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Achieving carbon neutrality in Africa is possible: the impact of education, employment, and renewable energy consumption on carbon emissions

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Abstract

This paper analysed the causal link between education, employment, renewable energy consumption and carbon emissions in Africa, where there is scant evidence. Relying on panel data obtained from the World Development Indicators for thirty-two African countries covering a period of 19 years, and five panel rigorous regression models, we found that renewable energy, investment in education, school enrolment, net national income per capita, and employment had negative and significant effects on carbon emission, thus increasing these predictors would result in significant reduction in carbon emission in Africa. We identified a bidirectional causality between carbon emissions and net national income per capita, education expenditure and renewable energy consumption, and carbon emissions and employment. Our findings suggest that investment in education, renewable energy, and employment are relevant in mitigating carbon emissions in Africa. We recommend African governments to invest heavily in education, improve school enrolment, environmental education, renewable energy and employment provision to mitigate carbon emissions.

Highlights

- Achieving carbon neutrality in Africa is important.
- This research investigated the impact of education, employment, and renewable energy consumption on carbon emissions in Africa.
- This study utilized five panel regression models – fixed effect with Driscoll-Kraay standard errors, panel fixed effect model, random effect model, panel fully modified ordinary least square model, and panel canonical correlation analysis and panel data from 32 African countries.
- The results shed new light on the emission reduction potential of renewable energy consumption, education expenditure, school enrolment, per capita income, and employment.
- This article offers recommendations to attain carbon neutrality and environmental sustainability.

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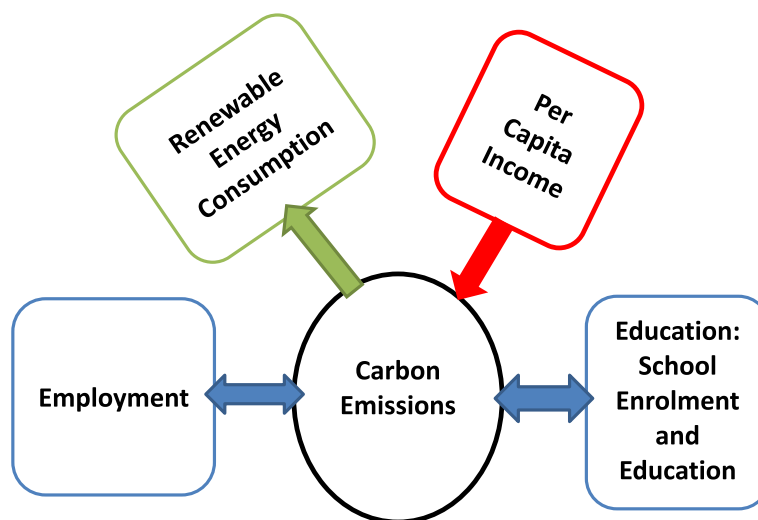
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Keywords Carbon emissions, Net national income per capita, Education expenditure, Primary school enrolment, Renewable energy consumption, Employment, Panel data

Graphical Abstract



1 Introduction

Climate change manifested through carbon emissions remains the most prominent topic around the globe and there continues to be frantic efforts and advocacy towards the consumption of renewable energy, investment in education, and the provision of environmentally friendly employment in mitigating carbon emissions, particularly in achieving global sustainable development goals (SDGs) such as quality education (Sustainable Development Goal 4), use of clean energy (Sustainable Development Goal 7), decent work and economic growth (Sustainable Development Goal 8), and climate action (Sustainable Development Goal 13). Despite attempts to reduce carbon emissions, global emissions appear to be increasing at an astronomical rate in the global north (Acheampong et al. 2021). Generally, sub-Saharan Africa (SSA) contributes less to global carbon emissions, but recent accounts show a rise in the region's carbon emissions, raising policy concerns (Acheampong 2019). Neglect in addressing carbon emissions in the sub-region has dire economic consequences (Acheampong et al. 2021). This article focuses on examining the link between education, employment, renewable energy consumption and carbon emissions in Africa, where there is a paucity of information concerning the dynamic causal impacts. The paper argues that investment in education, employment, and renewable energy influences carbon emissions

in sub-Saharan Africa (SSA). Even though empirical evidence on this argument is expected to abound, there appears to be scant empirical evidence specifically focused on SSA.

Generally, the literature (Salahuddin et al. 2020; Apergis et al. 2018; Bhattacharya et al. 2017; Inglesi-Lotz and Dogan 2018; Acheampong et al. 2019) establishes that renewable energy reduces carbon emissions. But there appears to be mixed findings. For instance, some literature (Ghorbal et al. 2022; Ali and Kirikkaleli 2022; Mentel et al. 2022; Adams and Nsiah 2019) argued that renewable energy increases carbon emissions, while Al-Mulali et al. (2015) however showed that renewable energy has no effect on carbon emissions in Vietnam. Others (Amri 2017; Pata and Kartal 2023; Yazdi and Shakouri 2018a) argued that renewable energy consumption impact on carbon emissions remains insignificant. The literature points to mixed findings on the impact of renewable energy on carbon emissions, and hence there is a need to draw more understanding on the subject, particularly in SSA, where the topic is under-researched.

The nexus between economic growth and carbon emissions appears mixed. Generally, some literature (Yusuf et al. 2020; Salahuddin et al. 2020; Adams and Nsiah 2019; Apergis et al. 2018) establishes a positive impact between economic growth and carbon emissions. For instance, Adu and Denkyirah (2018) showed

that economic growth has significant positive impacts on carbon emissions in the short-run. Economic growth is embedded with employment, and this study considers segment of the population aged above 15 years who are gainfully employed. The proportion of individuals gainfully employed obtain disposable income from various employment outlets. There will be differential impacts in areas of low economic opportunities and carbon emissions, where geographical spaces with more economic opportunities and higher incomes are likely to emit more carbon. For instance, Grunewald et al. (2017) established the link between income inequality and carbon emissions where they found that higher income inequalities lead to low carbon emissions in low and middle-income countries, while Adeleye et al. (2021) observed that, per capita income positively impacts carbon emissions. Specifically, per capita income positively increases carbon emissions by 0.84% and 0.87% in Africa. El Montasser et al. (2018) examined income and carbon emissions relationships in 12 Middle East and North Africa (MENA) countries. However, literature that establishes the simultaneous impact of per capita income, education, employment, and renewable energy consumption on carbon emissions in Africa is scarce. Hence, the motivation for this study.

