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RESEARCH ARTICLE

Beyond COP26: can income level moderate fossil fuels, carbon emissions, and human capital for healthy life expectancy in Africa?

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Abstract

The growing concerns on the need to moderate the unceasing surge in global greenhouse gas (GHG) emissions believed to be detrimental to the environment and wellbeing of the human race have generated concerted efforts from governments and policymakers worldwide. Among many other factors, fossil fuels which remain the most consumed energy resource have been identified as the primary culprit to demeaning life expectancy. To this end, this study probes how income mediates between fossil fuels and carbon emissions to promote life expectancy in selected oil-abundant African economies from 1980 to 2019. The roles of human capital through investment in education are considered in the current inquiry. The empirical evidence is anchored on second-generation tests comprising cross-sectional dependence, slope homogeneity, and Westerlund cointegration tests. The empirical model is estimated based on advanced panel techniques comprising cross-sectional dependence autoregressive distributed lag model, common correlated effects mean group, augmented mean group, and quantile regression. Findings from the study reveal that fossil fuels and carbon emissions reduce life expectancy. Besides, income level promotes healthy life expectancy while equally subduing the negative impacts of fossil fuels on it. Additionally, the life-improving roles of human capital are empirically confirmed. Based on the findings, withdrawing the subsidies on fossil fuels and making aggregate income inclusive are among the key policies formulated.

Keywords Fossil fuels · Carbon emissions · Income level · Human capital · Healthy life expectancy

Introduction

Since March 1995, the Conference of the Parties (COP1) has maintained persistent contributions to policy discussions and implementations on global warming issues. From the first edition (COP1) to the twenty-sixth (COP26), the international body has recorded unprecedented achievements in charting a clear course toward mitigating the surging trend in global warming. Among many agreements, keeping global warming lower than 2 °C and achieving a limit of 1.5 °C are among the recent targets under consideration. Tracking this benchmark remains a common and ambitious goal necessary for environmental sustainability because every portion of climate warming leads to the loss of invaluable human lives and impairments of livelihood. Consequently, following the submission of Prime Minister Mia Mottley at COP26 Climate Summit, entering a 2 °C global warming is a death sentence (UN-Climate Change Conference, 2021 (COP26)). In terms of practicable suggestions on addressing global warming, the 2021 conference of the parties (COP26) set up new dimensions for reaching net-zero emissions by 2050. For instance, the conference recorded commitments covering nearly 85% of global GDP within the net-zero agreement. More so, not less than 153 economies buy into the idea of taking practical actions on the nationally determined contributions (NDCs), which account for approximately 80% of the world's greenhouse gas (GHG) emissions, with plans to strategize toward cutting off GHG emissions of around 5 billion by 2030. COP26 emphasized massively reducing coal power, ending deforestation, fast-tracking the transition to electric vehicles, and phasing down methane emissions to achieve the new or modified commitments. In addition, COP26 advocates for the indispensable need to bring down fossil fuel subsidies (estimated at around $5.9 trillion in 2020), contributing not less than 89% to global carbon emissions.

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The ensuing effects of global warming transcend the deterioration of the ecosystem to demean the quality of lifestyle of the people. Alluding to this fact, Koengkan et al. (2022) aver that aside from the pollution inducing effect of carbon emissions and other environmental contaminants, pollution generated through the air causes severe damage to the ecosystem (including fauna and vegetation) and human health. To this end, extant empirical studies have identified fossil fuels and carbon emissions as prominent contributors to the declining global life expectancy rate (Ibrahim et al. 2022). For instance, air pollution generated from burning fossil fuels is responsible for reducing global mean life expectancy by closely 3 years, such that a significant reduction in fossil fuels would increase the global life expectancy by an average of 1.1 years (Lelieveld et al. 2020). Besides, pollution emitted through fossil fuel burning has been linked to several diseases such as cancer, asthma, heart disease, and untimely death (Manisalidis et al 2020). Hence, available statistics reveal that one in every five deaths is caused by fossil fuel complications (Savannah 2021). Furthermore, the adverse effects of carbon emissions on life expectancy have been empirically documented. For example, World Health Organization (2018) reports that in 2016, nearly 4.2 million untimely deaths globally were connected to ambient air pollution. For this reason, some findings in the empirical literature submit that carbon emissions constitute one of the most prominent factors deteriorating human health (Rahman et al. 2022; Hill et al. 2019; Mohmmed et al. 2019). Similarly, available statistics reveal that environmental-related complications constitute 23% of global deaths, with values ranging from 847,000 in America to 854,000 in the Eastern Mediterranean region, 1.4 million in Europe, 3.5 million in the Western Pacific, and 3.8 million in Southeast Asia.

Although available statistics show that life expectancy is recording marginal increase over the years (Fig. 1), the dual effects of fossil fuels and carbon emissions on life expectancy are more pronounced in developing countries like Africa than in other developed regions. This suggests that more progresses could be recorded if the adverse effects of fossil fuels and carbon emissions are subdued significantly. According WHO (2019) report, about 2.2 million deaths annually are reportedly caused by environmental-related illnesses in Africa. Specifically, air pollution accounts for over 600,000 annual deaths of the estimated yearly deaths. Consequently, carbon emissions constitute one of the leading environmental challenges facing countries in the African region (Demissew Beyene and Kotosz, 2020; Ibrahim and Ajide 2022). The severity of the health complications is more pronounced among children and females due to heavy reliance on solid fuels used for indoors heating and cooking (United Nations Children Fund (UNICEF), 2016). According to United States Agency for International Development (USAID 2021), Africa records the highest rates of child mortality, with an estimated 1 in every 9 children dying before reaching age five, which is approximately 16 times more than the mean mortality death in developed regions estimated as 1 in every 152. Furthermore, Africa ranks highest in terms of death caused by pregnancy or childbirth (maternal death), recording over 533 maternal deaths in every 100,000 live births (UNICEF 2019).

