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The role of technology in the non-renewable energy consumption-quality of life nexus: insights from sub-Saharan African countries

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Abstract
This study examines the impacts of non-renewable energy (NRE) on quality of life (QOL) through the conditioning role of technology on a panel of 43 Sub-Saharan African (SSA) countries over the period spanning 1990–2019. For easy traceability of the channel through which NRE affects QOL, the aggregate measure of Human Development Index (HDI) was decomposed into three namely life expectancy, education, and per capita GDP (GDPPC). Four indicators such as coal, natural gas, petroleum oil (disaggregated), and fossil fuel (aggregated) capture NRE while ICT service exports are used to proxy technology. The empirical analyses are deployed on a two-step system generalized method of moments (SYS-GMM) with forward orthogonal and the Panel Fixed Effects. Similarly, the empirical analyses also consider four regions (viz: South, West, East, and Central) in SSA. The following findings are established. First, the indicators of non-renewable energy (NRE) are statistically significant and negatively signed when HDI, life expectancy, and GDPPC are the outcome variables but positive for education. Second, the role of technology is examined from two angles: unconditional (single) and conditional (interaction with NRE variables). Across all models, technology proves to be QOL enhancing. Third, while the test of nonlinearity in the NRE-QOL nexus is confirmed, the findings are also consistent with the sub-regional analyses.

Keywords Non-renewable energy · Quality of life · Sub-Saharan Africa · GMM

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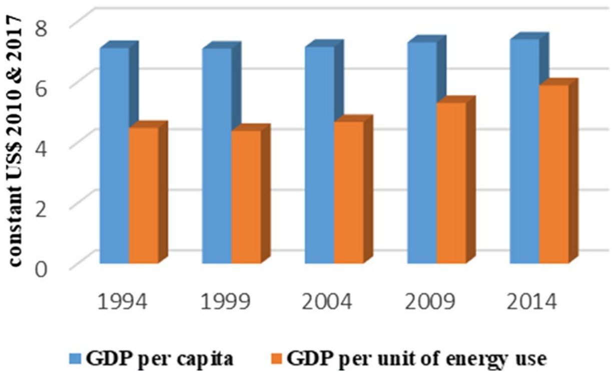

Fig. 1 Economic performance

1 Introduction

The recent decades have witnessed a series of economic renaissances in Sub-Saharan Africa (SSA) leading to improvements in the rates of economic growth and development. According to World Bank (2017), six[1] of the ten fastest emerging economies are from SSA. While the growth strides seem to be good for the region and attractive to foreign investors, the consequential impact on the quality of life has constituted a major cause for concern for at least two reasons. First, the increase in growth rates has led to a corresponding increase in the consumption of non-renewable energy in the region. Second, the surge in non-renewable energy (NRE) consumption can be attributed to the region's economic activities that are heavily dependent on the production of primary goods and non-renewable sources of energy (Akinyemi et al 2017). Thus, the use of conventional energy sources like wood fuels, petroleum, coal, and biofuel in SSA remains the major source of environmental problems (Ahuja et al. 2009). The last three decades have seen a remarkable increase in GDP per unit of NRE consumption in SSA (Fig. 1) and the corresponding trend in the consumption of fossil fuels further underscores the preceding arguments on NRE-growth nexus in SSA (Fig. 2).

The surge in NRE in SSA has coincided with overwhelming cases of health issues in the region. Particularly, the quality of life is deteriorating due to the rising contamination of the environment by the consumption of NRE. For instance, the records of nearly 176,000 deaths and 626,000 disability-adjusted lives in the region have been attributed to exposure to outdoor air pollution. More so, World Health Organization (WHO, 2018) posits that lower respiratory infection caused by environmental pollution has remained the major driving factor of high mortality rates in SSA.

[1] These SSA countries and together with their corresponding GDP growth rates include Ghana (8.3%), Ethiopia (8.2%), Cote D'Ivoire (7.2%), Djibouti (7%), Senegal (6.9%), and Tanzania (6.89) (World Bank, 2017).

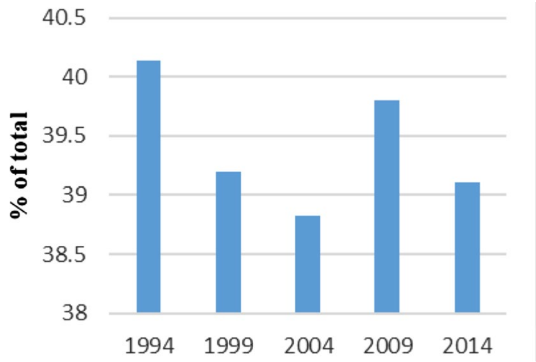

Fig. 2 Fossil fuel energy consumption

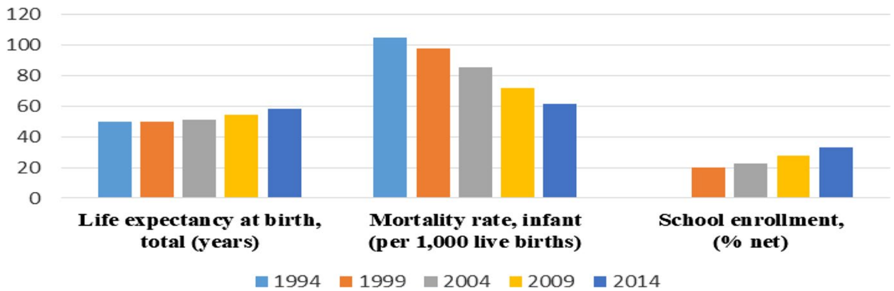

Fig. 3 Quality of life

Analysis of a timeline data on life expectancy showed inconsistency in the rates until the recent decade. Specifically, the quality of life in SSA countries has remained the lowest compared to other world regions. Supporting this assertion, statistics from WHO (2018), revealed that SSA is the only region with a life expectancy of fewer than 60 years (52.3 years) as against 60.1 years in the Eastern Mediterranean Region. The gap in healthy life expectancy between the region and the best performing region globally (Western Pacific Region) is 16.4 years, signifying a huge disparity for its population. (Fig. 3)

Despite the disappointing macroeconomic indicators, particularly those relating to health outcomes, income, and human capital development, the persistent growth and massive acceptance of technology in SSA seem to hold some promising future for the region. This is based on the remarkable progress recorded in terms of ICT usage in SSA (Edo et al. 2019). Besides, despite recent literature establishing the fact that ICT is rapidly transforming the world into a global village and equally bringing unprecedented changes in all spheres of life (Ridwan et al. 2019), the place of technology and its wider acceptance is still at the early stage in SSA (Asongu and Odhiambo 2020; Asongu and Boateng 2018). That notwithstanding, the fact that there are empirical backings for the role of technology in delivering positive externalities (Asongu and Odhiambo 2020; Efobi et al. 2018) could leave one without any doubt that the role of technological progress could be highly significant in mediating the negative impacts of nonrenewable energy on the quality of life in emerging nations like SSA. While this may sound plausible and intuitive, the empirical evidence advancing this proposition is largely lacking at least in the SSA region to the best of our knowledge.