The current paper finds few studies that examine the dynamic impact between education (proxied by primary school enrolment and adjusted savings on education expenditure) and carbon emissions in SSA. However, interrogating the impact of education on carbon emissions is important for the following reasons. First, we find that education is positively correlated with increased labour productivity and enhances economic development (Chansarn 2010; Razzak and Timmins 2010; Vladimirova and Le Blanc 2016). Low literacy has the tendency to reduce efficiency and productivity of labour, and eventually negatively impact economic growth. Second, education improves human capacity development that eventually improves productivity at the workplace. Indeed, some growth models (Pelinescu 2015; Mankiw et al. 1992) indicate that education improves economic development. Specifically, an additional \$1 investment in education will generate between \$10 and \$15 in economic growth (See Ahmmed and Uddin 2022). With a causal effect on how much an individual can earn based on the level of education (Ahmmed and Uddin 2022; Psacharopoulos and Patrinos 2018). Other studies present contrary findings on the impact of education on carbon emissions. For instance, Sarwar et al. (2021) found no significant impact of education on carbon emissions in the short-run, but found positive significant impacts in the long run. Bello et al. (2021) found two impacts of education on carbon emissions in Africa. First, the authors established that estimation from the pooled ordinary

least square (OLS) regression indicated a negative impact between education and carbon emissions, while the random effects and system generalized method of moments (GMM) showed a positive impact between education and carbon emissions. Few studies (Umaroh 2019; Barro 2001) have examined the impact of education on carbon emissions but with mixed findings. For instance, Balaguer and Cantavella (2018) found that education has a positive effect on environmental quality, Sapkota and Bastola (2017) found mixed results on the impact of education on carbon emissions, while others (Williamson 2017) showed no relationship between education and carbon emissions. This implies that educational policy reforms will influence an economy in the long term. However, studies that examine the impact of education on carbon emissions in Africa remain limited.

Therefore, empirical evidence on the impact of education, employment, and renewable energy consumption on carbon emissions in Africa is largely scanty and the existing studies yielded mixed findings. Specifically, our paper contributes to the carbon emissions and sustainable development literature through the identification of the causal pathways of the extent to which renewable energy, investment in education, primary school enrolment, net national income per capita, and employment impact on carbon emissions in Africa. First, we show the impact of education (proxied by net primary school enrolment) on carbon emissions, a pathway less studied for the African geographical space. Bello et al. (2021) appears to be the closest in examined the impact of education on carbon emissions in Africa studying 46 African countries covering the period between 1996–2018 using four different estimators (fixed effects, random effects, pooled OLS, and system-GMM). Mahalik et al. (2021) examined educational level on environmental quality in BRICS (Brazil, India, China, and South Africa) countries. The few literatures that examine the impact of education on carbon emissions present mixed conclusions that fails to focus on SSA with the exception of a recent study by Bello et al. (2021). A distinct feature of our study is the inclusion of investment in education (adjusted savings -educational expenditure) and primary school enrolment as proxies. Thus, our study contributes to the burgeoning literature on the nexus between education and carbon emissions in SSA. The main reason for highlighting education as a covariate in the carbon emissions nexus is because carbon emissions are closely associated with increasing human economic activities (Wang et al. 2017). Additionally, education and economic growth are highly correlated. Economists strongly believe that human capital plays a vital role in shaping a country's long-term economic growth. Human capital is a by-product

of education expenditure, school enrolment, and skilled labour, which remain vital inputs to economic growth.

Second, we find that few studies jointly examine the causal impact between renewable energy, education, employment, and carbon emissions. The literature (Matei 2017; Singh et al. 2019), showed that recent studies on the nexus between renewable energy, education, employment, and carbon emissions largely focus on non-SSA countries. Even more compelling are the contradictory findings (see Adewuyi and Awodumi 2017; Ito 2017; Lu 2017; Ozcan et al. 2019) in the under-researched area. Indeed, Arminen and Menegaki (2019) indicated that given the limited studies and the contradictory findings, further research is needed to deepen knowledge and understanding of the dynamic relationship between renewable energy, economic growth proxied by employment, net national income, education, and carbon emissions. Given the steady rise in carbon emissions in Africa, Antonakakis et al. (2017) argue that establishing low-emissions pathways is necessary in mitigating the climate crisis. And rightly so, our study seeks to contribute to the extant literature in this direction.

Finally, our study utilises five panel regression models – fixed effect with Driscoll-Kraay standard errors, panel fixed effect model, random effect model, panel fully modified ordinary least square model, and panel canonical correlation analysis model to examine the dynamic causal pathways between education, employment, renewable energy, net national income per capita, and carbon emissions in Africa which remain rare. To the best of our knowledge, this is the first attempt to model the impacts of education, employment, renewable energy, and economic growth on carbon emissions using five different panel regression approaches as a way to ascertain consistency and robustness of the dataset. Our study contributes to the methodology on consistently estimating the determinants of carbon emissions using different approaches as a way to demonstrate consistency and robustness of panel datasets used.

Our study contributes to the methodological estimation rigour.

The remainder of the article proceeds as follows, the next section (Section 2) reviews the relevant extant literature pertinent to the study. Section 3 presents the methodology underpinning the study. Section 4 presents the results, while Section 5 discusses the results within the body of relevant extant literature. A final section concludes and offers policy recommendations worthy of consideration.

2 Literature review

2.1 Education and carbon emissions

The relationship that exists between education and carbon emissions may be complex and multifaceted.

