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ORIGINAL ARTICLE

Does energy consumption improve human capital development? Empirical evidence from panel non-linear autoregressive distributed lag in Africa

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Abstract

The contributions of human capital to improvement in socio-economic outcomes have generated significant interest in its determinants. On one hand, there is the orthodox view which states that energy consumption does not promote human capital development. In contrast, the heterodoxies argue that energy consumption is an essential driver of human capital development. Thus, we explore the asymmetric effects of energy consumption on human capital development for 22 African countries from 2000 to 2018 within the framework of panel non-linear ARDL (NARDL). The long-run results indicate that energy consumption is vital for human capital development. Specifically, in the long-run, positive and negative shocks to energy consumption significantly improve human development. In addition, we find that economic growth, government effectiveness and foreign direct investment improve human capital only in the long-run, while carbon dioxide emission retards it in both the long- and short-runs. We found similar results for oil and non-oil producing countries, ECOWAS, SADC, CEN-SAD and COMESA countries.

1 | INTRODUCTION

Human capital development and its determinants have become an important subject extensively discussed for many decades in the human capital literature. The Human Development Report (1990) stresses the importance of human capital by arguing that people constitute the actual wealth of a nation. A high human capital development can promote and support technological innovation (Alvarado et al., 2021), economic growth (Romer, 1994) and reduce the consumption of fossil fuels (Chang et al., 2020). Similarly, human capital development has been seen to play a central role in reducing climate change (Sarkodie et al., 2020). In addition, there is strong evidence which suggests that highly educated household heads and employees of firms and well-trained managers are very sensitive to energy-efficient appliances and equipment, which can reduce energy intensity in production (He & Huang, 2020).

The contributions of human capital to improvement in socio-economic outcomes have generated significant interest in its determinants. According to Becker (1962) and Stokey (1991), the length of investment in education is a crucial determining factor of human capital which affects the degree and effectiveness of human capital development. Again, GDP per capita and openness have also been identified as important drivers of human capital development across countries (Attanasio, 2015; Bareke et al., 2021). Others have revealed that government expenditure and capital–labour ratio are important determinants of human capital development (Bareke et al., 2021). Following the Sen's capability method, some studies find institutions, health and infrastructure essential impetus for human capital development (Shuaibu, 2016). Given the significant transformation and changes in the global economy, recent extant studies have identified novel additional determinants of human capital development. One of these novel drivers is energy consumption. This has recently been considered as an important driver of human capital development which supplements the traditional factors of human capital development. Energy services facilitate improvement in communication, enhance the efficient function of hospital equipment for better healthcare and improve the number of hours for school children to enhance academic performance, which are key drivers of human capital development. Electricity, particularly, is needed to promote the adoption of new technology and replace inefficient traditional cooking methods such as biomass, which may induce human capital development. Lastly, electricity may be a catalyst for entrepreneurship and productivity. That is, electricity complements capital for production and releases women from long hours of gathering firewood for cooking. Electric energy often does not have a direct substitute, making it inevitable for improving socio-economic development in Africa.

This study is important because Africa accounts for about 17% of the world's population but provides only 4% of the world's investment in power supply. A little over 58% of the population of Africa is provided with electricity, while about 600 million have no access to electricity in 2018 (International Energy Agency [IEA], 2021). Furthermore, nearly 80% of the companies in Africa experience severe electricity interruptions which have caused heavy production losses (IEA, 2021). Notwithstanding these challenges, Africa consumed primary energy to the tune of 18.6 exajoules in 2020 after falling marginally by 1.3% in 2019 (British Petroleum, 2020). Per capita energy consumption declined by 9% relative to the world average of 5% (British Petroleum, 2020). According to the IEA (2021), the continent performs worse in terms of access to clean, affordable and sustainable energy as 600 million of its population are without electricity (IEA, 2021). Similarly, the human capital index (HCI) for most countries in Africa is low, ranging between 0.30 and 0.50 from 2010 to 2020 compared to developed countries, with HCI ranging between 0.78 and 0.99 (World Bank, 2022). For instance, Benin recorded HCI of 0.37 in 2010 and this rose marginally to 0.40 in 2020; Burkina Faso obtained HCI of 0.32 in 2010 and this increased to 0.38 in 2020; Botswana recorded 0.37 in 2010 and rose to 0.41; Cote d'Ivoire had HCI of 0.30 and this increased to 0.38; Egypt reported 0.52 in 2010 and 0.59 in 2020; Nigeria had 0.36 in 2020; Ghana had 0.45 in 2022; South Africa reported 0.43 in 2010 and 0.45 in 2020.

The World Bank (2022) ascribed the marginal growth performance of Africa in HCI to bridging the gender gap in employment and education, improvement in years of schooling among the younger generation and quality of education, high rates of unemployment and underemployment. However, the dramatic increase in population growth and the rising quest for high human capital development in Africa will have profound consequences for the energy sector. Among them is the need for governments in Africa to provide collective access to unfailing, modern and sustainable energy to facilitate efficient communication to improve learning and health outcomes.

Based on the above deliberations, the objective of this study is to explore the asymmetric relationship between energy consumption and human capital development in Africa spanning 2000–2018. Particularly, our study focusses on energy consumption as a new driver of human capital development, alongside the traditional determinants such as GDP, foreign direct investment, education and government effectiveness. As indicated, Africa could be a perfect case for analysing the drivers of human capital development because it performed worse than the global average in HCI in 2022 (World Bank, 2022). In addition, Africa is home to a substantial amount of energy resources, such as 14.4 trillion cubic metres of global natural gas reserves, 125.8 billion reserves of crude oil in 2018 (BP, 2020), solar energy generation potential of more than 10 terawatts (World Economic Forum, 2016), 350 GW hydro, 15 GW geothermal energy and 110 GW of wind (African Development Bank, 2018). In light of the above, we relate energy consumption of Africa to its human and capital development by examining the asymmetric effects of energy consumption on human capital development.