Despite the associated life challenging risks of fossil fuels, most African countries are fossil fuel dependent (Ibrahim et al. 2021; Oke et al. 2021; Mutezo and Mulopo 2021; Mensah et al. 2019). Specifically, over a third of African economies relies on fossil fuels for production activities and generates significant percentage of their revenues from fossil fuel commodities (Jeremiah 2021). A general overview of the energy consumption in Africa as presented in Fig. 2 reflects a persistent rise in fossil fuel energy in the last three decades. Besides, the rising trend and projection of carbon emissions in Africa, especially with regard to the oil-abundant countries, suggest a possible increase of 30%

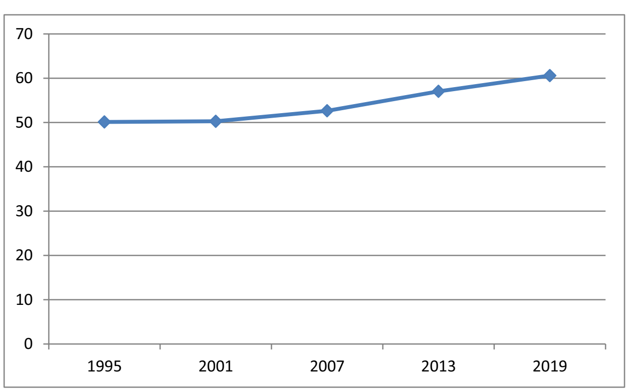

Fig. 1 Life expectancy at birth, total (years)

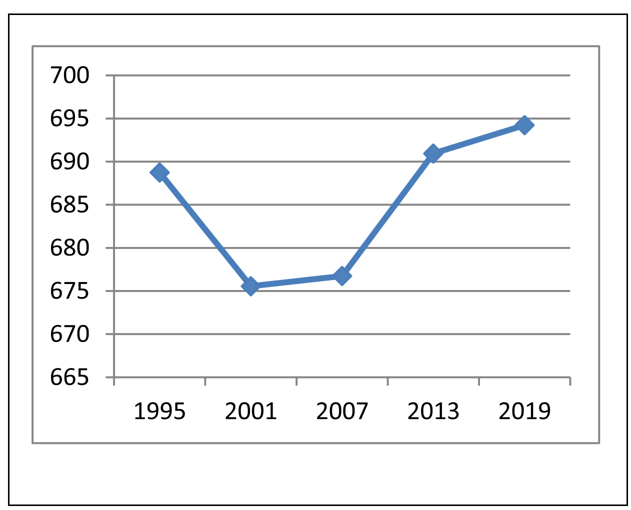

Fig. 2 Fossil fuel consumption (kg of oil equivalent per capita)

from 2017 to 2030. There are revealing facts that the coming years might witness an unprecedented rapid increase in fossil fuels and carbon emissions (Steckel et al. 2020). Carbon emission growth is anticipated to double by 2050 in Africa despite the advocacy for net-zero emissions (van der Zwaan et al. 2018). Worst enough, Africa is projected to record a 50% increase in carbon emissions by 2050 (Ayompe et al. 2021). Available statistics in Fig. 3 accentuates the preceding narratives.

Given the above expositions on the nexuses of fossil fuels, carbon emissions, and life expectancy in Africa, the extent to which the demeaning life expectancy can be corrected amidst the heavy dependence on fossil fuel-induced carbon emissions in the coming decades will depend on the income level and human capital through education and health investment. This is so as income level effectively addresses agriculture-induced carbon emissions and life expectancy-related issues in Africa (Ibrahim et al. 2021; Olanipekun et al. 2019). More so, higher educational attainment has been attributed to improved health and longevity whereas people with lower education experience less (Raghupathi and Raghupathi, 2020). More specifically, since there are available facts affirming the rising level of aggregate income (Fig. 4) and progressing rates of human capital (Fig. 5) in Africa, assessing the extent to which these indicators could enhance life expectancy becomes highly pertinent. Consequently, the current study examines how income level would moderate among fossil fuels, carbon emissions, and human capital for achieving healthy life expectancy in oil-abundant African countries.

Although there are evolving studies on determinants of life expectancy in Africa, such as nonrenewable energy (Ibrahim et al. 2021), carbon emissions (Matthew et al. 2020), and environmental hazards (Nkalu and Edeme 2019), among others, this study deviates from them based on the research objectives and contribution to knowledge. First, the majority of the extant studies considered the effects of either carbon emissions or fossil fuels on life expectancy or other health indicators. The present study adds to the stock of literature by considering the tripartite impacts of fossil fuels, carbon emissions, and human capital on life expectancy. An examination of this nature is necessary to ensure the progresses being recorded on these indicators promote social wellbeing through increase in healthy life expectancy. Second, the study decomposed the effects of fossil fuels into two comprising disaggregated (coal, oil, and gas) and aggregated

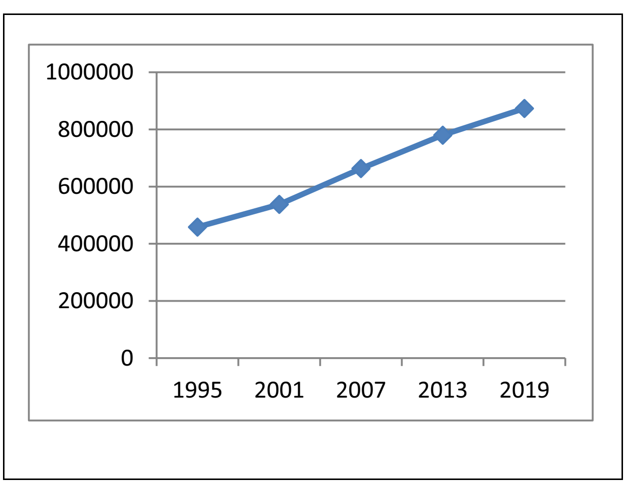

Fig. 3 CO2 emissions (kt)

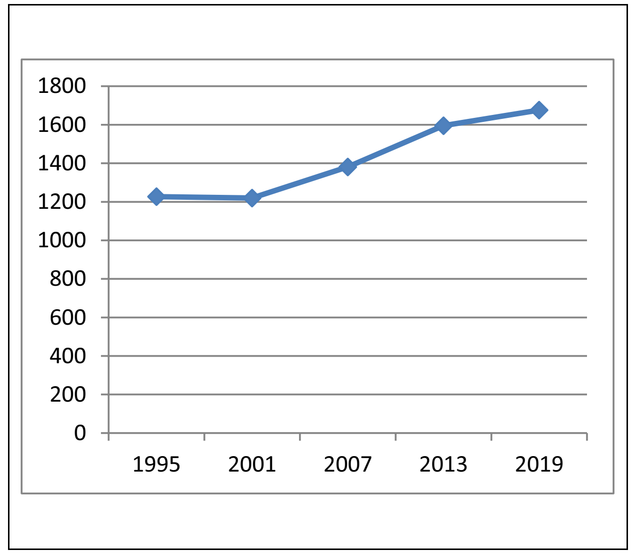

Fig. 4 GDP per capita (constant 2010 US$)

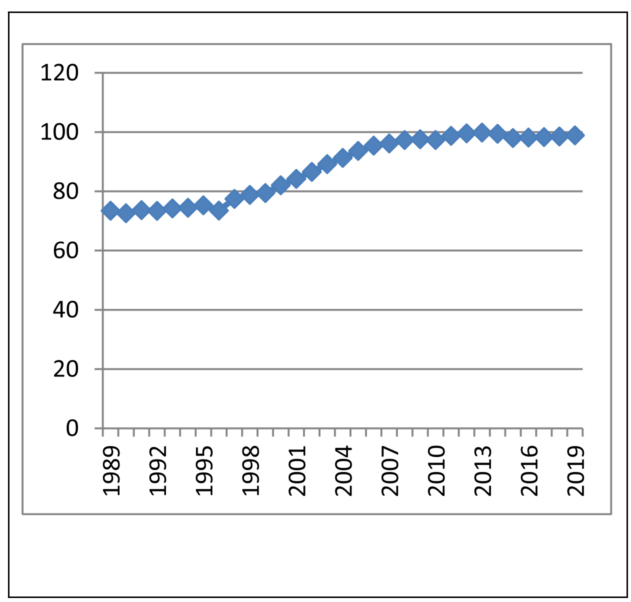

Fig. 5 Human capital (school enrollment, primary % gross)