However, education plays an effective role in building social responsibility, promoting sustainable behaviour, reducing carbon emissions, and creating a more sustainable future (Alkhateeb et al. 2020; Gheraia et al. 2023). Several studies have highlighted the positive relationship between education and carbon emissions reduction. Higher level of education is associated with demand for clean energy leading to lower individual and household carbon emissions (Versteijlen et al. 2017; Cordero et al. 2020). Balaguer and Cantavella (2018) argued that the human capital and educational systems of a country are critical to the energy resources, and that education can play a significant role in an economy on many fronts. The authors conclude that an expansion in the educational system can make up for carbon emissions that are associated with income growth. A panel analysis of the Organization for Economic Cooperation and Development (OECD) countries on the role of human capital on energy consumption concluded that up to 86% of clean energy consumption was associated with investments in human capital, especially higher education (Yao et al. 2019). Similar conclusions on the role and benefits of education in reducing carbon emissions and achieving ecological footprints exist in the literature (Furqan and Mahmood 2020; Ma et al. 2019; Zafar et al. 2019; Zamil et al. 2019). This has led to a call to promote sustainability education in higher education institutions and the business community to reduce greenhouse gas emissions (Kiehle et al. 2023; Liu et al. 2022a, b, c; Molthan-Hill et al. 2020). This includes advocacy for online education (Yin et al. 2022; Liu et al. 2022a; Heller et al. 2021).

Other studies have established the positive effect of education in the promotion of environmental sustainability and called for the promotion of investment in education as a way of improving the ecological quality (Zafar et al. 2020; Reimers 2021; Sinha et al. 2019, 2020). Education remains an important characteristic at both the individual and national levels (Zaman et al. 2021) as improvement in education levels aligns with the SDGs (Rasool et al. 2020). One way of doing this is through adult education which has potential to make impact on improving renewable energy consumption and reducing carbon emissions (Hanmer and Klugman 2016).

Angrist et al. (2023) also argued that educated individuals have the likelihood to understand the nuances of climate science. They further argued that this requires the accumulation of human capital through increased educational attainment as people with higher education were more likely to see climate change and carbon emission as existential a threat to humanity. Leal Filho et al. (2023) arrive at a similar conclusion where they recommend that climate literacy and climate education are needed to raise awareness among children on the implication

of climate change on the environment and human race. Unfortunately, education has been missing in most of the discourse on renewable energy emissions and climate change (Fagan and Huang 2019). This notwithstanding, increases in educational attainment could foster economic growth which may have its downsides including increases in carbon emissions (O'Neill et al. 2020).

It must be noted that, despite the strong association between education and the reduction in carbon emissions, other studies have indicated the non-significant impact of education on the reduction of carbon emissions in the short-run, but positive and significant in the long-run suggesting that policies and reforms related to an educational system and reduction in carbon emission and climate change mitigation need long term effects to have its influence on an economy (Sarwar et al. 2021; Zhu et al. 2021). Therefore, investments in education, particularly in developing countries, may be associated with significant long-term implications for reducing carbon emissions while combating climate change.

2.2 Employment and carbon emissions

The literature on carbon emissions and employment generation suggests a strong correlation between employment and carbon emissions (Li et al. 2021; Sun et al. 2022; Cui et al. 2022a). A study by the International Labour Organization (ILO) suggests that achieving a low carbon economy could create up to 24 million jobs globally and reduce global carbon dioxide emissions by up to 70% by 2050 (ILO 2018). The OECD (2016) concludes that the renewable energy sector alone employed 8.1 million people globally in 2015. In a similar study, the International Renewable Energy Agency (IRENA) concludes that the renewable energy sector employed 10.3 million people globally in 2017, representing a 5.3% increase over the previous year (IRENA 2018).

This notwithstanding, the European Trade Union Confederation cautions that while traditional jobs in industries such as coal mining and oil drilling should be replaced with jobs in clean energy technologies, the transition to a low-carbon economy should be accompanied by proactive social policies to ensure that the existing workforce is not left behind (ETUC 2020).

Using data from China, Bai et al. (2021) cautions that transitioning to low emission sectors should be done in a way that does not have adverse impact on the economy. They argue that small changes in key emission sectors can affect economic growth and possibly lead to job losses. However, the promotion of the service sector which is labour intensive creates an opportunity for economic growth and stable jobs, and a reduction in carbon emissions, especially in contexts that promote employee participation in reduction of carbon emissions (Markey

et al. 2019). The review thus suggests transition to a low-carbon economy has the potential to create millions of new jobs globally, particularly in the renewable energy sector. Therefore, it is crucial for governments to implement policies that encourage investment in low-carbon industries and green sectors to reduce carbon emissions and stimulate economic growth as countries with higher levels of renewable energy investment have higher levels of employment in the renewable energy sector.

2.3 Renewable energy consumption and carbon emissions

Renewable energy consumption which is the use of renewable energy sources such as wind, solar, hydro, and biofuels for electricity generation, heating, and transportation has been promoted to mitigate climate change problems under various schemes, including the Paris Agreement and the Kyoto Protocol (Kwakwa 2021; Nguyen and Kakinaka 2019). Reaching the sustainable development goals (SDGs) requires closing of the gap between carbon emissions and economic development (Swain and Karimu 2020; Saidi and Omri 2020) as renewable energy has been associated with promoting economic growth and mitigating carbon emissions (Sadorsky 2012; Omri et al. 2015; Gozgor et al. 2018). Several studies have established a positive correlation exists between renewable energy consumption, carbon emission, and economic growth. A study by Ozturk and Al-Mulali (2015) examined the natural gas consumption and economic growth nexus using panel data from Gulf Cooperation Council (GCC) countries and concluded that natural gas energy consumption affects GCC countries economic growth positively. Jin and Kim (2018) also concluded from their analysis of panel data that renewable energy, but not nuclear, contributes to reduction in carbon emissions, and ultimately to the promotion of economic growth.