A few studies consider the effect of energy consumption on human capital development. For instance, Ouedraogo (2013) investigates the impact of energy use on human development and finds that energy consumption and energy price reduce human development. Lekana and Ikiemi (2021) find that energy consumption improves human capital development among the Economic and Monetary Community of Central African countries. However, these studies failed to consider the asymmetric effects of energy consumption on human capital development. In addition, these studies failed to capture the transmission channels of energy consumption in human capital development. Our study attempts to seal these gaps by investigating the asymmetric effects of energy consumption on human capital development by applying the panel nonlinear autoregressive distributed lag (NARDL) technique. Information given by symmetric models may be inadequate to generate robust inferences and produce a consistent forecast for policy purposes (Shin et al., 2011). The panel NARDL method also allows for simple and unrestricted estimation of asymmetries in both the long-run equilibrium relationship and the dynamic short-run adjustments which produce robust inferences and reliable forecasts relevant for policy purposes. This study also fills the second gap by identifying and capturing transmission channels in the association between energy consumption and human capital development. We further divided the data into regional blocs such as the Common Market for Eastern and Southern Africa (COMESA), Community of Sahel–Saharan States (CEN-SAD), as well as the Economic Community of West African States (ECOWAS) and Southern African Development Community (SADC) to ensure robustness check of our findings.

The rest of the study is structured as follows. The literature review is presented in Section 2. Section 3 presents the methods based on the literature review. Analysis and discussion of results are presented in Section 4. Finally, we outline the conclusion and policy suggestions in Section 5.

2 | LITERATURE REVIEW

Past studies examining energy use and development of human capital are usually focussed on determining their effect on economic growth. We divide the literature into strands. The first component of the literature considers the impacts of energy consumption on economic growth. This is termed the 'energy-induced growth hypothesis'. There is extensive literature on this area (see Bayramoglu & Yildirim, 2017; Giray et al., 2018; Katsuya, 2017; Kris et al., 2021; Kunofiwa & Lindiwe, 2020; Montassar et al., 2016; Olabanji & Adeolu, 2020; Yajie et al., 2021). These studies find that energy use induces economic growth. Similar studies include Chen et al. (2012), Chontanawat et al. (2008), Gyimah-Brempong et al. (2006) and Lee and Chang (2008). On the contrary, using panel techniques, Mahmoud (2006) finds the presence of a one-way causality moving from GDP to energy use. Thus, the study offers evidence conflicting with the hypothesis that energy consumption is key for GDP growth in the Gulf Cooperation Council. This describes the 'conservation hypothesis'. However, Mohamed et al. (2016) and Lee et al. (2008) establish a bidirectional connection between economic growth and electricity consumption, which supports the 'feedback hypothesis'.

Secondly, other prior studies also concentrate on investigating the impact of energy use and human capital on economic growth. Such studies include Alaali et al. (2015) who argue using a panel of 130 countries spanning 1981–2009 and the GMM technique that health capital, education and energy consumption possess a momentous consequence on economic growth. Fang and Chang (2016), Fatima et al. (2019), Chang et al. (2020) find similar results. However, Fang and Chang (2017) reveal that both human capital and energy play a significant part in growth using cointegration and Granger causal techniques for the period 1995–2014. Further, Oluwatoyin et al. (2018) used data spanning 1981–2016 and applying fully modified ordinary least squares technique finds human capital development has insignificant effects on economic growth, while electricity consumption has significant effects. Van Tran et al. (2019) found similar results for global sample and sub-panels of developed and developing countries.

Finally, other literature has considered the consequence of human capital on energy consumption. Such studies include Yao et al. (2019) that was based on a panel of OECD countries spanning 1965–2014. The study indicates that one standard deviation growth in human capital decreases total energy use by 15.36%. By distinguishing between non-polluting and polluting energy sources, the finding unearths that increase in human capital is positively related to increase in non-polluting energy consumption and negatively impacts polluting energy. Also, Akram et al. (2020, 2019) and Salim et al. (2017) find weighty adverse impacts between human capital and energy use. Corroborating this finding, Salim et al. (2017) indicate that the growth of human capital promotes the adoption of energy-efficient technologies by households, leading to a reduction in energy use.

With regards to studies relating energy consumption to human capital development, the evidence available is scanty and limited if not non-existent in Africa. These few studies include Wang et al. (2021) for BRICS countries, Kanagawa and Nakata (2007), Lekana and Ikiemi (2021) for EMCCA countries and Niu et al. (2013) for 50 low-, high- and middle-income countries. These studies found energy consumption to induce human capital development. However, the study of Masur (2011) found otherwise in a sample of 22 developed economies. Other studies include Steinberger and Roberts (2009), Ouedraogo (2013), Pîrlogea (2012), Wang et al. (2021), and Martinez and Ebenhack (2008).

The above literature review reveals that there is a scanty number of studies which have directly explored energy consumption and human capital. Additionally, these studies have not accounted for how asymmetric effects in energy consumption affects human capital growth. In addition, the extant studies have not explored the transmission channels of asymmetric effect of energy consumption on human capital growth in Africa. This present study addresses these research gaps by answering the question 'does energy use improve human capital growth in Africa?'

