et al. (2016) for Malaysia, and Sarkodie (2018) for 17 African countries. In contrast, numerous critics find no evidence to validate the existence of the CKC hypothesis. For example, Acaravci and Ozturk (2010) found no evidence for 19 European countries, Alam et al. (2011) and Ahmad et al. (2016) found no evidence for the hypothesis in India, and Fei et al. (2011) found no validity for the CKC hypothesis in China.

Several factors justify the need to investigate the CKC hypothesis for Africa. *Firstly,* the inseparability of natural resource usage from climate related events call for an urgent need for more information that will help African nations to implement an integrated policy towards reducing carbon emission and promoting sustainability. *Secondly,* there is a recent increase in attention to poor governance issues as a major bottleneck to realising environmental quality (Acemoglu, 2001; Shobande & Enemona, 2021; Schmalensee eta l., 1998; Taskin & Zaim, 2000). For example, recent studies suggest that economic growth can be associated with environmental pollution and the degree of such a nexus may be explained by certain economic and institutional factors such as poor governance, rule of law, bureaucracy in government and repudiation of contracts (Nwani & Adam, 2021; Lee & Kim, 2009; Lau et al., 2014; Bulte et al., 2005; Tiba & Frikha, 2020). Thus, reassessing whether poor governance can play an important role in managing climate related risk will further help African countries promote environmental sustainability. *Thirdly*, studies have shown that natural resources are unlikely to promote sustainable growth in Africa (Shobande &

Enemona, 2021; Nordhaus, 2019; Stavin, 2011; Bulte et al., 2005; Shobande & Ogbeifun, 2021). Moreover, building on the attendant literature, the overutilization of natural is often cited as a contributing factor in annual carbon emissions from Africa. *Fourthly*, in the light of the literature highlighted on the third point above, African countries have continued to witness a consistent increase in the level of economic activities which been accompanied with a rise in energy consumption. Thus it is important to investigate whether energy consumption explains to a large extent vulnerability of the continent to climate risk.

The stakes in the CKC debate have remained high, while the associated mechanism for validating the hypothesis is still controversial. In the existing literature, three main channels have been identified through which economic activities can clearly influence carbon emissions. First, several studies have identified energy consumption as one of many potential mechanisms to explain the CKC hypothesis (*see* Acaravci & Ozturk, 2010; Ahmad et al., 2016; Apergis & Paynes, 2009; Kais& Sami, 2016; Sharma et al., 2021). For example, an increase in the intensity of economic activities can enhance energy consumption and, in turn, increase carbon emissions. Second, excessive natural resource exploration has also been identified as a potential cause of carbon emissions. Some studies have argued that the lack of a market for natural resources can lead to environmental degradation. Third, poor governance has been identified as one of the numerous ways in which the size of economic activity exacerbates carbon emissions (Shobande, 2021a; Asongu, 2019; Asongu & Odhiambo, 2021a). Indeed, governance failure can occur when environmental damage is a result of policy incentives to promote growth without due consideration to social costs or environmental values (Shahbaz et al., 2012; Asongu, 2019; Asongu & Odhiambo, 2020, 2021b; Ongan et al., 2021). Likewise, poor governance may arise from coordination failures among governmental agencies and such coordination issues can affect the level of emissions. In addition, the lack of a participatory mechanism and structural failure in the existing institutional framework can lead to inefficiency in the management system and by extension, engender more carbon emissions.

Numerous empirical studies have tested the CKC hypothesis using time series and panel evidence, but they have not accounted for cross-sectional dependency among the variables which biases the conflicting results that have been reported (Shahbaz et al., 2018; 2018; Shobande & Asongu, 2021). Similarly, one important point of contention often cited by critics is that the hypothesis is based on assumptions regarding several factors that are likely to cause a marginal change in carbon emissions (Wang et al., 2016; Shobande, 2021). In this study, we contribute to the existing literature in the following ways: (a) we investigate the potential of the CKC in promoting environmental sustainability in Africa and (b) we consider the mediating role of energy consumption and governance in explaining the CKC hypothesis, by controlling for cofounders and making corresponding inferences. The framework follows the second-generation panel approach, which accounts for potential cross-sectional dependency. In particular, we explore the Westerlund panel cointegration approach, augmented mean group method, and heterogeneous panel Granger causality tests. The results confirm the validity of the CKC hypothesis in Africa and highlight the importance of energy consumption and governance as associated mechanisms.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical and empirical literature, Section 3 provides the methodological framework for the study, Section 4 presents and discusses the results, and Section 5 concludes with policy implications.