The motivation for this study emanates from some lacuna identified in the literature. First, despite the growing research interests on factors influencing the quality of life, the extant literature is still neglectful of the role of non-renewable energy (NRE) consumption, particularly in SSA. The available studies in this research area have been limited to factors such as electricity consumption (Nadimi and Tokimatsu 2018; Mazur 2011), and energy efficiency index (Liu et al. 2016) among others. Second, the research interests on the NRE-quality of life nexus in Africa are evolving let alone for SSA. The recent study in this respect is Shobande (2020) but only considered selected countries in Africa (23 countries) and still limited to infant mortality indicator. Third, the measure of quality of life (QOL) has been undertaken from different angles with evidence ranging from mortality rates to life expectancy and HDI. This divergence in the measures of QOL could be held responsible for the mixed results in the literature. Consequently, the present study contributes to the ongoing research interests on QOL with a particular focus on SSA in the following ways. First, we take due cognizance of the observed inconclusiveness in the literature by capturing QOL with a wide range of indicators viz: HDI as the aggregated measure which is further decomposed into three namely life expectancy, education, and GDP per capita. Our choice of QOL indicators is equally motivated by the need to account for the diverse and multidimensional nature of the countries in SSA. Second, we considered the impacts of NRE from both aggregated (fossil fuel) and disaggregated (coal, oil, and natural gas) angles. This is a novel idea that has seen scarce attention in the literature. Third, the role of technology in intermediating between nonrenewable energy and quality of life is largely lacking in the literature and particularly for the SSA region. Hence, this study extends the frontier of debate on NRE-QOL nexus by probing the role of technology in the relationship. Fourth, the empirical analyses are further conducted for four regions within the SSA to examine whether what applies to SSA as a whole is equally valid for the regions (South, West, East, and Central). Fifth, we employ an estimation technique capable of solving econometric problems such as endogeneity concerns, simultaneity bias, or reverse causality inherent in macro data used on capturing energy-quality of life nexus through the two-stage system generalized method of moment (SYS-GMM). Similarly, the panel fixed effects are equally employed as robustness checks on the main empirical analyses.

Beyond the introduction, the remaining parts of the paper include Sect. 2 that presents a review of related literature, Sect. 3 entails the method which elucidates on the theoretical framework, strategic modeling, and estimation technique while Sect. 4 presents the results and the discussion of findings and finally, Sect. 5 concludes with relevant policy recommendations.

2 Literature review

The research interests in the quality of life have taken a multidimensional approach in the literature. Unarguably, previous studies have been largely motivated by the growth impacts of quality of life (QOL). Among these clusters of studies are Asiedu et al (2015), who investigated the link between income per capita, adult life expectancy, and children mortality rate for Africa between 1994 and 2014 using a dynamic panel model. Their findings revealed that global factors are significantly positively related to health outcomes and the effect has been increasing over time. It also showed that countries in SSA have been recording higher mortality rates and lower life expectancy than non-SSA countries. Hence, the study submitted that an increase in per capita income improved health outcomes and the effect is stronger with the higher levels of income. In a similar study, Salahuddin et al. (2020), studied the impact of economic growth, foreign direct investment, and internet use on child health outcomes in South Africa between 1985 and 2016 using Auto-regressive Distributed Lag (ARDL). The findings from the study indicated that economic growth and foreign direct investment (FDI) have a negative significant effect on infant mortality rate and under (5) child mortality rates. The study noted that increasing the growth rate of GDP would lead to a lower rate of infant and child mortality in South Africa. In Pakistan, Wang et al. (2020), examined the dynamic relationship between economic growth and life expectancy by considering the intervening roles of financial development and energy consumption in Pakistan, using ARDL bound testing approach. The findings revealed a positive association between economic growth and life expectancy, while energy consumption was found to lower life expectancy through environmental degradation. Further, Urhie et al. (2020) examined the relationship between economic growth, air pollution, and health outcomes in Nigeria. Using a moderated mediation model, findings showed that air pollution and government expenditure on health has a significant negative impact on health outcomes in Nigeria.

Another strand of studies was driven by the need to unravel the effects of energy consumption or environmental quality on quality of life. Among them are Nkalu and Edeme (2019), who recently investigated the impact of environmental Hazards on life expectancy in Africa with a focus on Nigeria from 1960 to 2017 using the generalized autoregressive conditional heteroscedasticity (GARCH) model. Their findings revealed that environmental hazard proxy by carbon dioxide CO_2 emission from solid fuel consumption reduces life expectancy. They however found that income as a proxy by GDP, and population growth positively impacts life expectancy. In line with these findings, the study suggested a reduction in CO_2 emission from solid fuel consumption to mitigate its negative impact on life expectancy. In a similar study, Shobande (2020) examined the effect of energy use on infant mortality rates in a panel of 23 African countries between 1999 and 2014. Findings from the study indicated a positive significant impact of energy predicators on infant mortality rate among the countries studied. However, the findings showed that proceeds from natural resource rents negatively impact infant mortality. The position of Shobande (2020) is similar to that of Suleiman (2017), who studied the impact of wood fuel consumption on health outcomes in sub-Saharan Africa using a generalized method of moment's estimators. His findings revealed that wood fuel consumption has positive significant impacts on both child and adult mortality rate and the impact was more severe on child mortality as compared to adult mortality rate. He equally found that the effect was more on female adults than male adults. Liu and Matsushina (2019) examined the relationship between annual changes in energy quality and quality of life in 66 OECD and non-OECD countries spanning 1990 to 2015. Using simple regression analysis, their findings showed that the quality of life proxy by Human Development Index (HDI) changes annually as energy quality also changes. It also revealed that the differences in quality of life in relation to changes in energy quality differ between OECD countries and non-OECD countries. In China, Wang et al. (2019) undertook a study on the linkages between residential energy consumption and life expectancy in Mainland China between 1990 and 2010. Using a geographically weighted regression approach, the study found a close association between household consumption of coal and electricity and life expectancy at the provisional level in Mainland China. In a similar vein, Nadimi and Tokimatsu (2018) modeled quality of life in terms of energy and electricity consumption of 112 countries during the period of 2005 to 2013 using a one-way analysis of variance method. The findings showed that the entrance of technology has influenced the quality of life and energy consumption per capita in developing countries more than in developed countries.

3 Method

3.1 Theoretical architecture and strategic modeling

To model the functional relationship among nonrenewable energy, technology, and quality of life in SSA, this study takes its motivation from the extended version of the Solow–Swan growth model, which incorporates natural resources as a factor of production (Nordhaus 1992). However, the exploration of natural resources with a focus on nonrenewable energy has been noted to substantially impact human lives (Jones and Vollrath 2013). The authors further submit that there is always a trade-off in the consumption of nonrenewable energy for production processes and the damages caused to the environment. The increasing environmental impacts of nonrenewable energy consumption are however limited to a certain threshold where the reverse is applicable. At this point, pollution tends to fall as an economy expands in income level (Jones and Vollrath 2013). The argument is that, at a low level of income, pollution tends to be higher but as income level rises to a certain point, a decline is recorded in pollution with income levels (Stern, 2004). This is consistent with the submission of Grossman and Krueger (1995) on the inverted U-shape nexus between pollution and income per capita level. Among other factors, technological advancement has been singled out as a key factor responsible for some falls in pollution and leveling off of energy consumption (Jones and Vollrath 2013). This proposition has been previously advanced by Acemoglu et al. (2012). In essence, the present study is thus positioned upon the argument that a nonlinear relationship is hypothesized between nonrenewable and quality of life with the conditional role of technological progress in the SSA region.