3 | MODEL SPECIFICATION, DATA AND ESTIMATION STRATEGY

3.1 | Model specification

This study aimed to explore the long-run asymmetric connection between energy consumption and human capital development in Africa. Drawing inspiration from Lekana and Ikiemi (2021) and Wang et al. (2021), the econometric model specification is presented in Equation (1)

$$\mathrm{HC}_{it} = f\left(\mathrm{EC}_{it}, Z_{it}\right), \tag{1}$$

where HC is human capital development, EC is energy consumption, Z is a vector of other determinants of human capital, t is time ($t = 1, \ldots, T$) and i represents individual countries. According to Wang et al. (2018) and Lekana and Ikiemi (2021), human capital development depends on other factors such as foreign direct investment, emissions of carbon dioxide, economic growth and literacy. Therefore, the Z variable is augmented as,

$$Z_{it} = f\left(Y_{it}, \mathrm{CO}_{2it}, \mathrm{FDI}_{it}, \mathrm{EDU}_{it}, \mathrm{GVE}_{it}\right). \tag{2}$$

We then combine Equations (1) and (2) as follows:

$$\mathrm{HC}_{it} = f\left(\mathrm{EC}_{it}, Y_{it}, \mathrm{CO}_{2it}, \mathrm{FDI}_{it}, \mathrm{EDU}_{it}, \mathrm{GVE}_{it}\right), \tag{3}$$

where Y, CO_2, FDI, EDU and GVE are economic growth, carbon emission, foreign direct investment, education and government effectiveness, respectively. Following Wang et al. (2021), we apply natural logarithm (ln) transformation to all the variables to reduce autocorrelation and ensure covariance stationary as presented in Equation (4).

$$\ln\mathrm{HC}_{it} = \alpha_0 + \alpha_1 \ln\mathrm{EC}_{it} + \alpha_2 \ln\left(\mathrm{EDU} \times \mathrm{EC}_{it}\right) + \alpha_3 \ln Y_{it} + \alpha_4 \ln\mathrm{CO}_{2it} + \alpha_5 \ln\mathrm{FDI}_{it} + \alpha_6 \ln\mathrm{EDU}_{it} + \alpha_7 \ln\mathrm{GVE}_{it} + \mu_{it}, \tag{4}$$

where $\alpha_0, \ldots, \alpha_7$ are the parameters to be estimated. HC is human capital development which is the dependent variable and $\mathrm{EDU} \times \mathrm{EC}$ is the interaction term between education and energy consumption. It measures the complementarity effect of education and energy consumption on HC. EC is the explanatory variable of interest, which is expected to positively impact human capital development because energy is needed to promote healthcare, education and the welfare of the citizenry in developing countries (Lekana & Ikiemi, 2021). Therefore energy is considered as an indicator of well-being (Niu et al., 2013). In this context, a positive relationship is expected between the two variables as well as their interaction term ($\alpha_1 > 0$ and $\alpha_2 > 0$). Considering other control variables, economic growth increases individuals' purchasing power to acquire basic commodities and services to improve their welfare. However, economic growth may shift the structure of an agrarian economy which may exacerbate rural–urban inequality, thereby reducing human capital development. This is pertinent in most developing countries (see Wang et al., 2018). Hence, a negative or positive relationship is expected ($\alpha_3 > 0$ or $\alpha_3 < 0$). A positive impact is expected for FDI on human capital because investment expedites the transfer of knowledge which contributes to human capital development ($\alpha_5 > 0$). Further, education improves human development, hence $\alpha_6 > 0$ is expected. We believe that effective government participation will facilitate the efficient allocation of resources to promote human capital development. However, in most developing countries, this may not be true as countries are prone to wars and autocratic leadership which undermines accountability. Therefore, $\alpha_7 > 0$ or $\alpha_7 < 0$ is expected. Lastly, climate change resulting from high carbon emission concentration is inimical to human health. It is therefore expected that, $\alpha_4 < 0$.

3.2 | Data

The study utilises historical series data from 2000 to 2018 ($T = 18$) for 22 countries ($N = 22$): Ghana, Botswana, Congo DR, Egypt, Ethiopia, Nigeria, South Africa, Angola, Algeria, Cameroon, Kenya, Côte d'Ivoire, Mauritius, Morocco, Namibia, Niger, Tanzania, Sudan, Togo, Senegal, Zambia and Zimbabwe. The dependent variable is human capital development (HC), which is proxied by human capital development index (measured by life expectancy, knowledge and a decent standard of living), and the independent variables are energy use (EC) measured in kWh of per capita electricity, GDP per capita (constant 2010 USD) as a representation for economic growth (Y), CO_2 is calculated in tons per capita, Government effectiveness (GVE) is defined as the value of public service delivered by state institutions and the degree to which these institutions are independent of political meddling. FDI represents the net inflow of investment funds. Education (EDU) is a proxy for literacy level, which encompasses anticipated years of schooling (children) and average years of schooling (adults). HC data were sourced from UNESCO (2020) database. Energy use and GDP per capita were sourced from WDI (2020), education data were obtained from UNDP (2020) and the variable for institution is collected from the World Governance Indicators of the World Bank (World Bank, 2020a, 2020b).

3.3 | Estimating strategy

It is conventional in empirical literature to investigate the stationarity properties of macroeconomic data since most data involving macroeconomic analysis may suffer from unit roots which may affect the estimated results (Lekana & Ikiemi, 2021). More so, the NARDL may be ineffective once the variables are integrated in the second order, $I(2)$. To avoid this drawback, we utilise Harris and Tzavalis (1999) (HT henceforth), Breitung (2001), Levin et al. (2002) (LLC hereafter), and Im et al. (2003) (IPS henceforth) and Hadri (2000) panel unit root tests to detect the stationarity properties of human capital development and its determinants. We performed these unit root tests grounded on their individual assumptions. For example, the LLC assumes that the estimated coefficients of the explained variable are homogeneous across all sample units of the panel, while the IPS assumes a cross-sectional heterogeneity of the lags of the explained variable (Hurlin & Mignon, 2007). Hadri (2000) assumes a null hypothesis of no unit roots. HT (1999), Breitung (2001), LLC (2002) and IPS (2003) tests, on the other hand, assume a null hypothesis of a unit root.

Once the order integration is determined, it is important to test panel cointegration among the series. To achieve this, we utilised the residual-based panel cointegration test proposed by Pedroni (1999). This test is advantageous because it allows for the intercept and trend coefficients to vary across cross-sections. Pedroni (1999) suggests seven tests of the null hypothesis of no cointegration vis-à-vis a alternative hypothesis of cointegration. Four of the tests are based on the pooled autoregressive coefficients across countries (within-dimensions) and three hinges on the means of the estimated coefficients for each country (between-dimensions). When the cointegration is established, we then estimate the short and long-run linkage between human capital development and its determinants under investigation using the panel NARDL.