2. Related Studies

In this section, we present a review of the theoretical and empirical papers on the relevance of the energy-carbon Kuznets curve hypothesis and its associated mechanism. We aim to provide a brief state of the art of research on the subject while highlighting the merits and demerits of scholarly contributions.

2.1 Energy-carbon Kuznets curve

As mentioned earlier, there is an accumulated literature that provides statistical evidence regarding the relevance of the energy-carbon Kuznets curve hypothesis, but the findings are far from conclusive. For example, Jalil and Muhmud (2009) assessed the link between energy consumption, economic growth, trade, and carbon emissions using an autoregressive distributed lag model (ARDL) and validated the CKC hypothesis for China. Saboori et al. (2016) applied the ARDL to investigate the causal link between economic growth and carbon emissions in Malaysia and reported that economic growth was correlated with carbon emissions in the country. Jaunky (2011) validated the CKC hypothesis for 36 high-income countries between 1980 and 2005. On the contrary, Narayan and Narayan (2010) observed the link between economic growth and carbon emissions using a cointegration approach for 43 developing countries between 1980 and 2006 and found no evidence for validating of the CKC hypothesis. Wang et al. (2016) found a unidirectional causality occurring from energy consumption to carbon emissions and feedback evidence between economic growth and energy consumption. However, they were unable to validate the CKC hypothesis. Antonakakis et al. (2017) investigated the link between energy consumption, economic growth, and carbon emissions by applying vector autoregressive and impulse responses and found no evidence for CKC. However, they uncovered a feedback between carbon emissions and energy consumption. He et al. (2018) examined CKC for 25 developing countries between 1996 and 2012 using a dynamic approach and reported a positive impact of energy on carbon emissions. Fei et al. (2011) found evidence of a long-term relationship between energy consumption and economic growth. They however, did not establish evidence of the CKC hypothesis.

2.2 Natural resources-carbon Kuznets curve

Numerous empirical studies have sought to validate the link between natural resources and the CKC hypothesis. Contrasting results have emerged from these studies. Li et al. (2019) used panel threshold analysis to confirm that natural resource dependency affects the level of carbon emissions in China, while Hussain et al. (2020) reported a positive influence of natural resources on carbon emissions in the Belt and Road Initiative countries. Bekun et al. (2019) suggested that the long-term risk to natural resources can influence environmental sustainability across European Union countries. Similarly, Balsalobre-Lorente et al. (2018) observed that availability of natural resource can improve environmental quality across European countries. Nathaniel et al. (2021) showed that economic growth and natural resources increase ecological footprints, and Ullah et al. (2021) found a positive relationship between natural resource rent and ecological footprint.

2.3 Governance-carbon Kuznets curve

Some studies that have investigated whether governance matters for reducing carbon emissions report conflicting evidence (Zhang et al., 2021; Karim et al., 2021; Teng et al., 2021; Long, 2021; Mehmood et al., 2020; Kim et al., 2021; Omri et al., 2021; Yuan et al. 2021). Zhang et al. (2021) reported that environmental regulations can help reduce carbon emissions in China, while Karim et al. (2021) confirmed that internal governance can help moderate carbon disclosure in the United Kingdom. Teng et al. (2021) suggested that institutional quality positively influences environmental degradation. Using dynamic panel analysis, Muhammad and Long (2021) showed that the rule of law can reduce carbon emissions. Mehmood et al. (2020) observed that economic growth and institutional quality can reduce carbon emissions in three developing countries, and Kim et al. (2021) also observed that political institutions play an essential role in reducing carbon emissions. Omri et al. (2021) observed that good governance can moderate carbon emissions in Saudi Arabia, while Yuan et al. (2021) showed that institutional quality and green innovation reduce carbon emissions in China.

Given the controversy surrounding the proper functional transformation of the carbon Kuznets curve and the limitation between choice of time series and lack of consideration for cross-sectional dependency in most existing studies, further inquiry is required to validate the hypothesis for Africa.