Leveraging on the preceding arguments, the baseline model for examining the tripartite nexuses among nonrenewable energy, technology, and quality of life follows the extant literature (see Shobande 2020; Nadimi and Tokimatsu 2018; Khandelwa 2015; Pasten and Santamarina, 2012; Gangadharan and Valenzuela 2001) such that

$$QOL_{it} = \varphi_0 + \varphi_1 QOL_{it-1} + \varphi_2 TECH_{it} + \varphi_3 CO2_{it} + \varphi_4 NRE_{it} + \varphi_5 X_{it} + \varphi_6 \varpi \tag{1}$$

where *QOL* represents a vector of quality of life indicators comprising HDI (aggregated measure) and life expectancy at birth, education (proxy by gross secondary school enrolment), and GDP per capita (disaggregated indicators); QOL_{it-1} is the initial state of quality of life; *TECH* represents technology proxy by ICT service exports (BoP, current US$); *CO2* is carbon emission measuring the impacts of the environment, *NRE* implies non-renewable energy consumption proxy by (*fof)* fossil fuel consumption (aggregated), and coal, oil, and gas (disaggregated); *X* is the vector of control variables like general government final consumption expenditure (*gex*), inflation rate (*inf*), foreign direct investment (FDI), and population (*Pop*). $\partial_{1.............6}$ are parameter estimates; ϖ_i is the stochastic term.

3.2 Estimation technique

The empirical models explicating the relationship between nonrenewable energy consumption, technology, and quality of life are estimated using the dynamic GMM estimation technique. The choice of this technique is motivated by four main rationales that are exposited thus. First, the GMM estimate is observed to be very relevant when the structure of the panel is such that the observations (N) are more than the periods (T). Considering the present study, the observations (N) which numbered (43) surpassed the periods (T) (1990–201 or 29 years). Second, when the dependent variable is observed to be persistent in a model, the GMM estimator has been advanced to be of a good fit in such a situation. Third, cross-sectional variations are eliminated in the technique. Fourth, the prevalent issues relating to endogeneity, heterogeneity, and simultaneity are best treated through the instrumental variables employ in the GMM method (Asongu and Odhiambo 2019).

The study further employs the system GMM advanced by Roodman (2009a, 2009b) which is an extension of Arellano and Bover (1995). The system GMM estimator is very efficient in minimizing the proliferation of instrumental variables and controls for cross-sectional dependence (Ridwan and Ajide 2020; Asongu and Nwachukwu 2016b; Boateng et al. 2018).

Consequently, the standard *system* GMM estimation technique in level (1) and first difference (2) is specified thus.

$$QOL_{it} = \varphi_0 + \varphi_1 QOL_{it-\tau} + \varphi_2 tech_{it} + \varphi_3 CO2_{it} + \varphi_4 coal_{it} + \varphi_5 oil_{it} + \varphi_6 gas_{it} + \varphi_7 fof_{it} + \sum_{h-1}^{5} \varphi_h X_{it-\tau} + \eta_i + \mu_T + \varpi_{it} \quad (2)$$

$$QOL_{it} - \varphi_1 QOL_{it-1} = \varphi_1 (QOL_{it-\tau} - QOL_{it-2\tau}) + \varphi_2 \left(tech_{it} - tech_{it-\tau}\right) + \varphi_3 \left(CO2_{it} - CO2_{it-\tau}\right) + \varphi_4 \left(coal_{it} - coal_{it-\tau}\right) + \varphi_5 \left(oil_{it} - oil_{it-\tau}\right) + \varphi_6 \left(gas_{it} - gas_{it-\tau}\right) + \varphi_7 \left(fof_{it} - fof_{it-\tau}\right) + \sum_{h-1}^{5} \varphi_h \left(X_{it} - X_{it-\tau}\right) + \left(\eta_{it} - \eta_{it-\tau}\right) + \left(\varpi_{it} - \varpi_{it-\tau}\right) \quad (3)$$

These variables remain as previously defined. τ represents the coefficient of auto-regression that is significantly considered giving the structure of this study where a year lag is assumed adequate to control for past occurrences, η_{it} is the time and country-specific effect, and $\varpi_{i,t}$ the error term.

3.3 Variables and data description

The descriptive analysis for the various categories of data employed in gauging the effects of energy consumption (non-renewable) on quality of life with conditioning role of technology in SSA is presented in Table 1. For the aggregated indicator of quality of life (QOL) measured by human development index (HDI), the mean value stands at 0.37 indicating a low rate. This is consistent with HDI (2019) report, which ranks majority of the SSA countries low except for a few.[2] Regarding the decomposed indicators of HDI, which measures the quality of life (QOL), the average values stand at 56.89 for life expectancy, 39.34 for education, and 2521.2 for GDPPC. These three indicators cover the three pillars of HDI, which are health, education, and income. By and large, these indicators presuppose the fact that quality of life in SSA is in a sorry state and thus requires attention for improvement in the nearest period. This can be further accentuated by the high rate of deviation from the mean for all indicators except life expectancy. Coal constitutes the highest on average in the cluster of non-renewable (NRE) energies with 4310, followed by gas (47.20) and petroleum oil (32.9). The large quantity of coal can be attributed to three major factors such as the ease of accessing coal, the affordability of its price, and the composite nature of utilizing it for a variety of purposes as compared to petroleum oil and natural gas. This submission is in line with WHO report (2011) which notes that, emissions generated from wood and coal are major contributing fators to airpollution, most especially in the rural areas.

Table 2 presents that the correlation matrix shows the degree and direction of association among the variables. The major drive behind this exercise is to have a preliminary view of the hypothetical direction of causality between indicators of quality of life and non-renewable energy. In addition, the likely presence of the

[2] This includes Seychelles (very high); Mauritius, Botswana, South Africa, and Gabon (high) while other are in the medium and low categories.

Table 1 Descriptive statistics

Variables	Description/Measurement	Mean	*S.D*	Max	Min	Sources
QOL	Human development index	0.373	13.45642	74.68798	0	UNDP
	Life expectancy, total (years)	56.897	7.018798	74.51463	26.691	WDI
	School enrollment, secondary (%gross)	39.236	22.80907	115.9565	−10.8969	WDI
	GDP per capita (cons 2010 US$)	2521.79	3377.625	20,532.95	164.3366	WDI
COAL	Coal consumption (Mst)	4310.08	27,800.87	206,727.8	0	EIA
PET	Petroleum Consumption (Mb/d)	32.93221	88.73075	660.8463	0	EIA
GAS	Natural gas consumption (bcf)	47.2112	200.8615	2194.699	0	EIA
FFUEL	Fossil fuel consumption (% of total)	66.02943	112.0608	619.8494	1.639733	WDI
CO2	CO2 emissions (kt)	14,906.29	64,379.57	503,112.4	40.337	WDI
TECH	ICT service exports (BoP, current US$)	6.688	4.529	4.391	−5.431	WDI
FDI	Foreign direct investment, net inflows (% of GDP)	4.286726	9.73867	161.8238	−6.89768	WDI
GEX	General government final consumption expenditure (% of GDP)	16.97416	8.473383	62.13341	1.220141	WDI
INFL	Inflation, consumer prices (annual %)	48.81134	848.2598	23,773.13	−60.4964	WDI
POP	Population, total	15,982,592	26,527,150	1.86E+08	70,439	WDI

QOL Quality of life. *PET* petroleum consumption. *FFUEL* fossil. *WDI* World Development Indicators. *UNDP* United Nations Development Programme. *EIA* variables are computed based on data from US Energy Information Administration. *Min* Minimum. *Max* Maximum. *S.D* Standard deviation