2.4 National income and carbon emissions

Governments all over the world are confronted with the need to invest to transform their economies to create the needed jobs (Wang et al. 2016). The quest for economic growth has led to increased energy consumption and to greater carbon emissions. The relationship between income and carbon emissions may however not always be linear. Rather, it may follow an inverted U-shaped curve, otherwise referred to as Environmental Kuznets Curve (EKC). The EKC is anchored on the assumption that, as income increases, environmental degradation will increase initially, and decrease. That is, there is a tendency to see a positive relationship between pollution and national income, but a negative relationship is observed at high income levels (Liu 2005). Zafar et al. (2022) concludes from their studies on the determinants of carbon emission

that economic growth is conducive to environmental degradation. Factors such as remittances, export diversification, renewable energy consumption contributed to the reduction in carbon emission. Similar findings are observed by Hailemariam et al. (2020) where an increase in top income inequality is found to be positively correlated with carbon emissions, but a nonlinear association between economic growth and carbon emission. Overall, the relationship between national income and carbon emissions remains complex and varies across geographies. However, economic growth is associated with increased carbon emissions. Addressing this relationship is important to enhance sustainable economic development while mitigating the impacts of climate change.

3 Methodology

3.1 Data source

The paper focused on Africa, where educational attainment/enrolment and expenditure, employment, renewable energy consumption, and national income are low. Panel data for a period of 19 years (2000–2018) and obtained from the World Development Indicators were used (see Table 1 for details). The time-period, countries, and variables (renewable energy consumption, carbon emissions, education expenditure, employment level, school enrolment, and net national income per capita) chosen were informed by data availability.

The countries studied are presented in Table 2.

3.2 Analytical technique

We applied different panel regression models to analyse the impacts of education (proxied by education expenditure, and school enrolment), employment, and covariates (renewable energy consumption, and net national income per capita) on carbon emissions in Africa. Five panel regression models – fixed effect with Driscoll-Kraay standard errors, panel fixed effect model, random effect model, panel fully modified ordinary least square model, and panel canonical correlation analysis model were employed. We used different panel regression models to check the robustness and consistency of the estimates generated by each model. The implicit form of our models is stated as follows:

$$Y = f(X1, X2, X3, X4, X5) \tag{1}$$

Where;

- Y = Carbon emissions (kt)
- X1 = Adjusted net national income per capita (current US\$)
- X2 = Adjusted savings: education expenditure (current US\$)
- X3 = School enrolment, primary (% gross)
- X4 = Renewable energy consumption (% of total final energy consumption)
- X5 = Employment to population ratio, 15+, total (%) (modeled ILO estimate)

We converted the observed values of the variables to their natural logarithmic values as a traditional way to control for possible heteroskedasticity in the dataset. The panel regression model with the logarithm is presented thus:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln X1_{it} + \beta_2 \ln X2_{it} + \beta_3 \ln X3_{it} + \beta_4 \ln X4_{it} + \beta_5 \ln X5_{it} + \varepsilon_{it} \tag{2}$$

Where; $i:1, 2, 3, \dots, 32$ countries; $t:2000, 2001, 2002, \dots, 2018$ year; \ln denotes natural logarithm; ε is the error term. Furthermore, $\beta_1, \beta_2, \beta_3, \beta_4,$ and β_5 define the estimated percentage change in carbon emissions caused by a one percent change in net national income per capita, education expenditure, school enrolment, renewable energy consumption, and employment level, respectively, while all other factors are constant. We further carried out Granger causality test to determine the causal relationships existing among the variables. We used STATA 17 software to analyse the data.

4 Results

Descriptive statistics for the variables used in the study are presented in Table 3. The table presents the distribution of the respective variables (minimum and maximum), the mean values, standard deviations, skewness and kurtosis. A total of 608 data points was used representing a balanced panel data set. The mean value for adjusted net national income per capita (current

Table 1 List of variables

Variable	Data source
Adjusted net national income per capita (current US\$)	World Development Indicators (World Bank 2023)
Adjusted savings: education expenditure (current US\$)	World Development Indicators (World Bank 2023)
School enrolment, primary (% gross)	World Development Indicators (World Bank 2023)
Renewable energy consumption (% of total final energy consumption)	World Development Indicators (World Bank 2023)
Employment to population ratio, 15+, total (%) (modeled ILO estimate)	World Development Indicators (World Bank 2023)
CO ₂ emissions (kt)	World Development Indicators (World Bank 2023)

Data Source: <https://databank.worldbank.org/source/world-development-indicators#>

Table 2 List of countries studied

Code	Country
1	Algeria
2	Benin
3	Burkina Faso
4	Burundi
5	Cabo Verde
6	Cameroon
7	Djibouti
8	Egypt
9	Eswatini
10	Ethiopia
11	Gambia
12	Ghana
13	Guinea
14	Lesotho
15	Madagascar
16	Malawi
17	Mali
18	Mauritania
19	Mauritius
20	Morocco
21	Mozambique
22	Namibia
23	Niger
24	Nigeria
25	Rwanda
26	Senegal
27	South Africa
28	Tanzania
29	Togo
30	Tunisia
31	Uganda
32	Zambia

US\$) was 1408.27, while the minimum value was 41.53 and the maximum was 11,114.26. The mean value for CO₂ emission (kt) was 29,831.56, the minimum value was 447,927.20 and the maximum was 29,831.56.

4.1 Preliminary results

Table 3.

4.2 Multicollinearity test

In Table 4, the data series on the predictors were subjected to a variance inflation factor (VIF test) to test for multicollinearity. The result shows that the Variance Inflation Factor (VIF) for all the variables were < 5 signifying the absence of multicollinearity. Previous studies (Chidiebere-Mark et al. 2022; Emenekwe et al. 2022; Onyeneke et al. 2023a, b, c, d) have used 5 as the cut-off point for determination of multicollinearity.