3. Methodological framework and data

3.1 Methodological framework

The theoretical foundation of this study is settled in the carbon Kuznets curve hypothesis. The hypothesis posits an inverted-U relationship between economic growth and carbon emission (Cole et al., 1997). Factors such as energy consumption, natural resources rent and governance related problems that can have severe implications on carbon emission were omitted but reconsidered in this present study.

The basic model is:

$$CO_{2it} = f(Y_{it},\ Y_{it}^2, X_{it},\ v_{it}) \qquad (1)$$

Equation (1) represents the reduced form relationship postulated by the CKC hypothesis to have an inverted U-shape form which implies a quadratic term in levels or log quadratic in logs. This is estimated using a panel dataset from Africa. Where $i\ and\ t$ respectively denote individual countries and time; Co_2 is carbon emission per capita; Y represents income per capita; Y^2 is the quadratic function of income per capita; X denotes a vector of control variables (energy consumption, natural resource, and governance), and v_{it} is the error term. The estimated approach follows the panel heterogenous Granger causality test. Specifically, the vector autoregressive (VAR) /vector error correction (VEC) can help to dissect the dynamics of long and short relationships among the variables and provide inference on their convergence to equilibrium.

To capture the short run dynamic, Equation (1) is respecified by making all the variables endogenous and including an error term in Equations (2) to (7).

$$CO_{2it} = fCO_{2it-1}, (Y_{it}, Y_{it}^2, EC_{it}, NR_{it}, GOV_{it}, v_{1it}) \quad (2)$$

$$Y_{it} = f(Y_{it-1}, CO_{2it}, Y_{it}^2, EC_{it}, NR_{it}, GOV_{it}, v_{2it}) \quad (3)$$

$$Y_{it}^2 = f(Y_{\text{戲}t}^2, Y_{it}, CO_{2it}, EC_{it}, NR_{it}, GOV_{it,} v_{3it}) \quad (4)$$

$$EC_{it} = f(EC_{it-1}, Y_{it}, Y_{it}^2, CO_{2it}, NR_{it}, GOV_{it}, v_{4it}) \quad (5)$$

$$NR_{it} = f\left(NR_{it-1}, Y_{it}, Y_{it}^2, EC_{it}, CO_{2it}, GOV_{it}, v_{5it}\right), \quad (6)$$

$$GOV_{it} = f(GOV_{it-1}, Y_{it}, Y_{it}^2, EC_{it}, NR_{it}, CO_{2it}, v_{6it}) \quad (7)$$

Where EC denotes energy consumption; NR is natural resources; and GOV is the governance indicator and v is the error term. All the variables are indexed in natural logarithm. Equations (2-7) are further respecified to capture the speed of adjustment known as the long run dynamic of the variables in Equations (8) to (13).

$$CO_{2it} = fCO_{2it-1}, (Y_{it}, Y_{it}^2, EC_{it}, NR_{it}, GOV_{it}, v_{1it}, ect_{1it-1}) \quad (8)$$

$$Y_{it} = f(Y_{it-1}, CO_{2it}, Y_{it}^2, EC_{it}, NR_{it}, GOV_{it}, v_{2it}, ect_{2it-1}) \quad (9)$$

$$Y_{it}^2 = f(Y_{it-1}^2, Y_{it}, CO_{2it}, EC_{it}, NR_{it}, GOV_{it,} v_{3it}, ect_{3it-1}) \quad (10)$$

$$EC_{it} = f(EC_{it-1}, Y_{it}, Y_{it}^2, CO_{2it}, NR_{it}, GOV_{it}, v_{4it}, ect_{4it-1}) \quad (11)$$

$$NR_{it} = f\left(NR_{it-1}, Y_{it}, Y_{it}^2, EC_{it}, CO_{2it}, GOV_{it}, v_{5it}, ect_{5it-1}\right), \quad (12)$$

$$GOV_{it} = f(GOV_{it-1}, Y_{it}, Y_{it}^2, E\text{儎}_{it}, NR_{it}, CO_{2it}, v_{6it}, ect_{6it-1}) \quad (13)$$

The speed of convergence to respective long run equilibrium is represented by ect_{t-1} and v_{1-6it} is the error term for each endogenous model.