(fossil fuel total consumption). This is pertinent as the effects of each of the disintegrated components will be evident on life expectancy. This empirical approach will enhance all-inclusive policy implications in improving life expectancy from specific to general approach. Third, the mediating role of income level is evaluated on both aggregated and disaggregated indicators of fossil fuels on carbon emissions. Although Ibrahim and Ajide (2021a) conducted the interaction of income with nonrenewable energy, the study failed to examine how income can moderate the adverse effects of carbon emissions on life expectancy. The role of income in the nexuses of fossil fuels, carbon emissions, and life expectancy is further underscored by the concept of the fuel ladder, which emphasizes increased income as a necessary condition for moving from dirty to clean energy sources. Fourth, the varying estimators employed in this study comprise second-generation estimators that account for the issue of cross-sectional dependence, simultaneity, and reverse causality inherent in panel models. These estimators are cross-sectional autoregressive distributed lag model, common correlated effects mean group, and augmented mean group. Additionally, the novel quantile regression estimator is employed to estimate the various distribution points ranging from low to middle and upper quantiles. This allows drawing policy implications based on the multiple quantiles identified. Aside from the "Introduction" section, the structure of the study is delineated as thus: "Literature review" section centers on the literature review and the methodological approach is discussed in the "Method" section. "Empirical results and discussions" section presents and discusses the empirical outcomes, and the conclusion and recommendations are presented in the "Conclusion" section.

Literature review

The empirical studies clarifying the tripartite impacts of fossil fuels, carbon emissions, and human capital on life expectancy are yet to be fully exploited. When it comes to the conditional role of income in this nexus, we are not aware of any. However, some studies are reviewed in the following paragraphs to position the present research in the heart of the extant literature and equally unravel the ambiguities that have entrapped precision in the debates.

In the most recent order, Sial et al. (2022) evaluate the effects of fossil fuel energy consumption on infant mortality in selected fifteen Asian economies based on annual data from 1996 to 2019 using the generalized least square method (GLS). The empirical model considers the additional impacts of employment, gross capital formation, and pre-primary education. The study's findings reveal fossil fuels as positive predictors of infant mortality which follow the inverted U-shaped connection. The study alludes that over-dependence on fossil fuel energy complicates living standards due to the low air quality in Asian countries. Ibrahim et al. (2022) evaluate the moderating role of technology in the nexus between nonrenewable energy and quality of life in forty-three SSA economies from 1990 to 2019. The study employs both panel fixed effects and system generalized method of moments estimators to evaluate the empirical model. Analyses of the empirical model extend to the regional level in SSA comprising Southern, Western, Eastern, and Central regions. The study finds that nonrenewable energy reduces the quality of life measured by the human development index, gross domestic products per capita, and life expectancy. Technology promotes quality of life and moderates the adverse effect of nonrenewable energy on quality of life. Alharthi et al. (2022) evaluate how environmental pollution and renewable energy affect households' health and income level in a panel of Middle East and North African countries from 2000 to 2019. Based on the pooled mean group estimator, the study reveals that renewable energy promotes a healthy lifestyle and mitigates environmental pollution.

Nkalu and Edeme (2019) examine the impacts of environmental hazards on life expectancy in Nigeria using annual data from 1960 to 2017. The study's empirical analyses rely on generalized autoregressive conditional heteroscedasticity. Significant findings from the study show that carbon emissions used as a proxy for environmental hazards demean life expectancy by an estimated timeframe of 1 month and 3 weeks. Matthew et al. (2020) probe the extent to which carbon emissions influence the variations in life expectancy and agricultural output in West African economies based on annual data from 2000 to 2018 estimated using the two-stage least squares estimator. Feedbacks from empirical analyses reveal negative nexus between carbon emissions and agricultural output. In contrast, carbon emissions significantly promote life expectancy. The joint moderating roles of income level and institutional quality in the nonrenewable energy-life expectancy nexus constitute the core of Ibrahim and Ajide's (2021a) inquiry for a panel of selected four oil-producing African economies. The study's empirical analyses stretch from 1990 to 2017, with the empirical evidence relying on fully modified ordinary least square estimator. Findings from the study show that nonrenewable energy negatively impacts life expectancy while income positively affects it. Similarly, income moderates the adverse effects of nonrenewable energy while institutional quality stimulates it. Conversely, the enhancing role of renewable energy on life expectancy is corroborated by income but hindered by institutional quality. Rjoub et al. (2021) evaluate the functional effects of economic growth and carbon emissions on life expectancy in Turkey based on annual time series data ranging from 1960 to 2018. The study explores the novel wavelet coherence, Bayer–Hanck cointegration test, and Toda–Yamamoto. The findings provide empirically based evidence to advance the inducing roles of carbon emissions on life expectancy.

Wang et al. (2020) evaluate the association between economic growth and life expectancy with the additional role of energy consumption and financial development in Pakistan. The study draws inferences from the estimation method based on the autoregressive distributed lag model (ARDL). Empirical findings from the study show that financial development exerts statistically negative impacts on life expectancy. It equally uncovers how energy consumption reduces life expectancy due to the escalation of environmental degradation. Rasoulinezhad et al. (2020) evaluate the nexuses among fossil fuels, environmental pollution, and mortality rates in the Commonwealth of Independent States by employing the generalized method of moments on annual data from 1993 to 2018. The results show that environmental pollution influences the most remarkable changes in mortality while energy consumption equally affects the components of mortality positively.

Anser et al. (2020) evaluate how greenhouse gas (GHG) emissions, economic activities, and energy use impact health indicators comprising mortality and cases of respiratory diseases in a panel of selected Asian economies. The analyses cover 1995 to 2018 using the long-run and short-run estimators. Findings from the study show that GHG emissions compound health risk in the Asian economies through factors such as fossil fuels, natural resources, and GHG emissions in the long-run period. Conversely, increased per capita gross domestic product and clean energy significantly mitigate the health complications.