The significance of this study, among other things, lies in the fact that it makes use of the Shin et al. (2011) panel NARDL estimation technique to explore the long-run asymmetric impacts of energy use on human capital development for 22 African countries, as opposed to other studies which used linear models (see Azam, 2019; Kanagawa & Nakata, 2008; Mazur, 2011; Niu et al., 2013; Wang et al., 2021). In this case, we aimed to analyse how human capital development responds to positive and negative shocks in energy use. This is because most African countries over the years have invested in rural energy dissemination to extend energy to most parts of their respective countries, making energy use dynamic. We make use of this model for three main reasons: Firstly, it allows us to capture the non-linearity of energy use in human capital development. Secondly, the model intrinsically accounts for the possible heterogeneity effects in the data (see Salisu & Isah, 2017). Thirdly, it produces efficient results irrespective of whether the dependent or independent variable(s) are stationary at levels $I(0)$ or first difference $I(1)$ and it allows for the inclusion of lags for both the dependent and explanatory variable(s) to account for possible endogeneity problems. In addition, the pooled mean group approach is utilised since it can estimate the error correction term to determine the rapidity of modification of the variables to their long-run equilibrium and permits short-run heterogeneity in the assessment compared to the mean group (MG) estimation method. We then apply the NARDL-PMG model on Equation (4) as:

$$\begin{aligned}\ln\mathrm{HC}_{it} = {} & \gamma_{i0} + \gamma_{i1}\ln\mathrm{HC}_{it-1} + \gamma_{i2}\ln\mathrm{EC}_{it}^{+} + \gamma_{i3}\ln\mathrm{EC}_{it}^{-} + \gamma_{i4}\ln\mathrm{EDUEC} + \gamma_{i5}\ln Z_{it} + \sum_{j-1}^{p}\vartheta_{ij}\Delta\ln\mathrm{HC}_{it-j} \\ & + \sum_{j-1}^{m}\left(\varphi_{ij}\Delta\ln\mathrm{EC}_{i,t-j}^{+} + \phi_{ij}\Delta\ln\mathrm{EC}_{i,t-j}^{-}\right) + \sum_{j-1}^{r}\sigma_{ij}\Delta\ln\mathrm{EDEC}_{it-j} + \sum_{j-1}^{q}\delta_{ij}\Delta\ln Z_{it-j} + \varepsilon_{it},\end{aligned} \tag{5}$$

where Δ is the first difference operator, ln denotes the natural logarithm operator, Z_{it} is the set of control variables (economic growth, CO_2 emission, foreign direct investment, education and government effectiveness), γ_{i0} is the constant, γ_{ik} $(i = 1, 2, \ldots, N$ and $k = 1, 2, 3, 4, 5)$ is the long-run coefficients, ϑ_{ij}, φ_{ij}, ϕ_{ij}, and δ_{ij} are short-run parameters and ε_{it} is the error term. The long-run asymmetric shock is captured by γ_{i1} and γ_{i2}, while the short-run shock is encapsulated by φ_{ij} and ϕ_{ij}. EC_{it}^{+} and EC_{it}^{-} denote the partial sums of the positive and negative changes in energy consumption, respectively. Following Shin et al. (2011), the decomposition of energy use is as follows:

$$\mathrm{EC}_{it}^{+} = \sum_{j=1}^{t} \Delta\mathrm{lnEC}_{it}^{+} = \sum_{j=1}^{t} \max\left(\Delta\mathrm{lnEC}_{it}^{+}, 0\right), \tag{6}$$

$$\mathrm{EC}_{it}^{-} = \sum_{j=1}^{t} \Delta\mathrm{lnEC}_{it}^{-} = \sum_{j=1}^{t} \max\left(\Delta\mathrm{lnEC}_{it}^{-}, 0\right). \tag{7}$$

The corresponding asymmetric error correction term of Equation (5) yields the followings:

$$\Delta\mathrm{lnHC}_{it} = \psi_{0i} + \sum_{j-1}^{p} \vartheta_{ij}\Delta\mathrm{HC}_{it-j} + \sum_{j-1}^{n}\left(\omega_{ij}\Delta\mathrm{lnEC}_{i,t-j}^{+} + \varrho_{ij}\Delta\mathrm{lnEC}_{i,t-j}^{-}\right) + \sum_{j-1}^{r} \partial_{ij}\Delta\mathrm{lnEDEC}_{it-j} + \sum_{j=1}^{r} \psi_{1ij}\Delta Z_{i,t-j} + \varsigma_i \mathrm{ECT}_{it-1} + \mu_{it}, \tag{8}$$

where $\mathrm{ECT}_{i,t}$ and ς_i denote the long-term asymmetric error correction term and the rapidity at which the model reverts to the long-run equilibrium following a disturbance. It is expected that $\varsigma_i < 0$ to further validate the cointegration properties of the variables.

4 | EMPIRICAL RESULTS

4.1 | Descriptive statistics and correlation test

The summary statistics presented in Table 1 (upper panel) show that except for education and CO_2 emission, the rest of the variables have positive means. The negative means for education and CO_2 is credited to the log transformation. Human capital development and energy consumption recorded averages of 0.6123 and 5.7701, respectively. The implication is that human capital development is low in Africa and to some extent, energy poverty is eminent. Economic growth, FDI, education, CO_2 emission and government effectiveness recorded averages of 7.2862, 22.2009, −0.8092, −0.5838 and 3.2289, respectively. The interactive variable for energy use and education (EDUEC) recorded a standard deviation of

TABLE 1 Descriptive statistics and pairwise correlation among the variables.