3.2 Data

This study focuses on a panel from 16 African countries selected based on: (i) the wealth of countries in natural resources and (ii) availability of such data. The African countries comprise of Niger, Nigeria, Ghana, Guinea, Congo, South Africa, Tanzania, Algeria, Angola, Algeria, Botswana, Egypt, Morocco, Tunisia, Kenya, Cameroon, and Mozambique. The study utilized annual data from 1995 to 2019 sourced from the World Bank. The description of variables is provided in what follows. The dependent variable is carbon emission (CO_2 measured in metric tons) per capita, and an independent of interest is economic growth measured as per capita income (GDP constant 2010$). Consistent with the problem statement and extant literature (Shahbaz et al, 2017; Shobande, 2021b; Shobande & Asongu, 2021;

Asongu et al., 2020), energy consumption and natural resource variables are also involved.. Natural resources are measured as the total natural resource rent as percentage of GDP. Energy consumption is measured as energy use (kg of oil equivalent) per capita, and governance is captured with regulatory quality which is defined as the ability of a government to formulate and implement environmental policies (*See* Acemoglu et al., 2002).

As mentioned earlier, the focus of this study is Africa, and several factors justify the countries considered. *Firstly,* the major African countries examined endowed with natural resources. This is because these African countries have been spotted as potential hotspots for climate risk. *Secondly,* as discussed in the introduction, empirical research investigating the CKC hypothesis in Africa is relatively sparse. *Thirdly,* consistent with the narrative in the introduction, major studies attempting to assess role of energy consumption, economic growth, governance on carbon emission failed to distinguish between institutions and polices.

3.3 Rationale for variables used.

(i) CO_2 mitigating is a critical in mitigating climate change and ensuring sustainability (see, Schmalense et al., 1998; Donnella et al., 1972; Shobande, 2021). Therefore, by assessing various drivers of CO_2, policymakers can better mitigate their impact on climate change.

(ii) There is no consensus as to whether economic growth has a positive or negative impact on the environment. Some scholars contend that economic growth has helped to improve overall wellbeing and the development of technical know-how needed to improve the environment. Skeptics argue that economic growth is achieved at the price of carbon emissions (*see* Jaunky, 2011; Asongu & Odhiambo, 2021a). Thus, this variable requires further investigation.

(iii) The amount of energy consumed has been identified as a contributory variable that has the potential to have both a positive and negative impact on carbon emission (*see* Shahbaz et al., 2017; Shobande, 2021; DeBruyn et al., 1998).

(iv) There are two sides to every coin when it comes to natural resources. Natural resources provide economic benefits and environmental cost. Recent evidence shows that natural resources are responsible for half of the world's carbon emissions and nearly 80% of environmental deterioration (Li et al., 2019; Wang et al., 2020; McConnel. 1997; Yu et al., 2018; Wei et al., 2022). Therefore, natural

resource variable is included to reexamine it impacts on carbon emission, especially among resources rich countries in Africa.

(v) Three pillars entail the governance indicator: independence, accountability, and scope of action (regulatory mechanism). The indicator reflects the existing regulatory mechanisms, government autonomy and complexity in promoting institutional quality and market forces (Lemos & Agrawal, 2006; Mustalahti et al., 2020; Nelson, 2012). The governance variable is crucial because it sheds light on government effectiveness, regulatory mechanism and management tools used in mitigating carbon emissions.

The sampled countries are provided in Appendix 1 while the definitions and corresponding sources of the variables are disclosed in Appendix 2.

4. Empirical Results

This section presents and discusses the results of the estimated models and their policy relevance of their findings.

4.1 Preliminary Analysis

This section presents the pre-test analysis carried out to understand the prior behaviour of the series before formal analysis. It contains the summary statistics as well as the slope heterogeneity and cross-sectional dependency tests. Table 1 reports the summary statistics indicating the mean and associated standard deviation of each variable.

Table 1. *Summary Statistics*

Variables	Mean	Std Dev.	Skewness	Kurtosis	Jarque-Bera	P-value	Obs.
$\ln CO_2$	5.19	3.6	0.18	1.87	23.28	0.00	400
$\ln Y$	25.3	18.4	0.25	1.48	42.28	0.00	400
$\ln Y^2$	25.6	15.7	0.26	1.48	42.48	0.00	400
$\ln EC$	45.9	60.3	2.4	9.7	1138.45	0.00	400
$\ln NR$	17.7	11.3	1.15	3.9	101.13	0.00	400
$\ln GOV$	0.44	0.19	0.62	2.52	29.49	0.00	400

Notes. All the variables are in natural logarithm.