A critical review of the studies in the preceding paragraphs uncovers some notable lacunas in the literature. First, the tripartite effects of fossil fuels, income level, and human capital have been largely neglected in the literature especially for the oil-abundant economies. Second, the moderating role of income level has received less attention in the life expectancy determinants studies. Besides, employing quantile regression is quite scarce in explaining the distributive effects of selected determinants of life expectancy. Hence, the current study would constitute one of the evolving studies in this regard. Third, focusing on oil-abundant countries in Africa is a notable lacuna that this study seeks to fill. This is pertinent considering the criticality of the present study in providing concrete policy suggestions toward the pursuit of sustainable development agenda by 2030 and the African growth agenda by 2063.

Method

The current study builds the relationships among the variables of interest based on three pillars delineated across three sections thus: theoretical foundation and empirical model, data and source, and preliminary analyses.

Theoretical foundation and empirical model

Theoretical bases are necessary for developing insights into economic problems or relationships. Besides, the expectations about the outcome of a relationship between two or more variables are better understood through theoretical underpinning relating to the associating economic indicators. It is highly expedient to provide details about the economic theory guiding a proposed empirical model. Consequently, this subsection explains the nexuses among the variables of interest, drawing inferences from economic theory and empirical evidence. Following in the subsequent paragraphs are detailed explanations of the relationship between the explanatory variables comprising fossil fuels, carbon emissions, income, human capital, and the outcome variable, life expectancy.

Starting with the fossil fuel-life expectancy nexus, the increasing rates of fossil fuels (oil, coal, and gas) have been noted as one of the vital contributors to the rising greenhouse gas (GHG) emissions (Yu et al. 2022; Zhang et al. 2021). Precisely, pollution generated by burning fossil fuels can result in the spread of diseases that adversely affect the human lifespan. Corroborating these submissions, notable strands of empirical studies have confirmed that fossil fuels lessen life expectancy (Ibrahim et al. 2021). Consequently, we hypothesize negative sign in the fossil fuel-life expectancy nexus as follows: $\frac{\delta lept}{\delta ffuel} < 0$. By implication, a percentage increase in fossil fuels is expected to cause a significant reduction in the expected years of living. Carbon emissions have been identified as the major contributor to GHG emissions among other components (Ajide and Ridwan 2018; Ibrahim and Ajide 2021b). For this reason, the association of carbon emissions with the various health indicators has been theoretically advanced from a negative perspective. Besides, several complications have been connected with the devastating consequence of carbon emissions. These views are well supported by the existing empirical studies advancing that carbon emissions lessen life expectancy (Matthew et al. 2020; Nkalu and Edeme 2019). To this end, we hypothesize a negative nexus thus $\frac{\delta lept}{\delta co2} < 0$. Intuitively, an increase in carbon emissions is expected to reduce life expectancy. The role of income in enhancing quality living, leading to increased lifespan, has been empirically advanced. The arguments are positioned on the ground that a higher income level allows individuals to have adequate living standards, good healthcare services, and security which improves life expectancy. This argument is well documented in the extant studies (Ibrahim and Ajide 2021a). Following these propositions, we expect income level to positively drive life expectancy thus $\frac{\delta lept}{\delta income} > 0$. Through investment in education and health, human capital has been empirically documented as a boost to improved health and quality of life (Zhang et al.

2022). A positive relationship is anticipated in the relationship between human capital and life expectancy $\frac{\delta lept}{\delta hc} > 0$.

Drawing from the above theoretical foundation, this study models the determinants of life expectancy in selected oil-abundant African countries by relying on the model estimated by Ibrahim and Ajide (2021a) with modifications to suit the objective of the current inquiry. The model states thus:

$$lept_{it} = \tau_0 + \tau_1 ffuel_{it} + \tau_2 income_{it} + \tau_3 (income \times ffuels)_{it} + \tau_4 co2_{it} + \tau_5 hc_{it} + \omega_{it} \quad (1)$$

Such that *lept* denotes life expectancy by birth total for both genders. *ffuels* represent fossil fuels, a vector for the disaggregated indicators comprising coal, oil, and gas, and fossil fuels, denoting the disaggregated and aggregated effects of fossil fuels, respectively. *income* signifies income level. The moderating role of income on *ffuels* is represented by $income \times ffuels$. *co2* denotes carbon emissions, and *hc* represents human capital. The study period covering 1980 to 2019 and cross-sections comprising Angola, Egypt, Libya, Algeria, and Nigeria are denoted by t and i. The empirical model in the equation is estimated after converting the variables to the natural log. The choice of natural log is motivated by the need to overcome the twin issues of heteroscedasticity and sharpness in the level form of the variables (Usman et al. 2022).

Data and source

To establish the functional nexuses among fossil fuels, human capital, income level, and carbon emissions, this study employs yearly data from 1980 to 2019. The indicators and their respective sources are given thus. The first data source is World Bank's world development indicators with the following indicators; income level is measured by GDP per capita (constant 2015 US$). The choice of income level measured by GDP per capita is anchored on four motivations. First, since the domain of the current study falls within the macroeconomic analysis, exploring the most significant indicator of which GDP per capita stands out becomes highly pertinent. Second, GDP per capita also reflects income per head which aligns with the study's objective. Third, while there are other indicators of income reflecting the social status in the economy, majority are not available on equal level for the countries of interest to the current research. Hence, the availability of GDP per capita for the selected oil-dependent economies justifies its consideration over others. Fourth, the selection of GDP per capita aligns with recent related studies such as Ibrahim and Ajide (2021a) and Olanipekun et al. (2019). The other variables sourced from World Bank development indicators are life expectancy at birth, total (years), and human capital captured by school enrollment, primary (% gross). The second source of data is the United States Energy Information Administration (EIA), from which the following indicators are collated: fossil fuels total proxied by total fossil fuel consumption (quad Btu), and the disaggregated variables such as coal (quad Btu), natural gas (quad Btu), and oil and other liquids (quad Btu), and carbon emissions (MMtonnes CO2).

Preliminary analyses

The preliminary analyses of the current study are anchored on three statistics, namely, descriptive statistics, normality tests, and correlation matrix. The descriptive statistics are provided in Table 1. The mean expected years of living is 63.83 years, with the minimum and maximum ranging from 44.4 to 76.9 years. Among the components of fossil fuels, oil constitutes the highest with 0.57%, followed by gas which averages 0.55%, coal with 0.02%, while the aggregated average of fossil fuels is 1.18%. Overall, it could be inferred that the selected five African economies depend mostly on oil for their economic activities and revenue generation. The average values for income level, carbon emissions, and human capital are 8.11%, 69.02%, and 89.37%, respectively.