	HC	EC	EDUEC	*Y*	FDI	EDU	CO_2	GVE
Mean	0.6123	5.7701	3.7886	7.2862	22.8009	−0.8092	−0.5838	3.2289
Median	0.6135	5.5075	3.4026	7.2438	22.7976	−0.6992	−0.6870	3.4375
Maximum	1.0596	8.4871	8.6286	9.3244	23.6664	−0.3106	2.1481	10.5476
Minimum	0.1115	3.1248	0.3899	4.7179	−0.2106	−2.1542	−4.1158	−0.0513
SD	0.2366	1.3080	2.0852	0.9723	1.1616	0.3650	1.3548	1.0040
Observations	418	418	418	418	418	418	418	418
Correlation test								
lnHC	1.0000							
lnEC	0.8277*	1.0000						
lnEDUEC	0.9592*	0.9320*	1.0000					
ln*Y*	0.5932*	0.7573*	0.6800*	1.0000				
lnFDI	0.0878	0.0416	0.0807	−0.1850	1.0000			
lnEDU	0.6272*	0.8536*	0.7453*	0.7042*	0.0183	1.0000		
lnCO_2	0.8122*	0.7682*	0.7852*	0.6311*	0.0221	0.6965*	1.0000	
lnGVE	0.3388*	0.4486*	0.4205*	0.2991*	0.0467	0.4779*	0.4221*	1.0000

Abbreviation: SD, standard error.

**p*-value < 0.05.

Source: Constructed by authors using data from WDI, UNDP and WGI.

2.0852, while the remaining variables have a standard deviation lower than 1.5. This shows that there is little dispersion among the countries.

Regarding the correlation matrix, every variable is positively and significantly associated with human capital development, except FDI which is negative insignificant at 5% level of significance. The result of the correlation test means there is limited evidence of multicollinearity among the series since there is no perfect correlation among any of the variables. The number of observations for each variable is 418, indicating that the panel is strongly balanced.

4.2 | Unit root tests

Although the NARDL model can produce efficient results irrespective of the integrating order of the variables, performing unit root is important to guarantee that all the variables are integrated at the level or first order. The test results are reported in Table 2.

The tests reveal that most variables are stable at level [$I(0)$]. For instance, except for the Breitung test, human capital, FDI and energy consumption are $I(0)$. That is, the null hypothesis of unit root is not accepted for the IPS, HT, LLC and Fisher ADF tests at a 1% level of significance. We also found that economic growth and CO_2 emission are integrated in mixed orders of $I(0)$ and $I(1)$ while government effectiveness is only $I(0)$. Therefore, the unit root tests lend support for the panel NARDL approach since none of the variables is $I(2)$. We performed the Pedroni (1999) cointegration tests (see Table A1). The tests show five cointegration relations out of seven. That is, the null hypothesis of the absence of cointegration among the variables is rejected at a 5% significance level. This implies the presence of long-run connection among human capital growth and its determinants considered in this study.

4.3 | NARDL Results

In what follows, the NARDL model is estimated to observe the asymmetric effects of energy use on human capital growth and the outcome is represented in Table 3.

Table 3 shows that positive and negative changes in energy consumption exert a weighty favourable impact on human capital development especially in the long-run. Specifically, a 1% rise in positive (negative) change in energy consumption significantly improves human capital development by 0.0288% (0.0297%) in the long-run. The outcome for the short-run is insignificant, indicating energy consumption is not essential in human capital development in the short-run. This is intuitive as it takes time for human capital to improve.

The significant positive asymmetric effect of energy consumption on human capital development in the long-run implies that energy consumption stimulates human capital development. At the economy-wide level, it facilitates the installation and consumption of computers and the internet for teaching and learning as well as the dissemination of information. At the household level, energy consumption promotes productivity and self-employment by providing alternative sources of fuel which reduces the time for women to collect biomass. As a consequence, energy consumption improves the components of human capital development. We also find that energy consumption tailored towards education

TABLE 2 Panel unit root tests.

Variables	lnHC	lnEC	ln*Y*	lnFDI	lnEDU	$\ln CO_2$	lnGVE
IPS	−3.615***,a	−1.838**,a	−8.045***,b	−1.975**,a	−2.611***,a	−12.52***,a	−2.381***,a
LLC	−8.116***,a	−7.943***,a	−4.708***,a	−1.807**,a	−9.354***,a	−3.283***,a	−2.912***,a
Breitung *t*-test	−23.199***,b	−11.119***,b	−6.572***,b	−3.605***,b	−4.038***,a	−7.252***,a	−1.590*,a
HT rho	0.8451***,a	0.581*,a	0.237***,b	−0.184***,a	−0.184***,a	0.120***,b	0.129***,a
Hadri	—	−0.889***,b	—	0.5951**,a	0.595**,a	−0.285***,b	−4.555***,b
ADF Fisher χ^2	93.271***,a	64.136***,a	147***,b	74.979***,a	89.374***,a	223.48***,b	79.634***,a

Note: a and b represent significant at level [$I(0)$] and first-difference [$I(1)$], respectively, while ****, **, and * symbolise p-value < 0.01, p-value < 0.05 and p-value < 0.1, respectively.

Abbreviations: HT = Harris and Tzavalis (1999) test; IPS = Im et al. (2003) test; LLC = Levin et al. (2002) test.

TABLE 3 Non-linear ARDL results.

Dependent variable: Human capital development			
Variable	**Coefficient**	**SE**	***t*-Statistic**
Long-run			
$\ln EC^{+}$	0.0288***	0.0023	12.459
$\ln EC^{-}$	0.0297***	0.0023	13.136
lnEDUEC	0.1033***	0.0011	94.912
$\ln Y$	0.0082***	0.0011	7.1121
lnFDI	0.0134***	0.0018	7.4105
lnEDU	0.0089	0.0071	1.2618
$\ln CO_2$	−0.0138***	0.0013	−10.383
lnGVE	0.0008**	0.0003	2.5761
Short-run			
$D. \ln HC(-1)$	0.8125**	0.4076	1.9934
$D. \ln EC^{+}$	−0.0061	0.0097	−0.6233
$D. \ln EC^{-}$	−0.0063	0.0098	−0.6399
D. lnEDUEC	0.0597***	0.0152	3.9212
$D. \ln Y$	−0.0056	0.0034	−1.6359
D. lnFDI	−0.0022	0.0171	−0.1302
D. lnEDU	0.0203	0.0291	0.6993
$D. \ln CO_2$	−0.0079	0.0056	−1.4035
D. lnGVE	0.0002	0.0039	0.0445
C	−0.0684***	0.0193	−3.5431
ECT	−0.2128***	0.0624	−3.4103

Note: ****, **, and * represent p-value < 0.01, p-value < 0.05 and p-value < 0.1, respectively.