Table 2 Correlation matrix

HDI	LEP	EDU	GDPPC	COAL	PET	GAS	FFUEL	CO2	TECH	FDI	GEX	INFL	POP	VAR
1	0.02	0.16	0.15	−0.04	−0.09	−0.74	−0.02	−0.02	0.04	−0.08	0.06	−0.01	−0.09	HDI
	1	0.58	0.40	−0.01	−0.02	−0.00	0.27	−0.02	0.10	0.11	0.19	−0.06	−0.16	LEP
		1	0.52	0.33	0.30	0.20	0.15	0.33	0.12	0.05	0.22	−0.01	−0.04	EDU
			1	0.19	0.14	0.20	−0.02	−0.19	0.03	0.09	0.12	−0.03	−0.18	GDPPC
				1	0.54	0.04	0.03	0.67	−0.01	−0.05	0.04	−0.01	0.18	COAL
					1	0.15	−0.04	0.44	−0.02	−0.06	−0.10	−0.01	0.58	PET
						1	−0.02	0.11	−0.03	−0.04	0.04	−0.01	0.15	GAS
							1	0.00	−0.05	−0.03	0.30	−0.03	−0.17	FFUEL
								1	−0.02	−0.06	−0.01	−0.01	0.36	CO2
									1	0.02	−0.01	−0.01	−0.07	TECH
										1	0.03	−0.02	−0.08	FDI
											1	−0.07	−0.21	GEX
												1	0.05	INFL
													1	POP

problem of multicolinearity is easily diagnosed. Among these sets of motivations, the direction of the relationship as portrayed in Table 2 shows that the aggregated indicator of non-renewable (FFuel) negatively correlates with quality of life measures. However, the disaggregated measures exhibit diverging signs such as negative for life expectancy and positives for both education and GDPPC. Overall, the signs are consistent with our a priori expectation as exposited in Table 1. While these seem plausible, it is rather intuitive to rely on the outcomes from empirically backed results in the light of the econometric analysis. This is based on the ground that simple bivariate correlation in a conventional matrix is not sufficient to establish the degree of empirical association between dependent and independent (Akinlo and Sulola 2019).

4 Presentation of results

4.1 Main result

Before delving into the explanations of the economic intuitions of the empirical results of the present study, it is pertinent to first elucidate on the criteria, which by default are employed in assessing the validity and reliability of the GMM estimates. Four of these criteria are exposited as thus. First, it is important that the second-order Arellano and Bond autocorrelation test (AR (2)) in difference, which hypothesizes that the model does not suffer from the problem of autocorrelation in the residuals, is not rejected. Second, the over-identification restriction (OIR) tests based upon Sargan and Hansen with the null hypotheses of the validity of instruments or lack of correlation with the error are equally not rejected. To achieve the second criterion, it is conventional that the instruments are not more than the number of cross-sections in the majority of the specifications. Third, the test of instrument exogeneity anchored upon the Difference in Hansen Test (DHT) is also employed to examine the validity of the Hansen OIR test results. Fourth, a Fischer test validating the reliability of the general model specifications should be significant (Tchamyou and Asongu 2017; Asongu and De Moor 2016).

In light of the above-stated criteria on the GMM estimator, the majority of the models employed in this study are valid as they meet the stated conditions. That notwithstanding, it is very fundamental to mention that the validity of models is not synonymous with the persistence of the explained variable, which is highly sacrosanct for adopting the empirical results of the GMM estimator for policy implications. To be sure of the model persistence, the lagged values of the outcome variable should be significant and equally satisfies the convergence criterion. The convergence criterion is based on the argument that the absolute value of the lagged estimated NRE indicators should stand within the zero and one interval. Detailed intuitions expositing this criterion are well advanced in related extant literature employing the GMM estimator (Asongu, 2013, Fung, 2009).

The empirical analysis eliciting the functional relationship between non-renewable energy and quality of life in SSA are presented in Tables 3–6. Each table is

Table 3 System GMM estimation on the Non-renewable-Quality of life nexus (HDI) *Source* Author's computation (2020)

Variable	Dependent variable: HDI			
	Model 1	Model 2	Model 3	Model 4
L.hdi	0.301***	0.277***	0.142***	0.383***
	(0.006)	(0.006)	(0.006)	(0.010)
coal	−0.002***			
	(0.001)			
$coal^2$	0.003***			
	(0.001)			
techcoal	0.004***			
	(0.002)			
pet		−0.021***		
		(0.007)		
pet^2		0.003***		
		(0.001)		
techpet		0.005***		
		(0.002)		
gas			−0.026***	
			(0.002)	
gas^2			0.000***	
			(0.000)	
techgas			0.012***	
			(0.005)	
ffuel				−0.051***
				(0.001)
$ffuel^2$				0.000***
				(0.000)
techffuel				−0.000***
				(0.000)
tech	−0.002***	0.004***	0.008***	0.014***
	(0.001)	(0.003)	(0.000)	(0.001)
co2	−0.001***	−0.005***	−0.024***	−0.010***
	(0.001)	(0.002)	(0.006)	(0.001)
fdi	0.096***	0.093***	0.017***	0.083***
	(0.011)	(0.013)	(0.002)	(0.013)
infl	−0.026***	−0.024***	−0.007**	−0.052***
	(0.004)	(0.007)	(0.003)	(0.004)
pop	−0.032***	−0.014***	-0.009***	−0.006***
	(0.012)	(0.009)	(0.007)	(0.001)
gex	0.068***	0.057***	0.051***	0.026**
	(0.005)	(0.005)	(0.004)	(0.010)
_cons	2.876***	5.130***	1.898***	3.700***
	(0.150)	(0.280)	(0.052)	(0.221)

Table 3 (continued)

Variable	Dependent variable: HDI			
	Model 1	Model 2	Model 3	Model 4
AR(1)	(0.000)	(0.003)	(0.067)	(0.002)
AR(2)	(0.491)	(0.134)	(0.100)	(0.484)
Sargan OIR	(0.002)	(0.004)	(0.034)	(0.000)
Hansen OIR	(0.143)	(0.325)	(0.405)	(0.315)
DHT for instruments (a) Instruments in levels				
H excluding group	(0.001)	(0.001)	(0.008)	(0.001)
Dif(null, H = exogenous)	(0.992)	(0.883)	(0.997)	(0.982)
(b) IV (years, eq(diff))				
H excluding group	(0.112)	(0.002)	(0.351)	(0.266)
Dif(null, H = exogenous	(0.982)	(0.213)	(0.993)	(0.889)
Fisher	99.127***	40.359***	52.849***	79.830***
Instruments	32	36	36	36
Country	43	43	43	43
Observation	925	925	925	915

Standard errors in parentheses; ***$p<0.01$, **$p<0.05$, *$p<0.10$. and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to reject the null hypotheses of: (i) no autocorrelation in the AR(2) tests and; (ii) the validity of the instruments in the Sargan OIR test

dedicated to examining the impacts of the four indicators of non-renewable energy on the measures of quality of life for both aggregated (HDI) and disaggregated (life expectancy, education, and GDPPC). Specifically, Table 3 focuses on HDI as the dependent variable, Table 4; life expectancy, Table 5; education, and Table 6; GDPPC. For each of the respective tables, five models are specified in relation to the four indicators of non-renewable energy such as coal, gas, oil, and fossil fuel. The control variables are equally specified uniformly across tables and models.