The outcome of the correlation analyses is presented in Table 2. Based on the outcomes displayed, it is apparent that the components of fossil fuels exhibit a high correlation, with values ranging from 0.72 to 0.94%. This result implies that the indicators with high correlation

Table 1 Descriptive statistics

Variables	Mean	Median	Maximum	Minimum	Std. Dev	Skewness	Kurtosis	Jarque–Bera	Probability
LEPT	63.83	67.27	76.88	44.40	9.56	−0.89	2.55	20.75	0.00
COAL	0.02	0.00	0.11	0.00	0.02	1.56	6.29	127.52	0.00
OIL	0.57	0.40	1.78	0.04	0.47	0.98	3.03	23.88	0.00
GAS	0.55	0.22	2.18	0.01	0.59	1.05	3.04	27.36	0.00
FFUELS	1.18	0.95	4.03	0.06	1.05	1.12	3.55	33.16	0.00
INCOME	8.11	8.12	9.01	7.28	0.33	−0.01	3.33	0.70	0.71
CO2	69.02	56.22	235.49	3.37	60.67	1.14	3.67	35.22	0.00
HC	89.37	96.79	232.10	0.00	40.26	−0.46	5.02	30.46	0.00

should not appear in a single model to avoid the problem of multicollinearity from distorting the validity of the estimates. To resolve this econometric problem, each of the fossil fuels' indicators is estimated in different models bringing the total models to four.

Empirical results and discussions

Panel cross-section dependence and homogeneity tests

The current study conducts cross-sectional dependence (CSD) test before embarking on other conventional preliminary tests. According to Huang et al. (2022), CSD is a fundamental issue inherent in panel data that can cause distortions in choosing the most appropriate estimation method in terms of stationarity and cointegration tests. Consequently, we employ the Pesaran (2007) and (2004) CSD tests in examining the extent of interdependence among the cross-section units. Additionally, the assumption of homogeneity in the slope parameters is often assumed in panel datasets, which could hinder validity and reliability of the empirical outcomes (Ibrahim and Ajide 2021b). In contrast, the reality of economic phenomenon has proven that variations in economic structure, socio-economic settings, and demographic factors could lead to heterogeneity of the slope parameters (Khan et al. 2020). To this end, the current study employs the Pesaran and Yamagata (2008) slope homogeneity test.

The outcomes are presented in Table 3 for both CSD and slope homogeneity coefficient tests. Based on the results displayed, it is apparent that the null hypothesis of independence among the cross-sectional units is rejected, while the alternative hypothesis positing that the cross-section units are interdependent is accepted. The result is intuitional for the selected oil-abundant African countries due to the increasing rate of integration among the countries regarding trade relations, membership in the Organization of Petroleum Exporting Countries (OPEC), and other intergovernmental organizations in Africa and globally. Besides, the outcomes of the Pesaran and Yamagata (2008) test reveal that the slopes are not homogeneous. Instead, they are heterogeneous considering the significant level of the probability values. The results of the CSD and homogeneity tests are supported by the outcomes of the correlations, which provided high correlation values between 60 and 80%. The presence of CSD suggests first-generation panel unit root test would not be appropriate in examining the stationarity status needed to determine the order of integration in each of the series (Usman and Balsalobre-Lorente 2022). In this case, the second-generation panel stationarity tests believed to provide more robust and consistent results are conventionally recommended (Ibrahim and Ajide 2021c; Yang et al. 2021).

Stationarity and cointegration tests results

Among many other reasons, the necessity of resolving the non-stationarity issue that could lead the dataset to be spurious and biased (Kamal et al. 2021) motivates the adoption of panel unit root tests in empirical investigations. Feedback from the second-generation stationarity test based on Pesaran cross-sectionally dependent IPS (CIPS) is presented in Table 4. The results reveal that the series is non-stationary except for income and human capital. However, upon subjecting them to the first difference, they all become stationary

Table 3 Cross-sectional dependence and homogeneity tests results

Variables	Pesaran (2007)	Pesaran (2004)	Correlation
LEPT	19.970***	17.430***	0.872
COAL	12.628***	11.901***	0.678
OIL	18.980***	15.180***	0.759
GAS	18.323***	12.240***	0.612
FFUELS	15.683***	15.620***	0.785
INCOME	19.983***	8.160***	0.653
CO2	19.174***	15.500***	0.775
HC	16.359***	8.420**	0.645
Slope homogeneity	Delta	12.442***	
	Adj. delta	13.698***	

***and ** imply significant level at 1% and 5%

Table 2 Correlation matrix

LEPT	COAL	OIL	GAS	FFUELS	GDPPC	CO2	HC	Variables
1	0.30	0.60	0.64	0.64	0.36	0.64	−0.10	LEPT
	1	**0.74**	0.59	**0.72**	−0.43	0.43	0.11	COAL
		1	**0.76**	**0.94**	−0.17	0.34	0.09	OIL
			1	**0.94**	0.02	0.33	0.22	GAS
				1	−0.10	1.00	0.17	FFUELS
					1	−0.10	−0.22	GDPPC
						1	0.16	CO2
							1	HC

Table 4 Stationarity and cointegration test results

Variables	CIPS (2007)	
	Level, trend	First difference, trend
LEPT	−2.119	−5.142***
COAL	−1.106	−2.819*
OIL	−2.115	−3.456***
GAS	−2.693	−5.929***
FFUELS	−1.879	−4.234***
INCOME	−3.392***	−4.733***
CO2	−2.710	−6.183***
HC	−2.861**	−5.632***

***, **, and * imply significant level at 1%, 5%, and 10%

Table 5 Westerlund cointegration results

Gt	−3.477***
Ga	−5.612
Pt	−8.682***
Pa	−8.254

***impies significant level at 1%

mainly at the 1% significant level. Having established the stationarity status of the indicators, we move further to conduct a cointegration test to ascertain the presence of long-run nexus among the series. We employ the Westerlund (2007) cointegration test, which accounts for the joint issues of slope heterogeneity and cross-sectional dependence (Balsalobre-Lorente et al. 2022). Based on the Westerlund cointegration results presented in Table 5, it is evident that the null hypothesis of no cointegration is rejected based on one group (Gt) and one panel (Pt) statistics. Consequently, we can aver that fossil fuels, carbon emissions, income, and human capital have a long-term relationship with life expectancy in oil-abundant African economies.

Long-run coefficient estimates

The results of the long-run coefficients are presented in Table 5 with estimates emanating from cross-sectional autoregressive distributed lag (CS-ARDL) model. The choice of CS-ARDL estimator is motivated by its ability to provide estimates for both short- and long-run nexuses. Besides, the fact that the estimator can account for the presence of cross-sectional dependence further underscores the need to adopt it as the principal estimation technique in this study. More ever, it is important to clarify that the outcomes of the correlation matrix, which uncover the presence of high correlation among the indicators of fossil fuels, necessitate the need to segregate the effects of the regressors into four models with each focusing on the individual indicators of fossil fuels. Consequently, the models are slated thus: model 1 (coal effects), model 2 (oil effects), model 3 (gas effects), and model 4 (fossil fuel effects).