4.3 Cross section dependence test

A test of cross-sectional dependence formed our first step in the estimation strategy for this paper, since the presence of cross sectional dependence can bias the result while estimating a panel model. We used the cross-sectional dependence (CD) test to establish cross-section dependence in the data set. To reject the null hypothesis of no cross sectional dependency the *p*-values should be lower than 1%. From Table 5, we observed probability values for the computed CD were lower than 1%, hence the null hypothesis (absence of cross-sectional dependencies) is rejected and the subsistence of cross-sectional

Table 4 Multicollinearity test result using the variance inflation factor (VIF)

Independent variable	VIF
lnX1	2.57
lnX2	1.87
lnX3	1.12
lnX4	2.13
lnX5	2.24

Table 3 Descriptive statistics

Variable	N	Minimum	Maximum	Mean	Std. deviation
Adjusted net national income per capita (current US\$)	608	47.53	11,114.26	1408.27	1607.42
Adjusted savings: education expenditure (current US\$)	608	7,469,764.66	26,500,000,000.00	1,586,543,450.37	3,566,452,636.81
School enrolment, primary (% gross)	608	32.36	149.32	101.75	22.85
Renewable energy consumption (% of total final energy consumption)	608	0.06	96.04	58.38	30.62
Employment to population ratio, 15+, total (%) (modeled ILO estimate)	608	23.74	85.87	58.13	15.57
CO ₂ emissions (kt)	608	152.80	447,927.20	29,831.56	78,101.27

Table 5 Cross section dependence test

Variable	CD-test	P-value
lnY	79.39	0.000
lnX1	82.28	0.000
lnX2	88.06	0.000
lnX3	29.34	0.000
lnX4	51.27	0.000
lnX5	9.13	0.000

dependencies between the panels is found. The results indicate that the predictors X1, X2, X3, X4 and X5 and the dependent variable Y in one of the countries is likely to influence those of other African countries.

4.4 Unit test of the variables

The unit root test results for the data with their respective *p*-values are presented in Table 6. The test was conducted using both Pesaran’s Cross-sectional Augmented Dickey Fuller (CADF) test and Im-Pesaran-Shin Unit root test approaches for panel and times series. The predictors were tested at levels and first difference. Under the Pesaran’s CADF test, we found that the predictors (net national income per capita (lnX1); education expenditure (lnX2); school enrolment, primary (lnX3) were stationary at level; while all the variables were stationary at first difference. For the Im–Pesaran–Shin unit-root test, none of the variables was stationary at level, while all of them were stationary at first difference. Based on the results, the study rejected the null hypotheses that all panels contain unit roots and the time series data are not stationary (i.e. series have a unit root). The test findings indicate that the predictors are I (1) and the maximum integration level is specified as 1. The variables used for this paper showed mixed nature

of stationarity properties, being stationary at the level and first difference (Zaman et al. 2021).

4.5 Cointegration tests

The test for Co-integration between the dependent variable (CO₂ emission) and the independent variables are presented in Table 7. The null hypothesis of no cointegration was tested against the alternative using the Pedroni test (Philips-Perron *t* statistic). Other studies have used the ARDL bound test for cointegration based on F-test to check for cointegration (Narayan 2004). From Table 7, we confirm that a long-run relationship among the studied variables exists. Based on the *p*-values (critical values at 1% level of significance) the null hypothesis of no cointegration is rejected. Therefore, there is cointegration relationship between dependent variable and the predictors (net national income, education expenditure, school enrolment, renewable energy consumption and employment).

4.6 Empirical results from panel regression models

Although technological innovations are making life easy and comfortable, they come with some environmental challenges such as high emission of greenhouse gases into the atmosphere. These gases have led to changes in weather patterns, global warming with resultant effect on soil (flora and fauna), ocean life and the health of human (Wang et al. 2021; Rahman et al. 2020). Having established cointegration relationship among the variables for the study, different panel models were estimated to establish the effect of education, employment, renewable energy consumption on carbon emission in Africa. Results from the respective panel regression models are presented in Table 8.

Net income per capita had a negative and significant effect on CO₂ emissions as presented in Table 8. The variable was not significant in the second model even though

Table 6 Unit root test results

Variables	<i>H</i> ₀ = All panels contain unit roots <i>H</i> ₀ = series have a unit roots											
	Pesaran’s CADF test				Result	Im–Pesaran–Shin unit-root test				Result	Decision	
	Level	<i>p</i> -value	1 st diff.	<i>p</i> -value		Level	<i>p</i> -value	1 st diff.	<i>p</i> -value			
Net national income per capita (lnX1)	-2.51 ^a	0.000	-3.07 ^a	0.000	I(0)	1.18	0.880	-9.98 ^a	0.000	I(1)	Reject <i>H</i> ₀	
Education expenditure (lnX2)	-2.29 ^a	0.000	-2.98 ^a	0.000	I(0)	3.09	0.999	-10.03 ^a	0.000	I(1)	Reject <i>H</i> ₀	
School enrolment, primary (lnX3)	-2.20 ^a	0.010	-2.65 ^a	0.000	I(0)	1.67	0.950	-4.72 ^a	0.000	I(1)	Reject <i>H</i> ₀	
Renewable energy consumption (lnX4)	-1.75	0.460	-2.51 ^a	0.000	I(1)	1.02	0.850	-5.96 ^a	0.000	I(1)	Reject <i>H</i> ₀	
Employment (lnX5)	-1.94	0.120	2.19 ^a	0.010	I(1)	0.28	0.610	-3.65 ^a	0.000	I(1)	Reject <i>H</i> ₀	
CO ₂ emissions (lnY)	-1.94	0.120	-2.91 ^a	0.000	I(1)	0.07	0.530	-7.23 ^a	0.000	I(1)	Reject <i>H</i> ₀	

^a Indicate significance at 1% level

Table 7 Cointegration test

H_0 : No cointegration
 H_a : All panels are cointegrated

Pedroni test for cointegration

Test	Statistic	p-value
Modified Phillips–Perron t	6.33	0.000
Phillips–Perron t	-8.14	0.000
Augmented Dickey–Fuller t	-6.90	0.000

the direction of the effect was negative. In the other models net income per capita was highly significant at 1% level of significance.