Table 3 presents the impacts of NRE on the human development index (HDI) measuring the quality of life. The choice of HDI as an indicator of the quality of life lies in the fact that the variable measures the dimension of life that is highly important to the present study. Generally speaking, HDI measures the average achievement in human development with respect to three key dimensions such as long and healthy life, educational attainment, and desirable standard of living. Hence, an increase in HDI score implies a progression while a reduction implies the opposite. The main findings from Table 3 reveal negative and statistical impacts of non-renewable energy (coal, gas, oil, and fossil fuel) on quality of life proxy by HDI. Intuitively, a proportional increase in the consumption of non-renewable energy such as coal, petroleum, natural gas, and fossil fuel reduces improvement on human development by 0.002, 0.121, 0.026, and 0.051%, respectively. This reduction is however limited to a certain threshold such that as the countries progress in the choice of NRE, advancement is recorded in technology and experience abound leading to more efficient utilization of NRE and alternative sources of energy consumption. At this point, the correlation between energy consumption and HDI becomes

Table 4 System GMM estimation on the non-renewable-quality of life nexus (LEP) *Source* Author's computation (2020)

Variable	Dependent variable: Life expectancy (LEP)			
	Model 1	Model 2	Model 3	Model 4
L.lep	0.074***	0.061***	0.015***	0.067***
	(0.005)	(0.006)	(0.005)	(0.007)
coal	−0.012**			
	(0.004)			
$coal^2$	0.015***			
	(0.011)			
techrcoal	0.009**			
	(0.002)			
pet		−0.207***		
		(0.004)		
pet^2		0.009***		
		(0.003)		
techpet		0.017**		
		(0.008)		
gas			−0.010**	
			(0.005)	
gas^2			0.0023**	
			(0.011)	
techgas			0.009**	
			(0.004)	
ffuel				−0.095***
				(0.002)
$ffuel^2$				0.014***
				(0.005)
techffuel				0.022***
				(0.013)
tech	0.000***	0.000	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
co2	−0.005***	−0.011***	0.005***	0.015***
	(0.001)	(0.009)	(0.000)	(0.005)
fdi	0.020***	0.010**	0.013***	0.045***
	(0.006)	(0.004)	(0.004)	(0.007)
infl	−0.033***	−0.069***	−0.040***	−0.015***
	(0.003)	(0.005)	(0.004)	(0.003)
pop	−0.016***	−0.029***	−0.035***	−0.042***
	(0.004)	(0.013)	(0.014)	(0.013)
gex	0.144***	0.210***	0.104***	0.097***
	(0.008)	(0.005)	(0.006)	(0.006)
_cons	51.247***	49.932***	54.994***	48.483***
	(0.327)	(0.311)	(0.409)	(0.603)

Table 4 (continued)

Variable	Dependent variable: Life expectancy (LEP)			
	Model 1	Model 2	Model 3	Model 4
AR(1)	(0.001)	(0.002)	(0.006)	(0.000)
AR(2)	(0.218)	(0.555)	(0.388)	(0.982)
Sargan OIR	(0.011)	(0.000)	(0.003)	(0.001)
Hansen OIR	(0.315)	(0.144)	(0.313)	(0.156)
DHT for instruments (a) Instruments in levels				
H excluding group	(0.001)	(0.013)	(0.001)	(0.226)
Dif(null, H=exogenous)	(0.994)	(0.687)	(0.010)	(0.955)
(b) IV (years, eq(diff))				
H excluding group	(0.266)	(0.113)	(0.265)	(0.226)
Dif(null, H=exogenous	(0.789)	(0.918)	(0.988)	(0.298)
Fisher	15.949***	92.988***	16.219***	35.683***
Instruments	36	32	36	36
Country	43	43	43	43
Observation	947	947	947	977

Note: Standard errors in parentheses; ***$p<0.01$, **$p<0.05$, *$p<0.10$ and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to reject the null hypotheses of: (i) no autocorrelation in the AR(2) tests and (ii) the validity of the instruments in the Sargan OIR test

positive thus indicating nonlinearity in the nexus. This scenario is evidenced by the positive and significant impacts of the square of the indicators of NRE ($coal^2$, pet^2, gas^2, and $ffuel^2$). The unconditional (single) impact of technology is noted to be positive and statistically significant. Further, the conditional (interaction) impacts of technology on the indicators of NRE came out to be positive and statistically significant. This implies that as the countries in SSA progress in their level of technology, the tendency to use NRE more efficiently and advance to cleaner sources of energy increases that analogously leads to improvements in HDI.

The impacts of non-renewable energy on life expectancy are presented in Table 4. Life expectancy at birth implies the aggregate mortality rate in a given population. It is a statistical approach of estimating the average number of years human beings are expected to live or the mean age susceptible to death. In measuring life expectancy (LEP), credence is given to actors such as the year of birth, gender, age, location, and environmental factors. Hence, an improvement in LEP implies an increase in the number of years people are expected to live, and vice versa. The empirical results in Table 4 reveal negative and statistically significant impacts of all measures of non-renewable energy on quality of life when life expectancy is the explained variable. By implication, non-renewable energy deters improved life expectancy such that a percentage increase in the consumption of coal, petroleum oil, natural gas, and fossil fuel reduces by expectancy at birth by 0.012%, 0.207%, 0.010%, and 0.095% in that order. The health implications of these components of non-renewable energy endanger improved quality of life due to the pollutants emitted in the process of utilizing them. According to Smith et al. (2013), the consumption of fossil fuel

Table 5 System GMM estimation on the Non-renewable-Quality of life nexus (Education) *Source* Author's computation (2020)

Variable	Dependent variable: Education			
	Model 1	Model 2	Model 3	Model 4
L.edu	0.050***	0.172***	0.139***	0.093***
	(0.009)	(0.011)	(0.010)	(0.006)
coal	−0.002			
	(0.003)			
$coal^2$	−0.000			
	(0.000)			
techrcoal	−0.000			
	(0.000)			
pet		0.780***		
		(0.038)		
pet^2		−0.510		
		(0.019)		
techpet		−0.035***		
		(0.012)		
gas			−0.061	
			(0.025)	
gas^2			0.007	
			(0.001)	
techgas			−0.021	
			(0.009)	
ffuel				0.050***
				(0.007)
$ffuel^2$				−0.049***
				(0.012)
techffuel				0.011***
				(0.009)
tech	0.029***	0.030***	0.015***	0.008***
	(0.003)	(0.009)	(0.004)	(0.001)
co2	−0.001***	−0.001***	−0.003***	−0.010***
	(0.000)	(0.000)	(0.001)	(0.003)
fdi	0.012	0.021	0.111***	0.042
	(0.030)	(0.107)	(0.033)	(0.036)
infl	−0.258***	−0.011	−0.166***	−0.137***
	(0.022)	(0.057)	(0.032)	(0.019)
pop	−0.009***	−0.008***	−0.011***	−0.013***
	(0.002)	(0.001)	(0.005)	(0.005)
gexr	0.749***	0.771***	0.353***	0.284***
	(0.086)	(0.045)	(0.040)	(0.048)
_cons	27.254***	34.130***	38.038***	41.731***
	(1.720)	(1.668)	(1.179)	(0.810)

Table 5 (continued)

Variable	Dependent variable: Education			
	Model 1	Model 2	Model 3	Model 4
AR(1)	(0.006)	(0.002)	(0.023)	(0.008)
AR(2)	(0.161)	(0.044)	(0.501)	(0.348)
Sargan OIR	(0.004)	(0.004)	(0.011)	(0.000))
Hansen OIR	(0.367)	(0.237)	(0.261)	(0.213)
DHT for instruments (a) Instruments in levels				
H excluding group	(0.315)	(0.195)	(0.015)	(0.037)
Dif(null, H = exogenous)	(0.827)	(0.978)	(0.237)	(0.664)
(b) IV (years, eq(diff))				
H excluding group	(0.000)	(0.195)	(0.223)	(0.191)
Dif(null, H = exogenous	(0.367)	(0.885)	(0.663)	(0.47261
Fisher	61.550***	40.491***	13.540***	73.016***
Instruments	36	34	34	34
Country	43	43	43	43
Obsevation	693	693	693	717

Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$ and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to reject the null hypotheses of: (i) no autocorrelation in the AR(2) tests and; (ii) the validity of the instruments in the Sargan OIR test

has a deleterious effect across a life cycle and equally manifests on spatial scales ranging from local to global in both close and far distance, and both immediate and future. Further, every stage involved in coal processing generates pollutants, which adversely affect human life. Specifically, the air pollution generated during coal combustion in power plants can negatively affect the cardiovascular and respiratory systems, which by extension can lead to irregular neurological growth in children, poor development of the fetus during pregnancy, and can lead to cancer (Burt et al. 2013). Consequently, a persistent increase in the use of nonrenewable energy will continue to jeopardize the drive towards achieving goal-3 of the sustainable development agenda, which stipulates the need to ensure healthy lives and promote well-being for people of all ages. Also, while the nonlinearity relationship is equally established in the NRE—life expectancy nexus, the impacts of technology both as a single and interactive effect are consistently positive and statistically significant across the models.