The results presented in Table 6 show the disaggregated effects of fossil fuels comprising coal, oil, and gas, and the aggregated effects captured by *ffuels* significantly and negatively impact life expectancy in the short run and long run, thus implying that a percentage increase in fossil fuel energy consumption will lead to a percentage decrease in life expectancy in the oil-abundant African economies. The results corroborate previous empirical studies such as Sial et al. (2022), Alharthi et al. (2022), and Ibrahim and Ajide (2021a, b, c), which report that fossil fuels complicate health challenges and equally lead to a reduction in the expected years of living. The impacts of income on life expectancy are significantly positive in the short run and long run, suggesting that an increase in income would increase life expectancy. As previously illustrated, increased income leads to an improved standard of living and facilitates the provision of adequate health services at an affordable price. On the micro-level, an increase in household income enables the members to live a healthy and improved life with access to adequate healthcare services, leading to enhanced quality of life. The results corroborate Zhan et al. (2022), who find income a key determinant of healthy life. Similarly, the interaction of income with the disaggregated and aggregated indicators of fossil fuels reveals that income moderates the negative impacts of the various components of fossil fuels on life expectancy in the short run and long run. Consequently, an increase in income could allow the household consumer to move upper on the energy ladder from reliance on dirty energy sources to clean energy.

The impacts of carbon emissions on life expectancy are significantly negative, suggesting the militating role of the former on the latter in the selected African economies in the short run and long run. Consequently, a significant increase in carbon emissions would result in a substantial decline in life expectancy. Alluding to this result, previous empirical feedbacks like Matthew et al. (2020) and Nkalu and Edeme (2019) provide empirically supported evidence to advance that carbon emissions lessen life expectancy. Besides, WHO (2019) reports that approximately 2.2 million death cases are linked to environmental-related illnesses in Africa. The impacts of human capital are positive and significant in the long run implying that an increase in human resource skills through educational attainment and training would lead to a rise in life expectancy. Besides, when people are well trained and educated, they tend to attach values to things that better their lives.

The error correction model (ECM) reveals that the short-run distortions will be rectified by the speed of adjustments at between 8 and 11% as apparent from the significant and negative coefficient of the ECT in Table 6.

Table 6 Long-run and short-run estimates based on CS-ARDL

	Outcome variable: life expectancy			
	Model 1	Model 2	Model 3	Model 4
Shor-run				
Lncoal	−0.012***			
	(0.004)			
lnoil		−0.094***		
		(0.023)		
lngas			−0.052*	
			(0.027)	
lnffuels				−0.063***
				(0.017)
lnincome	0.013	0.008*	0.012**	0.027***
	(0.017)	(0.004)	(0.005)	(0.007)
interaction	0.008**	0.012	0.007**	0.010***
	(0.003)	(0.009)	(0.003)	(0.002)
lnco2	−0.011***	−0.013***	−0.023***	−0.033***
	(0.002)	(0.002)	(0.003)	(0.005)
lnhc	0.003	0.012	0.005	0.015
	(0.008)	(0.008)	(0.010)	(0.011)
ECM(−1)	−0.114***	−0.083**	−0.101***	−0.105***
	(0.034)	(0.036)	(0.031)	(0.032)
Long-run				
lr_lncoal	−0.013***			
	(0.002)			
lr_lngoil		−0.019**		
		(0.008)		
lr_lngas			−0.046*	
			(0.024)	
lr_lnffuel				−0.076**
				(0.024)
lr_interaction	0.012***	0.014**	0.019***	0.025**
	(0.003)	(0.005)	(0.006)	(0.009)
lr_lnincome	0.011**	0.007*	0.011***	0.015**
	(0.005)	(0.004)	(0.003)	(0.004)
lr_lnco2	−0.021***	−0.014***	−0.022***	−0.024***
	(0.002)	(0.003)	(0.005)	(0.006)
lr_lnhc	0.033***	0.032***	0.034***	0.044***
	(0.007)	(0.005)	(0.008)	(0.012)
Observations	195	195	195	195

***$p<0.01$, **$p<0.05$, *$p<0.1$. Standard errors are in parentheses. Interaction signifies the interaction of income level with coal, oil, gas, and *ffuel* in model 1 through model 4, respectively

To deepen our understanding of the drivers of life expectancy in the selected sample countries, we employ two additional estimators, common correlated effects mean group (CCEMG), credited to Pesaran (2006) and augmented mean group (AMG) proposed by Eberhardt (2012) to probe the nexuses among the variables of interest. The two estimators are considered because they provide long-run estimates, account for heterogeneous slope in the coefficients among the cross-section units, and address the estimation challenges that may arise in cross-sectional dependence (Usman and Makhdum 2021; Kapetanios et al. 2011). Feedbacks from the two estimators in Table 7 reveal robust evidence for the estimates reported in the CS-ARDL estimator. This is apparent in the long-run negative impacts of fossil fuels and carbon emissions on life expectancy. Similarly, the increasing effects of income and human capital on expected years of living are equally robust. The summary of the main empirical findings in the current study are presented graphical in Fig. 6.

Quantile regression results

Quantile regression, an estimator, credited to Koenker and Bassett (1978), assesses the independent variables' impacts on the outcome variable based on divergent distribution points (Salehnia et al. 2020). Besides, quantile regression evaluates the pattern of parameter estimates by minimizing the sum of the absolute values of the balancing residues, usually referred to as least absolute deviations (Koenker and Bassett 1978). Unlike the ordinary least square method, quantile regression provides information on how the impacts of the explanatory variables influence the totality of the conditional distribution in the presence of cross-sectional dependence (Koengkan et al. 2021).

The outcomes of the quantile regressions are presented in Table 8 for three different distribution points comprising lower quantiles (Q10 to Q40), middle quantiles (Q50 and Q60), and upper quantiles (Q70, Q80, and Q90). It is apparent from the results that the disaggregated (coal, oil, and gas) and aggregated (*ffuels*) components of fossil fuels negatively affect life expectancy across the three distribution points. By implication, the consumption of fossil fuels has deleterious effects on the expected years of living for the people in the selected five oil-dependent African economies. The effects have no particular reference to the phase of fossil fuels as explicated by the different quantiles implying that the first instance of fossil fuel consumption negatively affects the lifespan of the people. Corroborating these outcomes, Savannah (2021) notes that each phase of the fossil fuel supply process involving extraction, transportation, refining, and burning negatively affects the environment and human health. The effects of income are positive across the distribution points. However, the impacts are significant at upper quantiles (Q70, Q80, and Q90), suggesting that higher income leads to improved health and life expectancy. Evidence abounds that higher income has the possibility of lowering exposure to disease and premature death leading to better health outcomes (Braveman et al. 2010). Specifically, the importance of income has been connected to healthy