Abbreviations: C = constant term; SE = standard error.

is important in promoting human development. Our finding aligns with the heterodox understanding that energy is critical to human capital development. Our results corroborate with the conclusions of Wang et al. (2021) for BRICS countries, Lekana and Ikiemi (2021) for EMCCA countries and Niu et al. (2013) for 50 low-, middle- and high-income countries. However, Masur (2011) finds otherwise for 22 developed countries. This could be because developed countries have reached a plateau of human capital development. Hence, efforts to promote human capital such investment in energy may yield little or no significant outcome.

Further, Table 3 reveals that human capital development increases by 0.1033% (0.0597%) when the interactive variable for energy consumption and education increases by 1% in the long run (short-run). This means the complementarity effect of education and energy consumption cannot be ruled out in human capital development. However, education alone is statistically insignificant, suggesting that it needs to be complemented by energy consumption before it can induce human capital development significantly.

Regarding the other dependent variables, it is seen from Table 3 that a 1% increase in FDI, economic growth and government effectiveness would result in a 0.0082%, 0.0134%, 0.0089% and 0.0008% increase in human capital development in the long-run at 5% level of significance. A 1% increase in CO_2 emission reduces human capital development by 0.0138% (0.0079%) in the long-run (short-run). This is because CO_2 emission results in atmospheric pollution which is inimical to human health. Our result agrees with empirical findings such as Pîrlogea (2012) for six European countries, Bedir and Yilmaz (2016) for 33 OECD countries and Sinha and Sen (2016) for BRICS countries.

The positive effects of FDI and economic growth on human capital development imply that as per capita GDP increases, households can afford basic and better healthcare, better nutrition, and education, which induces human capital development. Investment also brings about development in infrastructures such as schools, hospitals, and plants and machinery to produce various healthcare products which may promote the standard of living. This is in harmony with Lekana and Ikiemi (2021) for EMCCA countries and Sinha and Sen (2016) for BRICS countries. Nevertheless, the outcome opposes the conclusion of Wang et al. (2018) for Pakistan. Regarding government effectiveness, the positive relationship may suggest that effective government may formulate policies and allocate resources towards the development of infrastructure as well as social welfare policies to improve human conditions. Finally, the error correction term is negative and statistically significant at a 1% significance level. This shows that the model will revert to its long-run equilibrium after a shock at a 21.28% adjustment rate.

4.4 | Robustness check

To scrutinise the robustness and the consistency of the baseline results, we perform wide-ranging checks on the results presented in Table 3 by utilising three approaches to analyse the non-linear impact of energy use on human capital development in Africa. Firstly, we realised South Africa is the largest energy consumer among the countries considered. This implies that there could be an outlier effect that may influence the outcome in Table 3. For example, the average energy consumption in South Africa is twice that of Nigeria, Kenya, Tanzania, Niger, Congo DR, Ethiopia, Sudan and Togo. We therefore estimate the baseline model excluding South Africa in the data to check whether outliers influence the baseline result in Table 3. Secondly, Lekana and Ikiemi (2021) argue that oil-producing countries experience similar shocks such as the oil crises in the 1970s and oil production quotas which affect demand and supply. More so, oil-producing countries may experience similar socio-economic environments driven by petroleum and natural gas production (Omolade et al., 2019). In this regard, we partition the data into non-oil-production countries and oil-producing countries. For a similar reason, we divide the data into ECOWAS, SADC, CEN-SAD and COMESA countries (see Table A2) to investigate if the asymmetric effect is consistent across subsamples. The output excluding South Africa is presented in Table 4, that of the

TABLE 4 Panel NARDL excluding South Africa.

Dependent variable: Human capital development			
Variable	**Coefficient**	**SE**	***t*-Statistic**
Long-run			
$\ln EC^{+}$	0.0551***	0.0122	4.5099
$\ln EC^{-}$	0.0548***	0.0121	4.5286
lnEDUEC	0.1127***	0.0144	7.8446
$\ln Y$	−0.0548***	0.0097	−5.6321
lnFDI	0.0237***	0.0080	2.9613
lnEDU	0.4159***	0.0877	4.7397
$\ln CO_2$	−0.0552***	0.0113	−4.8790
lnGVE	−0.0039*	0.0022	−1.7840
Short-run			
D. lnHC(− 1)	0.5217	1.0359	0.5036
D. $\ln EC^{+}$	−0.0089	0.0101	−0.8884
D. $\ln EC^{-}$	−0.0089	0.0100	−0.8871
D. lnEDUEC	0.0774***	0.0151	5.1057
D. $\ln Y$	0.0016	0.0038	0.4330
D. lnFDI	0.0029	0.0165	0.1733
D. lnEDU	0.0375	0.0415	0.9047
D. $\ln CO_2$	−0.0149***	0.0041	−3.6297
D. lnGVE	0.0003	0.0035	0.0757
C	−0.0150	0.0255	−0.5895
ECT	−0.1243	0.0757	−1.6412

Note: ****, **, and * represent p-value < 0.01, p-value < 0.05 and p-value < 0.1, respectively.

Abbreviations: C, constant term; SE, standard error.

TABLE 5 Panel NARDL for non-oil and oil-producing countries.