The empirical results emanating from Table 5 on the effects of NRE on education deviate from the previous results on HDI and life expectancy. As evident from the table, only petroleum and ffuel among the measures of NRE are statistically significant and positive. The economic intuition derivable from this result is that a proportionate increase in the consumption of energy increases the level of education attainment through the efficient utilization of educational materials and conduciveness of the teaching and learning environment. The consumption of energy, which is positive, implies an increase in energy consumption leads to an increase in educational attainment. This direct relationship is however limited to a certain threshold

Table 6 System GMM estimation on the Non-renewable-Quality of life nexus (GDPPC) *Source* Author's computation (2020)

Variable	Dependent variable: GDPPC			
	Model 1	Model 2	Model 3	Model 4
L.gdppc	0.221***	0.223***	0.213***	0.259***
	(0.002)	(0.003)	(0.002)	(0.002)
coal	0.265***			
	(0.026)			
$coal^2$	−0.036***			
	(0.012)			
techcoal	0.011***			
	(0.003)			
pet		0..155***		
		(0.015)		
pet^2		−0.022***		
		(0.003)		
techpet		0.031***		
		(0.026)		
gas			0.613***	
			(0.586)	
gas2			−0.002***	
			(0.001)	
techgas			0.022**	
			(0.003)	
ffuel				1.157***
				(0.384)
$ffuel^2$				−0.030***
				(0.001)
techffuel				0.030***
				(0.007)
tech	0.014***	0.012**	0.022**	0.026***
	(0.005)	(0.003)	(0.009)	(0.012)
co2	−0.092***	−0.011***	−0.017***	−0.013***
	(0.004)	(0.002)	(0.001)	(0.002)
fdi	0.111***	0.138***	0.152***	0.105***
	(0.034)	(0.033)	(0.048)	(0.032)
infl	−0.275***	−0.331***	−0.033***	−0.391***
	(0.029)	(0.024)	(0.027)	(0.023)
pop	−0.005***	−0.019***	−0.023***	−0.029***
	(0.001)	(0.006)	(0.011)	(0.014)
gex	0.193***	0.139***	−0.372	0.118***
	(0.025)	(0.024)	(0.024)	(0.033)
_cons	32.045***	30.218***	32.890***	30.301***
	(93.429)	(72.176)	(61.305)	(67.697)

Table 6 (continued)

Variable	Dependent variable: GDPPC			
	Model 1	Model 2	Model 3	Model 4
AR(1)	(0.000)	(0.001)	(0.041)	(0.162)
AR(2)	(0.274)	(0.160)	(0.675)	(0.001)
Sargan OIR	(0.019)	(0.001)	(0.002)	(0.028)
Hansen OIR	(0.317)	(0.653)	(0.318)	(0.235)
DHT for instruments (a) Instruments in levels				
H excluding group	(0.001)	(0.001)	(0.001)	(0.001)
Dif(null, H = exogenous)	(0.643)	(0.553)	(0.110)	(0.999)
(b) IV (years, eq(diff))				
H excluding group	(0.270)	(0.266)	(0.269)	(0.194)
Dif(null, H = exogenous	(0.835)	(0.778)	(0.974)	(0.890)
Fisher	32.550***	11.716***	66.757***	13.139***
Instruments	36	36	36	36
Country	43	43	43	43
Observation	947	947	947	982

Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$ and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to reject the null hypotheses of: (i) no autocorrelation in the AR(2) tests and; (ii) the validity of the instruments in the Sargan OIR test

where the attainment of educational status leads to awareness of the need to source for cleaner energy. At this point, a negative relationship between energy consumption and education is hypothesized. This is actually evident in Table 5 for the square of pet^2 and ffuel^2. This result complements the findings reported by Inglesi-Lotz and Morales (2017). The unconditional role of technology is found to be positive implying as countries in SSA advance in technology awareness and utilization, education should theoretically become more accessible, affordable, and outputs increase in terms of human capital development.

Table 6 reports the nexus between NRE and GDPPC for the SSA region. The empirical results reveal a direct and statistically significant relationship between NRE and GDPPC. By implication, a percentage increase in the consumption of coal, petroleum, natural gas and fossil fuel leads to a percentage increase in GDPPC by 0.265, 0.155, 0.613 and 1.157%, respectively. This result aligns well with extant studies on the energy-growth nexus (Buhari et al. 2020; Dogan et al. 2020; Ajide and Ibrahim 2018; Eregha and Mesagan 2017). On the contrary, the squares of the four indicators of NRE negatively correlate with GPPC which is a further confirmation of the nonlinearity nexus previously reported in preceding tables. Similarly, both marginal and conditional effects of technology are positive and statistically significant across the models.

Regarding other control variables, they are found to be significant for most of the models but differ in terms of magnitudes and signs. In particular, variables such as foreign direct investment (FDI) and government expenditure (GEX) are found to enhance quality of life with their positive signs. The attraction of FDI to SSA countries implies more multinational establishing either fully or partially in the region. This brings about increase in employment opportunities for the unemployed groups, which in effect, enhance the living condition, provided the activities of the multinationals are well regulated. In the same vein, the increase in government expenditure spurs an increase in economic growth with the multiplier effect leading to improved standard of living and by extension, quality of life. This submission is in agreement with Flavin (2019) who finds a robust empirical support for an improved state of living owing to an increase in government expenditure on public goods. On the contrary, variables like CO2, inflation, and population are quality of life retarding, thus implying that a proportional increase in these variables hinders or reduces quality of life. The impacts of CO2 can be explained by the environmental effects of CO2, which endanger the lives of the people in the immediate environment. The negative effects of inflation can be explained from the impacts it exerts on the economic well-being of the people, which increases the proportion of people in the poverty line. When prices are high, the purchasing power of money falls drastically and people can be denied the necessities of life, thereby affecting their living conditions.

The overall assessment of the nexus between non-renewable energy (NRE) and quality of life (QOL) shows that the former has a retarding influence on the latter. Hence, for the SSA countries to achieve some level of improvements in the devastating quality of life eroding the region, drastic efforts need to be made to reduce the consumption of non-renewable energy and adopt renewable energy options.