Table 7 Long-run estimates based on CCEMG and AMG

Variables	Outcome variable: life expectancy							
	CCEMG				AMG			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
lncoal	−0.122***				−0.192**			
	(0.029)				(0.063)			
lnoil		−0.733***				−1.059***		
		(0.091)				(0.057)		
lngas			−0.434***				−0.672***	
			(0.088)				(0.049)	
lnffuel				−0.569***				−0.782***
				(0.085)				(0.076)
lnincome	0.038***	0.047***	0.039**	0.069***	0.023***	0.126***	0.083***	0.053***
	(0.012)	(0.015)	(0.019)	(0.018)	(0.002)	(0.007)	(0.04)	(0.012)
lninteraction	0.086***	0.056***	0.053***	0.074***	0.073***	0.067***	0.096***	0.086***
	(0.017)	(0.013)	(0.011)	(0.014)	(0.008)	(0.016)	(0.015)	(0.012)
lnco2	−0.014	−0.014**	−0.016	−0.469	−0.047*	−0.029	−0.054**	−0.044***
	(0.009)	(0.007)	(0.009)	(0.048)	(0.027)	(0.021)	(0.019)	(0.013)
lnhc	0.016***	0.022**	0.042***	0.069***	0.014**	0.016**	0.013***	0.018***
	(0.005)	(0.009)	(0.015)	(0.008)	(0.007)	(0.006)	(0.003)	(0.004)
_cons	0.635	0.878	0.281	0.369	4.425***	4.433***	3.322**	2.182**
	(1.014)	(1.023)	(1.447)	(1.048)	(0.535)	(1.032)	(1.417)	(1.017)
Observations	200	200	200	200	200	200	200	200

***$p<0.01$, **$p<0.05$, *$p<0.1$. Standard errors are in parentheses. Interaction signifies the interaction of income level with coal, oil, gas, and *ffuel* in model 1 through model 4, respectively

living as families with higher income stand a better chance of accessing good health care services (Lenhart 2019). The deteriorating effects of carbon emissions on life expectancy are apparent across the quantiles, whereas human capital positively promotes life expectancy from middle to upper quantiles suggesting an increasing trend in the nexus. The plausibility of the human capital-life expectancy association lies in the fact that with an increased level of education and skills, individual persons will be more conscious of their health and try all within their reach to avert circumstances that could complicate their health.

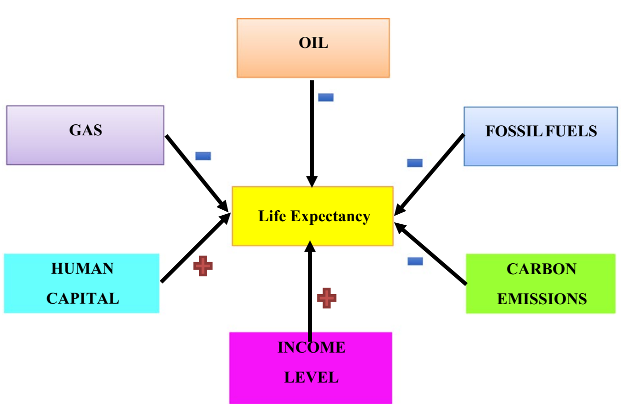

Fig. 6 Graphical representation of the main empirical findings

Dumitrescu and Hurlin panel causality test results

It is pertinent to note that the establishment of functional effects of fossil fuels, income, carbon emissions, and human capital on life expectancy in the preceding sections does not imply each of the regressors causes life expectancy or the other way round. To this end, the current study adopts the Dumitrescu and Hurlin (2012) Granger causality test to ascertain the directions of effects between the regressors and the outcome variable. This causality test has been empirically proven to effectively cater for cross-sectional dependence and heterogeneity issues inherent in panel regression (Huang et al. 2022). Following the findings of Table 9, a bidirectional causal association exists between the disintegrated components of fossil fuels (coal, oil, and gas) and the integrated indicator (*ffuel*). The implications of the bidirectional causality are that policy measures implemented to reduce the consumption rate of fossil fuels will affect life expectancy. In contrast, policy measures implemented to promote an increase in life expectancy will affect the consumption of fossil fuels. These outcomes are plausible because efforts to boost life expectancy and sustainable health would

Table 8 Quantile regression

Variables	Outcome variable: life expectancy								
	Lower quantiles				Middle quantiles		Upper quantiles		
	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
lnccoal	−0.037***	−0.035***	−0.029***	−0.027***	−0.020**	−0.023***	−0.025***	−0.026***	−0.025***
	(0.004)	(0.004)	(0.004)	(0.007)	(0.008)	(0.009)	(0.006)	(0.005)	(0.005)
lnoil	−0.162**	−0.256***	−0.323***	−0.399***	−0.503***	−0.484***	−0.38***	−0.266***	−0.175**
	(0.065)	(0.055)	(0.064)	(0.105)	(0.13)	(0.134)	(0.101)	(0.081)	(0.074)
lngas	−0.049	−0.091***	−0.108***	−0.148**	−0.214***	−0.235***	−0.230***	−0.176***	−0.120***
	(0.037)	(0.032)	(0.037)	(0.061)	(0.075)	(0.078)	(0.058)	(0.047)	(0.043)
lnffuel	−0.746***	−0.837***	−0.883***	−0.972***	−1.12***	−1.103***	−0.822***	−0.610***	−0.611***
	(0.142)	(0.121)	(0.141)	(0.23)	(0.286)	(0.295)	(0.222)	(0.179)	(0.162)
lnincome	0.025	0.009	0.009	0.001	0.037	0.030	0.130***	0.195***	0.213***
	(0.028)	(0.024)	(0.028)	(0.046)	(0.057)	(0.059)	(0.044)	(0.036)	(0.032)
lnco2	−0.402***	−0.345***	−0.304***	−0.263***	−0.192***	−0.107***	−0.226***	−0.205*	−0.136**
	(0.106)	(0.09)	(0.105)	(0.072)	(0.014)	(0.022)	(0.066)	(0.134)	(0.021)
lnhhc	0.045	0.051	0.068	0.124	0.297**	0.363**	0.369***	0.222**	0.114
	(0.075)	(0.063)	(0.074)	(0.121)	(0.15)	(0.154)	(0.116)	(0.094)	(0.085)
_cons	5.654***	5.012***	4.684***	4.246***	3.281***	2.607**	1.139	1.327*	2.382***
	(0.546)	(0.464)	(0.539)	(0.884)	(1.098)	(1.131)	(0.851)	(0.686)	(0.621)
Observations	120	120	120	120	120	120	120	120	120

Standard errors are in parentheses. ***$p<0.01$, **$p<0.05$, *$p<0.1$

require conscientious efforts at subduing factors that could undermine the achievement of the target. Since fossil fuel consumption and heavy reliance constitute one of the main culprits of demeaning life expectancy, such policies would significantly reduce fossil fuels. On the other hand, policies implemented to reduce fossil fuel consumption will automatically serve as indirect boosters of life expectancy. This is so as a significant reduction in fossil fuel is equivalent to improved quality of life and increased life expectancy. The economic situation of the oil-abundant African countries further supports the logicality of the reported fossil fuels-life expectancy causalities. Consequently, efforts to improve the quality of life in these countries would have abating effects on fossil fuel consumption.