From a theory perspective, education expenditure is hypothesized to influence environmental quality leading to economic growth and development (Duarte et al. 2012; Cui et al. 2022b). The a priori expectation is that expenditure on education targeted at creating awareness of environmental issues will significantly minimize environmental degradation through different transmission channels (Dedeoğlu et al. 2021; Zaman et al. 2021). The estimated models, presented in Table 8, show that education expenditure had positive effect on CO₂ emission in Africa. This relationship was significant at 1% level of significance for all the models. This suggests that in Africa increasing education expenditure would increase the CO₂ emission.

In terms of school enrolment (primary), the variable yielded significant and negative effect on carbon emissions. The variable was negative and significant at 1% level of significance in the first panel data presented in Table 8. Renewable energy was found to have a negative and significant effect on carbon emission from the panel data analysis presented in Table 8. An increase in the use of renewable energy is expected to result in significant reduction in CO₂ emission in Africa.

Employment had a negative but not significant effect on CO₂ emission under the fixed effect model with Driscoll-Kraay standard errors model, the variable,

however, had negative but significant effect on CO₂ emissions in Africa for the other models. The relationship was highly significant at 1% level of significance. This suggests that increasing employment (particularly green jobs) will help in reducing CO₂ emission by in the environment. The result of the study is in line with other studies indicating that increasing employment (particularly green jobs) levels has implications for CO₂ emission in Africa. Africa as a continent has the largest number of youth as well as high levels of youth unemployment, striking a balance between creating employment with minimal CO₂ emission would be a critical and important policy action. From the empirical literature, there is mixed results regarding the relationship between (un)employment and the environment (Liu and Feng 2022).

4.7 Granger test for panel causality

Granger test for panel causality was conducted using Dumitrescu and Hurlin (2012), the results and significant levels are presented in Table 9. The test Granger checks the relationship between the predictors in the model and the dependent variable. We identified bidirectional causality between the dependent variable CO₂ emission and net national income per capita (lnX1), education expenditure (lnX2), renewable energy consumption. The results also show bidirectional causality between CO₂ emissions and employment. In other words, carbon emissions Granger causes employment and employment Granger causes carbon emissions (bidirectional causality identified). In terms of relationship between Carbon emissions variable and school enrolment, the results show that CO₂ emission does not Granger cause school enrolment, but school enrolment Granger causes carbon emissions, hence a unidirectional causality was identified. The causality test to establish the relationship among each of the predictors is also presented in Table 9. There is bidirectional causality among all the predictors. For example, the study data showed that net national income per capita does Granger cause education expenditure and education expenditure does Granger cause net national income

Table 8 Panel regression estimates of the impact of education, employment, renewable energy consumption, and national income on carbon emissions

Variable	Fixed effect with Driscoll-Kraay standard errors	Fixed effect with ordinary standard errors	Random effect	Panel fully modified ordinary least square	Panel canonical cointegrating regressions
lnX1	-0.16 ^a (-2.62)	-0.08 (-1.38)	-0.21 ^b (-3.95)	-0.14 ^b (-8.39)	-0.13 ^b (-4.98)
lnX2	-1.10 ^b (-91.33)	-0.44 ^b (-10.62)	-0.55 ^b (-14.31)	-0.29 ^b (-49.65)	-0.28 ^b (-28.64)
lnX3	-0.63 ^b (-3.75)	0.08 (1.02)	-0.01 (-0.07)	-0.14 ^b (-6.76)	-0.15 ^b (-7.37)
lnX4	-0.21 ^b (-16.64)	-0.34 ^b (-6.17)	-0.37 ^b (-7.16)	-3.77 ^b (-193.89)	-3.76 ^b (-119.76)
lnX5	-0.04 (-0.25)	-1.05 ^b (-4.51)	-0.82 ^b (-3.91)	-0.96 ^b (-33.56)	-0.93 ^b (-19.89)