From the summary statistics, the average (standard deviation) of CO2 emission is 5.19 (3.6); economic growth 25.3 (18.4) and the quadratic term 256 (157); energy consumption, 45.9 (60.2); natural resource, 17.7 (11.3), and governance, 0.44 (0.19).

Next, we provide the slope heterogeneity test and the cross-sectional dependency test of the series. This is important for several reasons, notably: (a) Overlooking individual heterogeneity may generate inconsistent parameters. (b) Also, the poor knowledge of slope heterogeneity test may bias results estimated from our model. Therefore, we implement the slope heterogeneity test proposed by Pesaran and Yamagata (2008), and the results are reported in Table 2.

Table 2Slope Heterogeneity, using Pesaran and Yamagata (2008)

Statistics Criteria	*Value*	*p-value*
$\hat{\Delta}$	6.23***	0.00
$\hat{\Delta}_{adj}$	7.58***	0.00

Notes. *** denotes significance level at 1%.

Since the issue of slope heterogeneity has been settled, it is also important to cross check sectional dependency among the variables as well. In achieving this task, we employ the Pesaran (2004) cross-sectional dependency test that accounts for correlations among the variables and results are reported in Table 3.

Table 3 Cross-sectional Dependence (CD), using Pesaran (2004)

Variables	CD	Correlate
$\ln CO_2$	9.2**	0.30
$\ln Y$	12.5***	0.20
$\ln Y^2$	19.1**	0.26
$\ln EC$	6.9**	0.38
$\ln NR$	16.3**	0.44
$\ln GOV$	7.1**	0.20

Notes. ***; **, denote significance levels at 1% and 5%, respectively

The evidence confirmed the presence of cross-sectional dependency among the variables. This evidence can be attributed to common factors across the countries, notably: level of economic activities, deposit of natural resources, geographical and socio-political entities.

4.2 Panel unit root test

In the existing literature, there are conflicting reactions on the method for assessing the stationarity of series in a panel setting. Major debates favour the second-generation panel approach that accounts for the cross-sectional dependency in the series. Thus, we used the proposed Pesaran (2007) cross-sectionally augmented Dickey Fuller (CADF) approach and two reasons motivate this consideration. First, the CADF regression utilises the cross-section averages of the lagged level and first differences of the individual series instead of basing the unit roots on deviation from estimated factors. Second, the CADF regression is more asymptotic and efficient and does not depend on common factor loadings. Table 3 reports the results of the CADF panel unit root estimates.

Table 4: CADF Panel Unit Roots Test

Variable	I(0)	I(1)
$\ln CO_2$	-1.47	-4.65**
$\ln Y$	-0.55	-3.55**
$\ln Y^2$	-1.28	-3.93**
$\ln EC$	-0.61	-4.12**
$\ln NR$	-1.52	-3.36**
$\ln GOV$	-1.46	-3.67**

Notes. **, denotes significance level at 5%.

From the results, it is obvious that the series are not stationary at level but become stationary after taking their first difference. This result shows that short-run policy is unlikely to be efficient for reducing carbon emissions across these countries. This suggests that the variables have a long run relationship.

4.3 Panel cointegration test

Just after assessing the stationarity properties of the series, it is important to assess whether the series are cointegrated. In realising this objective, the second-generation panel cointegration approach proposed by Westerlund (2007) is used and the choice is motivated by two factors. First, its approach has potential to settle cross-sectional related problems. Second, the approach helps to correct common factors across unit roots. Third, the asymptotic distribution of the test is said to be normally distributed. Table 5 presents the results of the Westerlund panel cointegration tests.

Table 5. Westerlund Panel Cointegration Test

Statistics	*Value*	*p-value*
Gt	-8.36***	0.00
Ga	-14.51**	0.00
P_t	-19.8***	0.00
P_a	-15.78***	0.00

Notes. ***; **, denote significance level at 1% and 5%, respectively

The evidence from the Westerlund panel cointegration test confirmed the potential long-term relationship among the variables.

4.4 Augmented Mean Group Results

Here, we implemented the augmented mean group (AMG) estimator and results are presented in Table 6.