Unidirectional causalities are reported, from carbon emissions, income, and human capital to life expectancy. This implies that policies directed toward reducing carbon emissions would improve life expectancy rates in the selected

Table 9 Feedback from Dumitrescu Hurlin panel causality tests

Null hypothesis	W-Stat	Zbar-Stat	Prob	Remarks
Causality running from LNCOAL to LNLEPT	4.87185	2.70049	0.0069	Bidirectional
Causality running from LNLEPT to LNCOAL	4.42438	2.25993	0.0238	
Causality running LNOIL to LNLEPT	12.57145	10.37385	0.0005	Bidirectional
Causality running from LNLEPT to LNOIL	17.18286	11.97582	0.0000	
Causality running from LNGAS to LNLEPT	19.6239	17.2249	0.0000	Bidirectional
Causality running from LNLEPT to LNGAS	14.40795	12.21287	0.0000	
Causality running from LNFFUELS to LNLEPT	16.3471	13.9861	0.0000	Bidirectional
Causality running from LNLEPT to LNFFUELS	18.21313	15.98433	0.0000	
Causality running from LNCO2 to LNLEPT	14.8282	12.5032	0.0000	Unidirectional
Causality running from NLEPT to LNCO2	6.48356	4.28732	2.0105	
Causality running from LNINCOME to LNLEPT	44.1025	41.3256	0.0000	Unidirectional
Causality running from LNLEPT to LNINCOME	5.3555	3.7136	0.2315	
Causality running from LNHC to LNLEPT	14.4930	10.59544	0.0004	Unidirectional
Causality running from LNLEPT to LNHC	7.44614	4.15363	3.1205	

African countries. The unidirectional causality in the case of income suggests that policy measures to increase income levels would eventually enhance access to improved living standards and good healthcare services. The results would have consequential impacts on improving the life expectancy of the populace in the oil-dependent African countries. Similarly, improvements in human capital would aid a significant increase in life expectancy due to elite citizens' health awareness and consciousness.

Conclusion

The present study investigates the functional effects of fossil fuels, carbon emissions, and human capital on life expectancy in five oil-abundant African countries, considering the conditioning role of income level. The impact of fossil fuels on life expectancy is evaluated from two angles, including disaggregated (coal, oil, and gas) and aggregated (fossil fuels). The empirical model considers the critical role of human capital through investment in education to enhance sustainable health leading to improved lifespan. The empirical evidence relies on annual data from 1980 to 2019 across the five selected African economies comprising Algeria, Angola, Egypt, Libya, and Nigeria. The empirical model is subjected to preliminary tests within the second-generation groups comprising cross-sectional dependence and slope homogeneity tests, CIPS stationarity test, and cointegration test based on Westerlund (2007). Moreover, estimation of the model relies on a battery of second-generation techniques, which include the cross-sectional dependence autoregressive distributed lag (CS-ARDL) model, common correlated effects mean group (CCEMG), and augmented mean group (AMG). The novel panel quantile regression is equally employed to enhance policy implications from the study for improved life expectancy in the sample countries. The following results are evident from the empirical analyses. First, the presence of cross-sectional dependence and slope heterogeneity is confirmed. Second, the long-run nexus is empirically established in the relationships among fossil fuels, carbon emissions, income level, human capital, and life expectancy. Third, the effects of fossil fuels from both aggregated and disaggregated angles reduce life expectancy. Besides, deteriorating impacts of carbon emissions on life expectancy are empirically confirmed. In contrast, income level and human capital positively and significantly affect life expectancy. More so, the moderating roles of income level on the adverse effects of fossil fuels are established. This implies that an increase in income level is substantial in enhancing the transition from dirty to clean energy as stipulated by the theory of the energy ladder. Fourth, the distributive effects of the explanatory variables on life expectancy reported from the quantile regression are found to be robust for the main results from CS-ARDL, CCEMG, and AMG. Fifth, the emanating results from the Dumitrescu and Hurlin causality test provide empirically based evidence to advance that policy measures directed at reducing fossil fuels are substantial enough to enhance and improve life expectancy in the oil-abundant African economies. Similarly, policy measures implemented to increase life expectancy significantly reduce fossil fuel consumption. Moreover, carbon emissions, income level, and human capital exert unidirectional causality on life expectancy.

Consequent to the empirical outcomes, the following policies are suggested for achieving sustainable health and healthy life expectancy in the selected African country and beyond. First, the militating effects of fossil fuels on life expectancy imply that governments in the respective countries must embark on policy measures that will stimulate a gradual and persistent transition from fossil fuels to renewable energy believed to be environmentally friendly and supportive of good and healthy living. This can be achieved through regulations directed at discouraging the consumption of fossil fuels, such as reducing subsidies on fossil fuels. Besides, the promotion of renewable energy can be achieved by diverting the subsidy from fossil fuels to investment in renewable sources of energy to make them affordable and accessible. This would be a worthwhile move considering the global advocacy for 100% renewable energy in the aftermath of COP26. Second, carbon emissions continue to exert severe adverse effects on developing nations like Africa despite the continent's minimal contribution to global greenhouse gas (GHG) emissions. As such, environmental regulations in the form of carbon tax and pricing can be employed to reduce the stock of carbon emissions in the selected African countries. Further, keying into the various global climate agreements with concerted efforts to implement them to promote a carbon–neutral environment in these countries remains fundamental to achieving a sustainable environment. Third, the increasing and abating effects of income level on life expectancy and fossil fuels can be sustained if the government ensures growth in the various economies is inclusive. This will help raise the income status of the majority and empower them to afford clean energy and healthcare services. Besides, the government should invest more in education and health sectors to help sustain the positive impacts of human capital on life expectancy. Threading the path stipulated above is not only sacrosanct for improving life expectancy in the selected oil-abundant economies but also crucial for delivering on the target entrenched in the 2063 African growth plan.

The present study despite its novelties cannot be exempted from certain limitations which future studies could address. For instance, the analysis of the determinants of life expectancy which was confided to fossil fuels, income, carbon emissions, and human capital can be extended to other crucial indicators such as conflicts, political instability/terrorism, and infectious diseases like malaria, typhoid, and tuberculosis among others. The highlighted indicators are prevalent in Africa and influence the quality of life to a greater extent. Besides, the scope of the study can be extended to a large group focusing on African continent or Sub-Saharan African region to enhance comprehensive policy implications. Lastly, considering the pertinence of this study's scope, similar inquiry can be conducted in other samples such as Middle East and North African, G7, and G20 among others.

Author contribution RLI: conceptualization, methodology, data collection, and writing—original draft preparation.

Data availability The datasets used and/or analyzed during the current study are available on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The author declares no competing interests.

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