^a and ^b denote statistical significance at 1% and 5% levels, respectively

Table 9 Dumitrescu and Hurlin (D-H) Granger non-causality test results

Hypothesis	Z-bar	Z-bar tilde	Remark
lnY → lnX1	4.62 ^a	3.07 ^a	Carbon emissions Granger causes net national income per capita and net national income per capita Granger causes carbon emissions (bidirectional causality identified).
lnX1 → lnY	4.62 ^a	3.08 ^a	
lnY → lnX2	7.48 ^a	5.28 ^a	Carbon emissions Granger causes education expenditure and education expenditure Granger causes carbon emissions (bidirectional causality identified).
lnX2 → lnY	5.50 ^a	3.75 ^a	
lnY → lnX3	1.39	0.59	Carbon emissions variable does not Granger cause school enrolment and school enrolment Granger causes carbon emissions (unidirectional causality identified).
lnX3 → lnY	10.03 ^a	7.24 ^a	
lnY → lnX4	2.72 ^a	1.62	Carbon emissions Granger causes renewable energy consumption and renewable energy consumption Granger causes carbon emissions (bidirectional causality identified).
lnX4 → lnY	10.25 ^a	7.40 ^a	
lnY → lnX5	6.04 ^a	4.17 ^a	Carbon emissions Granger causes employment and employment Granger causes carbon emissions (bidirectional causality identified).
lnX5 → lnY	13.23 ^a	9.69 ^a	
lnX1 → lnX2	9.64 ^a	6.93 ^a	Net national income per capita does Granger-cause education expenditure and education expenditure does Granger-cause net national income per capita (bidirectional causality identified).
lnX2 → lnX1	6.84 ^a	4.78 ^a	
lnX1 → lnX3	10.84 ^a	7.85 ^a	Net national income per capita does Granger-cause school enrolment and school enrolment does Granger-cause net national income per capita (bidirectional causality identified).
lnX3 → lnX1	9.59 ^a	6.89 ^a	
lnX1 → lnX4	2.72 ^a	1.62	Net national income per capita does Granger-cause renewable energy consumption and renewable energy consumption does Granger-cause net national income per capita (bidirectional causality identified).
lnX4 → lnX1	5.4739 ^a	3.7324 ^a	
lnX1 → lnX5	3.9815 ^a	2.5859 ^a	Net national income per capita does Granger-cause employment and employment does Granger-cause net national income per capita (bidirectional causality identified).
lnX5 → lnX1	28.2825 ^a	21.2544 ^a	
lnX2 → lnX3	12.0853 ^a	8.8114 ^a	Education expenditure Granger causes school enrolment and school enrolment Granger causes education expenditure (bidirectional causality identified).
lnX3 → lnX2	9.0628 ^a	6.4894 ^a	
lnX2 → lnX4	3.9501 ^a	2.5618 ^b	Education expenditure Granger causes renewable energy consumption and renewable energy consumption Granger causes education expenditure (bidirectional causality identified).
lnX4 → lnX2	5.5854 ^a	3.8180 ^a	
lnX2 → lnX5	4.4827 ^a	2.9709 ^a	Education expenditure Granger causes employment and employment Granger causes education expenditure (bidirectional causality identified).
lnX5 → lnX2	25.4694 ^a	19.0933 ^a	
lnX3 → lnX4	9.4301 ^a	6.7716 ^a	School enrolment does Granger cause renewable energy consumption and renewable energy consumption does Granger-cause school enrolment (bidirectional causality identified).
lnX4 → lnX3	4.0286 ^a	2.6221 ^a	
lnX3 → lnX5	10.0982 ^a	7.2849 ^a	School enrolment does Granger cause employment and employment does Granger-cause school enrolment (bidirectional causality identified).
lnX5 → lnX3	32.4613 ^a	24.4646 ^a	
lnX4 → lnX5	8.4410 ^a	6.0118 ^a	Renewable energy consumption does Granger cause employment and employment does Granger-cause renewable energy consumption (bidirectional causality identified).
lnX5 → lnX4	22.9613 ^a	17.1665 ^a	

*H*₀ one variable does not Granger cause the other variable for at least one panel variable

^a and ^b denote statistical significance at 1%, 5%, and 10% levels

per capita (bidirectional causality identified). Details are presented in Table 9.

5 Discussion

Economic growth is expected to influence the emission of carbon into the environment through the pathway of industrialization. For instance, Xin et al. (2023) using Gross Domestic Product (GDP) as a proxy for income and economic growth found that increased output growth contributes to carbon emissions in China. We assumed that higher income per capita should translate to higher income levels of people living in the countries. As income per capita increases, people with high income will have more opportunities to fulfil their desires and maintain a good lifestyle that improves the

environment (Mulderij et al. 2021). Also, higher income per capita tends to promote better environmental awareness and consciousness, for instance, higher income groups tend to invest in more sustainable energy sources such as renewable energy, and hence income per capita is expected to lead to reduction in carbon emission. In this paper net income per capita was used as a proxy for economic growth, and the results shows that net income per capita negatively influences carbon emission in Africa. In other words, higher net income per capita in Africa would decrease the levels of carbon emission. Structural transformation of economies in Africa is propelled by the service than industry. Hence countries in Africa emit less carbon into the environment. Xin et al. (2023) confirmed the findings of the current study. Our findings

confirmed the study by Acheampong et al. (2021) who found that economic growth (proxied by GDP) reduces carbon dioxide emission significantly in the British ex-colonies but negligibly in other SSA countries. However, Grunewald et al. (2017) found that higher inequality is likely to lower carbon emissions for low income and middle income economies while a higher income inequality increases carbon emissions in upper middle income and high-income economies.

Education expenditure has been used as a proxy for human capital in studies that looked at the relationship between human capital development and carbon emission. Human capital contributes to the rising environmental sustainability by controlling carbon emission and sustainable growth. It is therefore, expected that increasing expenditure on environmental education should create awareness and lead to significant reduction in carbon emissions. Hence a significant negative a priori relationship was expected between education and carbon emissions. This paper also found a negative relationship between education and carbon emissions, implying that expenditure on education significantly decreased carbon emissions in Africa. The finding deviates from most empirical studies that looked at the relationship between education expenditure and carbon emission. High investments/budget in education with a commensurate curriculum that teaches environmental issues results in high level of environmental knowledge and the consequence of degradation on the environment. This finding supports the finding of Zaman et al. (2021), who found a negative effect between education expenditure and carbon dioxide emission in China. Another study by Liu et al. (2022b) found a negative association between education and carbon dioxide emission. Similarly, Li and Ullah (2022) reported that an increase in education significantly controls CO₂ emissions, while a decline in educational attainment thus amplifies carbon dioxide emission in BRICS economies. Zafar et al. (2022) reported robust findings between education and environmental deprivation.

The findings for school enrolment showed a significant negative effect on carbon emissions implying that school enrolment decreased carbon emissions on the continent. High enrolment in primary schools with a commensurate curriculum that covers environmental issues would likely result in high level of environmental knowledge and the implication on sustainable environmental management. Such people would be concerned about the environment and are likely to attach values to it (Mahalik et al. 2021). From the perspective of Xin et al. (2023) policy on environmental education should be considered at early levels of education such as the primary level.

The current paper sought to address the relationship between consumption of renewable energy and carbon

emission reduction. Renewable energy consumption significantly decreased carbon emissions in Africa. This substantiates the findings that posit that increasing renewable energy help improve environmental quality and reduces carbon emissions (Waheed et al. 2018; Bilgili et al. 2016; Danish et al. 2017; Wang et al. 2016). Furthermore, the finding supports a study conducted in Brazil, Russia, India, China, and South Africa (BRICS) countries by Dong et al. (2017), where increasing renewable energy consumption mitigates CO₂ emissions in the environment. The current paper also confirms the work of Jin and Kim (2018) who established a long-run relationship between carbon dioxide emission, renewable energy consumption and nuclear energy consumption. We also found that the current results are consistent with the findings of Chidiebere-Mark et al. (2022), Adams and Acheampong (2019), Yazdi and Beygi (2018) who established that renewable energy reduces carbon emission in Africa. This however contradicts the work of Hu et al. (2018) and Yazdi and Shakouri (2018b) who found that renewable energy consumption increased carbon emission.