Table 6. Long Run Elasticity, using Augmented Mean Group (AMG)

Variables	Coefficients	Z-Stat
$\ln Y$	0.28*	1.98
$\ln Y^2$	-0.00041**	-4.8
$\ln EC$	0.014*	1.99
$\ln NR$	0.05***	3.21
$\ln GOV$	-0.0016***	-7.18
Wald test		118.6*** [0.00]

Notes. ***; **, *; denote significant level at 1%,5%, 10%, respectively

From the results, initial coefficients of economic growth, natural resource rents and energy consumption positively correlate with carbon emissions. However, the squared of economic growth and governance negatively correlate with carbon emissions, validating the existence of an inverted U–Shape nexus which reflects the CKC hypothesis. This result is consistent with several previous studies (see Jalil & Mahmud, 2009; Sarkodie, 2018; Saboori et al., 2016; Omri et al., 2021; Shobande & Enemona, 2021).

4.5 Panel Granger Causality Test

As previously stated, the time series analysis based on the vector autoregressive (VAR) /vector error correction (VEC) approach is used. This consideration is motivated by four factors. *Firstly,* the VAR/VEC approach is a remedy for series that are stationary at their first difference (Jalil & Mahmud, 2009; Shobande & Enemona, 2021). *Secondly,* the approach helps to dissect the short and long run relation among the factors. *Thirdly,* the method allows for endogenous treatment of each variable, which is critical for identifying the major driver of carbon emissions (Shobande, 2021; Ullah et al., 2021). *Fourthly,* the method identifies the variable's rate of convergence to its equilibrium point, which is crucial for enhancing regional sustainability (Sharma et al., 2021; Ongan et al., 2021; Omri et al., 2021). Table 7 presents the estimated results from the Granger causality test.

Table 7. Long and Short Run Granger Causality Tests, using VAR/VEC approach

Independent Variable	*Short run Direction Causality*					
	Dependent Variables					*Long run*
	$\ln \Delta CO_{2it}$	$\ln \Delta Y_{it}$ $(\ln\Delta\, Y_{it})^2$	$\ln \Delta EC_{it}$	$\ln \Delta NR_{it}$	$\ln GOV_{it}$	$VECT_{t-1}$
$\ln \Delta CO_{2it-k}$	-	5.24** [0.00]	9.12** [0.00]	18.10** [0.00]	0.21 [0.16]	-0.35** [0.00]
$\ln \Delta Y_{it-k}$ $(\ln \Delta Y_{it-k})^2$	8.01** [0.00]	-	0.91 [0.24]	12.8** [0.00]	0.14 [0.22]	0.01 [0.15]
$\ln \Delta EC_{it-k}$	20.8** [0.00]	3.19* [0.00]	-	7.80*** [0.00]	0.25 [0.11]	-0.002** [0.00]
$\ln \Delta NR_{it-k}$	4.57** [0.00]	1.92 [0.15]	15.0** [0.00]	-	0.66 [0.29]	0.33** [0.01]
$\ln \Delta GOV_{it-k}$	3.60* [0.18]	2.88 [0.26]	0.81 [0.155]	0.54 [0.15]	-	0.17 [0.13]

Notes. ***; **, *; denote significance levels at 1%,5%, 10%, respectively

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Four main results can be deduced from the analysis. First, the speeds of adjustment of the variables are negative and statistically significant. The highest coefficient of the error correction term (*ect)* is about a 35% convergence speed, indicating the potential long run relationship among the variables. Second, the evidence suggests that bidirectional relationships exist among energy consumption, economic growth, natural resource, and carbon emissions. Third, governance unidirectionally Granger cause carbon emissions. Fourth, energy consumption unidirectionally Granger cause natural resource rents. The results are consistent with earlier studies by Saboori et al. (2018) and Omri et al. (2021) and Shobande and Asongu (2021).

The study has several policy implications: (a) the validity of the CKC hypothesis in Africa implies the need to reconsider environmental factors in resources exploration. Similarly, social cost must be considered for effective and efficient natural resource management. Likewise, policy incentives to promote economic growth must incorporate environmental consideration. (b) The unidirectional causality running from energy to carbon emission calls for the need to invest in energy efficiency. Evidence also suggests the need for good governance as a measure of promoting environmental quality. The negative correlation between governance and carbon emissions indicates that strengthening environmental regulation can help delay climate crisis. In particular, sustaining effective environmental regulation will require the design of appropriate monitoring, enforcement, and institutional capacity.