	Dependent variable: Human capital development					
	Non-oil producing countries			Oil-producing countries		
Variable	Coefficient	SE	*t*-Statistic	Coefficient	SE	*t*-Statistic
Long-run						
$\ln EC^{+}$	0.0435***	0.0044	9.9469	0.1068***	0.0069	15.418
$\ln EC^{-}$	0.0443***	0.0044	10.001	0.1092***	0.0068	16.137
lnEDUEC	0.1699***	0.0031	54.339	0.0612***	0.0033	18.394
ln*Y*	−0.0373***	0.0023	−16.013	−0.0107*	0.0058	−1.8494
lnFDI	−0.0027	0.0111	−0.2413	0.3867***	0.0326	11.867
lnEDU	0.2273***	0.0129	17.588	−0.0744***	0.0177	−4.1924
$\ln CO_2$	0.0344***	0.0079	4.3389	−0.0442***	0.0034	−12.827
lnGVE	−0.0028	0.0026	−1.0619	−0.0039**	0.0014	−2.8083
Short-run						
D. $\ln EC^{+}$	−0.0311	0.0306	−1.0196	−0.0076	0.0211	−0.3586
D. $\ln EC^{-}$	−0.0313	0.0306	−1.0227	−0.0081	0.0213	−0.3802
D. lnEDUEC	0.1540	0.0463	3.3316	0.0295	0.0192	1.5334
D. ln*Y*	0.0061	0.0085	0.7206	−0.0129	0.0098	−1.3157
D. lnFDI	−0.0446*	0.0447	−0.9995	−0.0430*	0.0248	−1.7365
D. lnEDU	−0.0442**	0.0972	−0.4548	0.1534**	0.0526	2.9149
D. $\ln CO_2$	−0.0175**	0.0131	−1.3329	−0.0381*	0.0191	−1.9982
D. lnGVE	−0.0055	0.0217	−0.2521	0.0061	0.0205	0.2955
C	0.3223*	0.1825	1.7664	−1.7411	0.8223	−2.1174
ECT	−0.2094**	0.1229	−1.7046	−0.2128**	0.1005	−2.1179

Note: ****, **, and * represent p-value < 0.01, p-value < 0.05 and p-value < 0.1, respectively.

Abbreviations: C, constant term; SE, standard error.

oil and non-oil producing countries is presented in Tables 5 and 6 mirrors the results for ECOWAS, SADC, CEN-SAD and COMESA countries.

As demonstrated in Table 4, the result of the main variable of concentration, energy consumption, corroborates the result in Table 3. It reveals that for positive and negative variations in energy consumption, the interaction term, FDI, education and CO_2 emissions are consistent with that reported in Table 3. However, we found that economic growth and government effectiveness negatively and significantly influence human capital development in the long-run but are positive and insignificant in the short-run. Moreover, education is significant in the long-run. As anticipated, the error correction term is negative but insignificant. We conclude that the statistically significant positive effects of energy consumption on human capital development is not by chance.

The panel NARDL results for non-oil and oil-producing countries are reported in Table 5. It shows that, inter alia, energy consumption and the interaction term improve human capital development which agrees with the baseline results in Table 3. Interestingly, economic growth records a long-run negative and significant effect on human capital development in both subsamples which deviates from the baseline results. This implies that as the economy expands, human capital reduces. Wang et al. (2018) made a similar conclusion for Pakistan. We also find that only the outcome of FDI for oil-producing countries is in agreement with the baseline results in the long-run. In the short-run, however, FDI for both subsamples were negative and significant. This may be because FDI in some sub-Saharan African countries is associated with inefficiencies and not necessarily tailored to human capital development (see Ndeffo, 2010). Except for non-oil producing countries in the long-run, the coefficient of CO_2 conforms with the outcomes in the baseline model, which argue that high CO_2 concentration decelerates human capital development. However, the positive coefficient for non-oil-producing countries is possible through the rebound effect. Pîrlogea (2012) made similar conclusions for the Netherlands and Ireland and Sinha and Sen (2016) found the contrary argument for Brazil and India. The result for education in Table 5 is in harmony with that in Table 3 for non-oil producing but the latter is statistically insignificant. Government

TABLE 6 Panel NARDL for ECOWAS, SADC, CEN-SAD and COMESA countries.

	Dependent variable: Human capital development							
	ECOWAS		SADC		CEN-SAD		COMESA	
Variable	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Long-run								
$\ln EC^{+}$	0.0601***	0.0112	0.2588**	0.0906	0.0173***	0.0045	0.2412*	0.1364
$\ln EC^{-}$	0.0568***	0.0113	0.2583**	0.0904	0.0194***	0.0045	0.2386*	0.1353
lnEDUEC	0.0384***	0.0036	0.1173***	0.0082	0.1001***	0.0022	0.0813***	0.0192
$\ln Y$	−0.0249***	0.0046	−0.0426**	0.0174	0.0098***	0.0025	−0.0448	0.0325
lnFDI	−0.0870***	0.0143	0.0248**	0.0114	0.0037	0.0035	−0.0085	0.0141
lnEDU	0.4927***	0.0338	−0.2606**	0.1302	0.0418***	0.0117	−0.0636	0.1957
$\ln CO_2$	−0.0005	0.0064	−0.0202**	0.0088	−0.0052**	0.0020	−0.0288	0.0452
lnGVE	−0.0184***	0.0054	−0.0394***	0.0118	−0.0018**	0.0005	0.0196	0.0171
Short-run								
$D. \ln EC^{+}$	−0.0144	0.0294	−0.0385*	0.0219	0.0135	0.0094	−0.0483	0.0303
$D. \ln EC^{-}$	−0.0140	0.0292	−0.0385*	0.0220	0.0134	0.0095	−0.0484	0.0303
D. lnEDUEC	0.0696*	0.0406	0.0500**	0.0176	0.0596**	0.0268	0.0951***	0.0185
$D. \ln Y$	−0.0011	0.0031	0.0008	0.0027	−0.0068**	0.0035	0.0064	0.0048
D. lnFDI	−0.0289	0.0442	0.0016	0.0193	0.0012	0.0261	0.0014	0.0107
D. lnEDU	0.0287	0.0584	0.0407	0.0436	0.0318	0.0199	−0.0188	0.0555
$D. \ln CO_2$	−0.0250**	0.0101	−0.0028	0.0063	−0.0119	0.0078	−0.0155*	0.0088
D. lnGVE	0.0303	0.0270	0.0042	0.0123	0.0047	0.0070	−0.0054	0.0058
C	0.7488	0.6673	−0.3095*	0.1613	0.0105	0.0070	−0.0505*	0.0286
ECT	−0.2653	0.2364	−0.1672**	0.0810	−0.2247*	0.1191	−0.0575	0.0390

Note: ****, **, and * represent p-value < 0.01, p-value < 0.05 and p-value < 0.1, respectively.