The result of this study shows that employment has a negative and significant effect on carbon emissions. This implies that employment decreased carbon emissions in Africa. The result of the study is in line with other studies indicating that increasing employment levels (especially green and climate compatible jobs) have implications for carbon dioxide emission in Africa (Liu and Feng 2022). Although the nexus between unemployment and the environment is found inconclusive (Mulderij et al. 2021), a few studies have established a relationship between unemployment and carbon emission. Xin et al. (2023) established that unemployment significantly increases carbon dioxide emission in the long-run. Based on the results of the current paper, we strongly note that structural changes in Africa and the creation of sustainable employment will lead to reduction in carbon emission. From the empirical literature, employment was found to be negatively related to carbon emission in Africa, this suggesting that all things being equal higher levels of employment will result in the significant reduction in CO₂ emissions on the continent.

6 Conclusions

Despite attempts to reduce carbon emissions, global emissions appear to be increasing at an astronomical rate. Mitigating climate change through reduction in emission of carbon becomes challenging given the need for countries to grow their economies, improve human capital development (through education) and provide jobs. Striking a balance between economic growth, education, employment, and renewable energy use and emission of carbon into the environment remains high on

the global policy agenda. The global sustainable development goals, advocacy for the consumption of renewable energy, investment in education, and the provision of environmentally friendly employment avenues are all priorities in the global policy goals.

This study therefore examined the dynamic causal link between education (proxied by adjusted savings in education expenditure, primary school enrolment), employment, renewable energy consumption and carbon emissions in Africa, where there is scant evidence. Our study relies on panel data obtained from the World Development Indicators for thirty-two African countries covering a period of 19 years (2000–2018), making use of five panel rigorous regression models – fixed effect with Driscoll-Kraay standard errors, panel fixed effect model, random effect model, panel fully modified ordinary least square model, and panel canonical correlation analysis model to establish causality of carbon emissions.

The results showed a positive impact of education expenditure on carbon emissions. Renewable energy reduced carbon emissions in Africa suggesting the need to promote renewable energy consumption in Africa. We conclude that policy initiative targeted at increasing the consumption of renewable energy as part of total energy mix will help mitigate carbon emission in the environment.

Employment significantly reduced carbon emissions in Africa. African governments are encouraged to target increasing avenues of creating decent and environmentally friendly employment to help mitigate carbon emissions. Similarly, net income per capita decreased carbon emissions on the continent. There is a bidirectional causality between carbon emissions and net national income per capita, education expenditure and renewable energy consumption, and carbon emissions and employment; However, carbon emissions do not Granger cause school enrolment, but school enrolment Granger causes carbon emissions, thus a unidirectional causality. The findings suggest that renewable energy and employment are relevant for mitigating carbon emissions in Africa. Fortunately, Africa abounds with renewable energy resources which currently remain under-utilized and exploited. We recommend African governments to invest heavily in renewable energy and provide environmentally friendly employment options that mitigate carbon emissions. Investments in education and the improvement in primary school enrolment have positive dividends on carbon emissions reduction; hence there is the need to turn attention to improvements in investment in education and primary school enrolment in Africa.

Abbreviations

BRICS	Brazil, Russia, India, China, and South Africa
CO ₂	Carbon dioxide
CD	Cross-sectional dependence

CADF	Cross-sectional augmented dickey fuller
D-H	Dumitrescu and Hurlin
DOLS	Dynamic ordinary least squares
EKC	Environmental Kuznets curve
FMOLS	Fully modified ordinary least squares
GMM	Generalized method of moments
GDP	Gross domestic product
GCC	Gulf Cooperation Council
ILO	International Labour Organisation
IRENA	International Renewable Energy Agency
MENA	Middle East and North Africa
OLS	Ordinary least square
OECD	Organization for Economic Cooperation and Development
SSA	Sub-Saharan Africa
SDGs	Sustainable development goals
VIF	Variance inflation factor

Authors' contributions

Conceptualization, Chinyere Ori Elom, Robert Ugochukwu Onyeneke and Chidebe Chijioke Uwaleke; Formal analysis, Robert Ugochukwu Onyeneke; Investigation, Chinyere Ori Elom, Daniel Adu Ankrah, Eric Worlanyo Deffor, Hayford Mensah Ayerakwa and Chidebe Chijioke Uwaleke; Literature Search and Review, Chinyere Ori Elom, Daniel Adu Ankrah, and Hayford Mensah Ayerakwa; Methodology, Robert Ugochukwu Onyeneke; Supervision, Chinyere Ori Elom, Daniel Adu Ankrah, Eric Worlanyo Deffor, and Hayford Mensah Ayerakwa; Validation, Chinyere Ori Elom and Robert Ugochukwu Onyeneke; Visualization, Chinyere Ori Elom, Robert Ugochukwu Onyeneke, Daniel Adu Ankrah and Eric Worlanyo Deffor; Writing—original draft, Chinyere Ori Elom, Robert Ugochukwu Onyeneke, Daniel Adu Ankrah, Eric Worlanyo Deffor, Hayford Mensah Ayerakwa and Chidebe Chijioke Uwaleke; Writing—review and editing, Chinyere Ori Elom, Robert Ugochukwu Onyeneke, Daniel Adu Ankrah, Eric Worlanyo Deffor, Hayford Mensah Ayerakwa and Chidebe Chijioke Uwaleke. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

The data used for this study are openly available. The data can be downloaded from the World Development Indicators website. <https://databank.worldbank.org/source/world-development-indicators#>.

Declarations

Competing interests

The authors declare no known conflict of interest.

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