4.2 Sub-regional analysis

To enhance our deep understanding of the nexus between NRE and quality of life (QOL), this study extends the frontier of the inquiry by conducting additional analyses based on regional groupings of countries within the SSA. Of the five regions in Africa, SSA accounts for four of them namely: Southern Africa, Western Africa, Eastern Africa, and Central Africa with the exclusion of North Africa, which belongs to the Arab league. To gauge the empirical relationship between NRE and QOL in these regions, we employ panel fixed effects estimation for three reasons. First, the categorization of observations in accordance to the regional groupings makes it difficult to fulfill the standard condition of employing the GMM estimator. Particularly, the condition that requires that $N > T$. In the case of this robustness, the N across the four regions includes 10 countries from the Southern region, 15 from the Western region, 14 from the Eastern and 9 from the Central region, are smaller than the T (1990–2019 or 29 years). Second, in the panel estimation, the choice of estimator between the fixed and random effects is usually decided by employing the Hausman test. Based on the analyses conducted, the null hypothesis of random effects was rejected by the Hausman test thus leaving the choice of employing the fixed effects. Third, the fixed effects estimator has been noted to be very efficient in controlling for time-invariant unobserved individual features that can be correlated with the observed explanatory variables. Worthy of mentioning is the fact that the joint validity for the stated models is confirmed significant by the Fisher test across

Table 7 Panel fixed effects estimation on non-renewable energy-quality of life nexus for the Southern SSA Region *Source* Author's computation (2020)

Variables	Model 1 HDI	Model 2 LEP	Model 3 EDU	Model 4 GDPPC
COAL	−4.581 (3.1)	−0.005 (0.778)***	0.910 (0.003)	−0.004 (0.009)
GAS	−0.002 (0.009)*	0.006 (0.002)***	0.015 (0.005)***	− −0.466 (0.466)**
PET	−0.033 (0.014)**	−0.005 (0.027)	0.002 (0.066)	0.518 (0.336)
FFUEL	−0.286 (0.029)***	−0.017 (0.057)	0.262 (0.141)*	−3.612 (0.719)***
$FFUEL^2$	0.505 (0.268)*	0.411 (0.177)**	−0.005 (0.611)***	0.192 (0.006)***
TECH	0.184 (0.541)***	1.791 (0.101)*	0.574 (0.225)**	0.478 (0.126)*
TECHFFUEL	0.201 (0.882)**	0.130 (0.018)**	0.960 (0.443)*	0.315 (0.221)**
FDI	0.103 (0.036)***	−0.084 (0.072)	0.333 (0.176)***	13.075 (0.908)
INFL	0.005 (0.014)	−0.025 (0.029)	−0.119 (0.071)*	−0.414 (0.359)
GEX	0.162 (0.045)***	0.002 (0.090)	−0.193 (0.236)	0.606 (0.113)***
POP	−0.689 (0.779)***	−1.491 (0.155)***	−1.871 (0.392)***	−3.581 (0.119)*
C	−2.227 (2.041)	4.085 (0.406)***	34.861 (0.111)***	15.711 (5.098)***
Hausman test	473.38***	12.998***	130.15***	565.44***
R-squared	0.996	0.72	0.908	0.973
F-stat	207.30***	20.374***	74.421***	32.548***

Standard errors in parentheses; ***$p<0.01$, **$p<0.05$, *$p<0.10$ and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to accept the null of random effects

the models for all the regions. Further, the R-squared values which range between 60% and 90% indicate how sufficient the impacts of NRE are in explaining variation in qualityof life across the models.

The results of the NRE-QOL nexus for the Southern region in SSA are presented in Table 7. In Model 1 with HDI as the dependent variable, all the indicators of NRE are statistically significant and negative except for education which is positive. The impacts of NRE on the majority of other indicators of quality of life are not significant enough to explain the variation in the outcome variables across the models. Perhaps one plausible reason can be attributed to this low impact of NRE on quality of life in Southern Africa could be placed on the fact that, of the 10 countries in the region, only Angola is a member of the Organization of Oil Producing Countries (OPEC). Historically, Angola produces over 1.4 million barrels of oil annually in

Table 8 Panel fixed effects estimation on non-renewable energy-quality of life nexus for the Western SSA Region *Source* Author's computation (2020)

Variables	Model 1 HDI	Model 2 LEP	Model 3 EDU	Model 4 GDPPC
COAL	0.005 (0.004)	−0.017 (0.003)***	0.042 (0.009)***	0.034 (0.212)
GAS	−0.018 (0.009)**	−0.023 (0.006)***	0.059 (0.022)***	−0.403 (0.482)*
PET	0.005 (0.017)**	−0.019 (0.012)***	0.087 (0.047)***	1.100 (0.949)**
FFUEL	−0.013 (0.012)**	−0.029 (0.008)***	0.253 (0.031)***	− −8.245 (0.664)***
$FFUEL^2$	0.546 (0.023)**	0.134 (0.015)***	−0.118 (0.023)**	0.323 (0.098)***
TECH	0.008 (0.128)**	0.222 (0.875)***	−5.141 (0.331)	3.711 (0.712)***
TECHFFUEL	0.421 (0.720)**	0.373 (0.493)	6.521 (0.188)***	2.691 (0.401)***
FDI	0.004 (0.023)***	0.108 (0.016)***	0.196 (0.091)***	−0.187 (0.129)
INFL	−0.034 (0.023)**	−0.047 (0.016)***	0.104 (0.064)	0.244 (0.128)
GEX	0.056 (0.042)	0.091 (0.029)***	0.009 (0.129)	0.119 (0.232)***
POP	−9.121 (0.511)*	−0.229 (0.350)***	−6.911 (0.162)***	−0.983 (0.285)***
C	0.752 (1.409)	4.995 (0.966)***	−5.419 (4.005)	−0.167 (0.785)
Hausman test	2.725***	76.535***	59.221****	52.339***
R-squared	0.665	0.721	0.741	0.919
F-stat	32.871***	36.327***	36.327***	17.122***

Standard errors in parentheses; ***$p<0.01$, **$p<0.05$, *$p<0.10$ and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to accept the null of random effects

2019 but has recorded persistent declines from its highest rate of 1.8 million barrels annually in 2015 (William, 2020). However, technology both in terms of marginal and conditional impacts is found to be statistically significant and energy efficiency enhancing. This implies that the EKC model appears as relevant for the western region of SSA. Among the set of control variables, population proves to be impactful across all the models but with negative signs.

Table 8 presents the results of the impacts of NRE on quality of life for the Western region in SSA. The results appear to be more impactful than what we have in Table 7. As can be seen in the Table, the impacts of NRE are found to be negative and statistically significant for the majority of the models except for education that is positive. The test of EKC on the return to more efficient use of energy is equally established for the region. The Western region has Nigeria as a member of countries

Table 9 Panel fixed effects estimation on non-renewable energy-quality of life nexus for the Eastern SSA region *Source* Author's computation (2020)

Variables	Model 1 HDI	Model 2 LEP	Model 3 EDU	Model 4 GDPPC
COAL	−0.001 (0.653)	−0.004 (0.004)	0.006 (0.512)	−0.363 (0.796)***
GAS	na	na	na	na
PET	−0.008 (0.007)	−0.019 (0.039)	0.037 (0.123)	0.758 (0.798)
FFUEL	−0.005 (0.018)	−0.081 (0.111)	0.104 (0.273)	0.191 (0.229)
$FFUEL^2$	0.002 (0.001)	0.004 (0.002)	−0.011 (0.005)	0.013 (0.009)
TECH	0.204 (0.645)***	0.804 (0.381)**	0.510 (0.772)***	0.115 (0.787)
TECHFFUEL	0.123 (0.381)***	0.496 (0.225)**	0.325 (0.456)***	0.626 (0.464)
FDI	0.002 (0.001)***	0.223 (0.080)***	0.053 (0.152)	0.373 (0.166)
INFL	−0.671 (0.006)***	−0.047 (0.041)	−0.150 (0.134)	−0.603 (0.089)*
GEX	0.004 (0.001)***	0.027 (0.065)	0.276 (0.325)	0.299 (0.129)**
POP	−0.101 (0.137)***	−0.548 (0.810)***	0.804	−0.522 (0.196)***
C	0.140 (0.063)***	4.641 (0.374)***	3.892	0.295 (0.883)***
Hausman test	14.488***	80.790***	15.780***	49.132***
R-squared	0.891	0.734	0.906	0.896
F-stat	11.084***	34.506***	86.571***	86.571***

Standard errors in parentheses; ***$p<0.01$, **$p<0.05$, *$p<0.10$ and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to accept the null of random effects

and according to OPEC (2020), the country is the largest oil-producing nation in Africa and about 10th global with nearly 8.2 million barrels per annum in 2020. This implies that if the impacts of NRE are to be measured by the volume of oil in each region, then, the Western region serves as a favorite candidate. Further, the marginal and conditional impacts of technology are statistically significant and positive. Other significant control variables maintain their expected signs across the models.