Abbreviations: C, constant term; CEN-SAD, Community of Sahel–Sahara States; COMESA, Common Market for Eastern and Southern Africa; ECOWAS, Economic Community of West African States; SADC, Southern African Development Community; SE, standard error.

effectiveness is negative and significant for oil-producing countries. This underlies the lack of public policies and governments' commitment to human capital-oriented policies in some African countries.

Finally, Table 6 presents NARDL results for ECOWAS, SADC, CEN-SAD and COMESA countries. On average, the results further affirm the outcome of the baseline results in Table 3. That is across all subsamples, the heterodox hypothesis holds for energy consumption and human capital development in the long-run, whereas the orthodox hypothesis is evident in the short-run. We also found that the interactive variable for energy consumption and education is positive and statistically significant in both long- and short-run across all subsamples. Again, Table 6 confirms the output of the baseline model that CO_2 emission harms human capital development while education significantly promotes it for both ECOWAS and CEN-SAD in the long-run. Conversely, the variable has a negative effect on SADC and COMESA with the former statistically significant and no significant impact was found across all subsamples in the short-run.

Regarding economic growth, the results from the CEN-SAD lend support for the baseline results of a favourable and momentous relationship in the long-run while ECOWAS and SADC countries recorded a negative result which is in harmony with the results for non-oil and oil-producing countries. These results may be driven by countries where rapid economic expansion is attributed to the exporting of crude oil which does not tally with human capital development. However, FDI records a positive and significant result for SADC countries, but a negative and statistically significant effect is recorded for ECOWAS countries. Also, in compliance with the outcome for non-oil and oil producing countries, government effectiveness is negative and significant for ECOWAS, SADC and CED-SAD countries in the long run.

In summary, our results in Table 3 are robust since they are free from outlier problems. Furthermore, disaggregating the countries into subsamples on average supports the baseline model where positive and negative changes in energy consumption improve human capital development in the long-run. This implies that our results are free from unobserved heterogeneity across samples. The interaction term between energy use and education records a positive and significant link throughout the subsamples. This, among other things, validates our conclusion that energy consumption promotes human capital development in Africa in the long-run.

5 | CONCLUSION

The connection between human capital development and energy consumption has been categorised into two broad arguments. On one hand is orthodox approach, which is of the view that energy consumption may not promote human capital growth. However, the heterodox argument posits that energy is crucial for human capital development. Nonetheless, empirical investigation on these divergent views is scanty in Africa. Based on this, we explored the asymmetric impact of energy consumption on human capital development for 22 African countries from 2000 to 2018 within the framework of panel non-linear ARDL (NARDL).

Our findings disclose that the variables are integrated in mixed orders [$I(0)$ and $I(1)$] and are cointegrated. The long-run results of the NARDL align with the heterodox augment that energy consumption is important for human capital development. Also, the interactive variable for electricity consumption and human capital development is positive and significant in both long and short-run. Therefore, our results support the heterodox hypothesis. In addition, we find that economic growth, FDI and government effectiveness significantly improve human capital only in the long-run, while CO_2 emission harms human capital growth both in the long and short-run.

We perform a series of robustness checks to validate the outcome of our baseline model. Firstly, we exclude South Africa from the data to examine the problem of outlier effect. Secondly, we partitioned the countries into non-oil and oil-producing countries because oil-producing countries respond differently to economic shocks. Thirdly, we disaggregated the data into ECOWAS, SADC, CEN-SAD and COMESA countries (see Table A2) because similar development and interaction patterns may exist among these countries. On average, all the results were consistent with the baseline model which produced a positive and significant connection between energy consumption and human capital development in the long-run as well as the interaction term. Finally, our long-run results show that for the 22 African countries, there is a healthy interaction between energy use and education which promotes human capital development.

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APPENDIX

TABLE A1 Panel cointegration test.

	Panel	Group
V	24.257***	
Rho	3.558	5.657
PP	−1.848**	−2.799***
ADF	−2.578***	−3.567***

Note: Cointegration are computed with deterministic trend and intercept computed. Automatic lag selection by the Akaike Information Criterion (AIC). The lags were selected automatically using the SIC.

*** and * represent significant level at 1% and 5%, respectively.

TABLE A2 Subsample countries.

Non-oil producing countries	Selected Oil producing/ exporting countries	ECOWAS	SADC	CEN-SAD	COMESA
Botswana	Angola	Côte d'Ivoire	Botswana	Nigeria	Egypt
Ethiopia	Algeria	Ghana	South Africa	Ghana	Kenya
Kenya	Cameroon	Togo	Angola	Morocco	Mauritius
Mauritius	Côte d'Ivoire	Senegal	Namibia	Senegal	Sudan
Namibia	DR Congo	Niger	Tanzania	Togo	Zambia
Senegal	Egypt	Nigeria	Zambia	Côte d'Ivoire	Zimbabwe
Tanzania	Ghana		Zimbabwe	DR Congo	
Zambia	Morocco			Sudan	
Zimbabwe	Nigeria			Niger	
	Niger				
	South Africa				
	Togo				
	Sudan				

Source: Authors' construction.