4.6 Discussion of findings

Our paper provides new evidence about the energy - carbon Kuznets curve. Prior to implementing our empirical research, we have discussed the extant literature surrounding the CKC hypothesis and provided some background on certain economic and institutional conditions that were neglected by CKC hypothesis. Then we have explored and implemented the second-generation tests to estimate the role of energy consumption, economic growth, natural resources, and governance in promoting environmental quality in Africa. Interestingly, the empirical results obtained enable us to draw some conclusions. *Firstly,* economic growth determines environmental quality. Specifically, our results confirmed the existence of the CKC hypothesis. Initially, a rise in economic growth is positively correlated with carbon emission, while the quadratic term of economic growth is negatively correlated with carbon emission. *Secondly,* the evidence suggests that energy consumption is positively correlated with carbon emission. *Thirdly,* energy consumption and natural resources are positively correlated with carbon emission. *Finally,* the governance indicator negatively affects carbon emission.

Further evidence shows that economic growth, energy consumption, natural resources, and governance are key determinants of environmental quality in Africa. Precisely, the evidence from the VEC indicates potential short and long run relationships among the variables. For example, the error correction term (ect) for almost all the endogenous models is negatively and statistically significance indicating that the variables can converge to a long run. In the short run, economic growth, energy consumption, and natural resources bidirectionally Granger cause carbon emission. Also, governance indicator unidirectionally Granger cause carbon emission.

5. **Conclusion**

The carbon Kuznets curve (CKC) remains a promising strand of research that has the potential to boost sustainable development. With few exceptions, in this study, we examine the role of energy consumption, natural resources, and governance in explaining the carbon Kuznets curve in Africa. We employ the second-generation panel approaches that account for cross-sectional dependence across the series. Specifically, we explore the Westerlund panel cointegration test, vector autoregressive (VAR) method, and augmented mean group (AMG) approach. The results validated the CKC hypothesis in Africa. Similarly, evidence suggested that bidirectional relationships exist between energy consumption, economic growth, natural resources, and carbon emissions. Using the AMG approach, we found evidence confirming the inverted U-shaped Kuznets curve. Specifically, the initial coefficients of economic growth, natural resource rents, and energy consumption were positively correlated with carbon emissions. However, the squared value of economic growth and governance were negatively correlated with carbon emissions. Our analysis is consistent with prior evidence by Jalil and Mahmud (2009), Sarkodie (2018), and Saboori et al. (2016). We recommend an effective and efficient environmental policy tailored towards mitigating the effect of carbon emissions, while strengthening institutional capabilities to promote sustainable development in Africa. Overall, fundamental changes in institutions for environmental governance are necessary if there is to be any hope for improving environmental quality in Africa. Improvement of such governance standards could be within the remits of political governance, economic governance, and institutional governance. (i) In terms of political governance, electing political leaders that are favorable to green economic policies is worthwhile. (ii) With respect of economic governance, it is important to formulate and implement policies that are favorable to environmental sustainability and green economics. In this direction, the legislative and executive bodies should consist of elements that are favorable to green economics. (iii) Regarding institutional governance, both citizens and the State should strictly adhere to environmental regulations governing interactions between them.

Future studies can consider the impact of governance on ecological footprint within country-specific and panel remits. Moreover, since this study is limited to African countries, extending the analysis to other regions and continents is worthwhile.

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Appendix 1: Sampled countries

African Countries			
Niger	Congo	Tanzania	Tunisia
Nigeria	South Africa	Botswana	Kenya
Ghana	Algeria	Egypt	Cameroon
Guinea	Angola	Morocco	Mozambique

Appendix 2: Definitions and sources of variables

Variables	Signs	Descriptions	Source
Carbon emission per capita	CO_2	Carbon emission (CO_2) measured in metric tons) per capita.	World Bank
Economic Growth	Y	Income per capita (GDP (constant 2010$).	World Bank
Energy consumption		Energy consumption is measured as energy use (kg of oil equivalent) per capita.	World Bank
Total natural resources	NR	Natural resources are measured as the total natural resource rent as percentage of GDP.	World Bank
Governance indicator	GOV	Governance indicator captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. The standard normal units of the governance indicator, ranging from around -2.5 to 2.5, and in percentile rank terms ranging from 0 (lowest) to 100 (highest) among all countries worldwide	World Bank