The empirical results in Table 9 are based on the NRE-QOL nexus for the Eastern region. As evident in the Table, the impacts of NRE indicators are not significant for all the NRE indicators. This is not surprising, as the Eastern region is not a member of OPEC. This implies that it is not an officially recognized oil-producing region. The impacts of technology are found to be significant both in terms of marginal and conditional effects. An important insight from the statistical relevant of technology-NRE interaction in the region is that, with consistent advancement in technology,

Table 10 Panel fixed effects estimation on non-renewable energy-quality of life nexus for the Central SSA Region *Source* Author's computation (2020)

Variables	Model 1 HDI	Model 2 LEP	Model 3 EDU	Model 4 GDPPC
COAL	−0.003 (0.006)	−0.019 (0.015)	−0.074 (0.052)	0.335 (1.299)
GAS	0.007 (0.006)***	0.094 (0.016)***	0.193 (0.081)***	0.208 (0.146)***
PET	−0.002 (0.002)*	0.156 (0.043)***	0.411 (0.159)**	0.332 (0.386)*
FFUEL	−0.005 (0.003)*	−0.094 (0.008)***	0.209 (0.029)***	0.328 (0.737)
$FFUEL^2$	0.015 (0.013)*	0.009 (0.008)***	−0.019 (0.002)***	0.025 (0.7012)**
TECH	0.203 (0.163)**	0.332 (0.387)***	2.871 (0.138)**	0.312 (0.347)**
TECHFFUEL	0.123 (0.101)	0.211 (0.241)	0.277 (0.887)***	0.236 (0.216)
FDI	0.008 (0.005)	0.019 (0.894)	0.086 (0.039)**	0.255 (0.982)***
INFL	−0.114 (0.376)**	−0.52 (0.894)**	−0.004 (0.003)***	−0.097 (0.082)***
GEX	0.004 (0.002)	0.006 (0.049)	0.628 (0.184)***	−0.422 (0.447)
POP	−0.503 (0.190)	−0.960 (0.453)**	0.182 (0.180)	−0.003 (0.407)***
C	0.349 (0.043)**	4.334 (1.012)***	3.919 (0.371)	0.702 (0.909)***
Hausman test	22.864***	43.820***	10.791***	48.320***
R-squared	0.758	0.833	0.753	0.889
F-stat	34.844***	48.741***	32.348***	87.579***

Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$ and the bolded values signify significance of (a) estimated parameters and F-statistics and (b) failure to accept the null of random effects

the countries are bound to grow to produce NRE in large quantity to enter the global market. For instance, Ethiopia that is located in the Eastern region of SSA possesses nonrenewable energy resources such as oil, gas, and coal but does not export them. With the technical progress, the country and a host of others are bound to achieve NRE production in exportable quantities. Also, other control variables are most significant for the HDI model.

The impacts of NRE on quality of life for the Central African region are presented in Table 10. The indicators of NRE are noted to be significant with diverging signs as thus HDI, LEP, and GDPPC (negative), and EDU (positive). The nonlinear trend is observed to hold as well for the indicators of NRE. The level of NRE significance in the Central region of SSA is quite understood going by the fact that three of the nine countries (Guinea, Equatorial Guinea, and Gabon) are clustered in the region. Meanwhile, the impacts of technology from the two angles of marginal and conditional effects are consistent with the previous tables in terms of positive signs.

The overall assessment of the robustness check does not deviate much from the main results rather, it further buttresses the empirical findings of the latter. The only area of divergence lies in the extent of impacts of NRE on quality of life in relation to the stock of energy resources. This further clarifies the fact that the impacts of NRE on quality of life (QOL) are not homogeneously determined, and as such, policy implementations should be carefully taken to cater for the diversity observed in the NRE-QOL nexus of the SSA as well as its regions.

5 Conclusion

This study examines the impacts of non-renewable energy (NRE) on quality of life (QOL) via the conditioning role of technology in 43 Sub-Saharan African (SSA) countries for the period spanning 1990–2019. The study is primarily motivated by the deteriorating state of life in SSA owing to declining rates of human development. For easy traceability of the channel through which NRE impacts QOL, the aggregate measure (HDI) was decomposed into three namely; life expectancy, education, and GDPPC. Four indicators such as coal, natural gas, petroleum oil (disaggregated), and fossil fuel (aggregated) capture NRE while ICT service exports are used to proxy technology. The empirical analysis is deployed on a two-step system generalized method of moments (SYS-GMM) with forward orthogonal and the Dynamic Panel Fixed Effects (DynFE). Similarly, the empirical analyses also consider four regions (viz: South, West, East, and Central) within the SSA region. The following findings emanate from the study. First, the indicators of non-renewable energy (NRE) are statistically significant and negatively signed when HDI, life expectancy, and GDPPC are the outcome variables. This implies that NRE hinders the quality of life on the aggregate with HDI as the indicator and uses the channels of life expectancy and income (GDPPC) for the observed negative effects. On the contrary, the channel of education remains a desirable medium with positive impacts but not sufficient on the overall effects. Second, the role of technology is examined from two angles, which are marginal (single) and conditional (interaction with NRE variables). Across all models, a technology from the two ends proves to be QOL enhancing. Third, the test of nonlinearity in the NRE-QOL nexus is observed to fulfill the a priori expectation of positive for HDI, life expectancy, GDPPC, and negative for education. By implication, continuous consumption of NRE with the interplay of technology will avail the region the opportunity to access more efficient and cleaner NRE sources. Fourth, results of the robustness checks provide supports for the negative effects of NRE on HDI, life expectancy, and GDPPC. The positive impacts on education are equally accentuated. Interestingly, the stock of NRE resources seems to exert significant impacts at the regional level. Fifth, regarding the control variables, foreign direct investment (FDI) and government expenditure are found to improve QOL while carbon emission (CO_2), inflation (INFL), and population (POP) exacerbate it.

On the policy fronts, there is a need for the government in the SSA region nationally and regionally to embark on measures that will discourage the consumption of non-renewable energy. This can be achieved by increasing efforts in making renewable energy more accessible, cheaper, and affordable as a perfect substitute for NRE. Advancing in technology seems inevitable if the region must overcome the current devastating state of life. More importantly, the choice of technology looks more promising for the regions within the SSA to achieve more efficient and cleaner energy on the one hand, and a viable means of achieving energy production in commercial quantity for the countries that are presently marginalized from the global oil commodity markets on the other hand. Worthy of note for future research is the impact of renewable energies on QOL in order to unravel if embracing renewable means of energy consumption can actually salvage the region from the incessant deteriorating state of life.

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