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Pollutant emissions, energy use and real output in Sub-Saharan Africa (SSA) countries

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Abstract

Industrialisation is pivotal to growth sustainability and this requires intense energy use that may invariably trigger pollutant emissions thereby necessitating some evidence-based policy concerns. This study therefore examines the dynamic connection among pollutant emission, energy use and real output per capita in SSA. Owing to cross-sectional dependence, the Prais-Winsten model with panel-corrected standard error (PCSE) alongside the panel spatial correlation consistent (PSCC) approach is applied and key findings are established. First, the EKC hypothesis holds and this is striking for both oil-rich and oil-poor SSA countries. Second, energy use induces pollutant emissions in oil-rich SSA countries but not in oil-poor SSA countries. Third, pollutant emissions and energy use are real output per capita-enhancing in SSA generally and in oil-poor countries. Thus, policy measures to safeguard efficient optimisation of energy use in ensuring a balance as well as developing SSA's rich renewable energy sources is imperative for long-run growth.

Keywords: Pollutant emissions; Energy use; Real output; Oil-rich SSA countries; Oil-poor SSA countries; Prais-Winsten model

JEL classification: C33; O13; O50; Q43

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1. Introduction

Sub-Saharan Africa's real growth and energy use per capita averages 3.0% and 612 kW h respectively (UNEP, 2017). Policymakers within and outside the region considered these statistics very low to engender sustainable real GDP per capita growth in taking a significant number of the population out of the current worrisome poverty trap (UNEP, 2017). This has been a major policy concern especially considering recent global attention on the need for environmental sustainability via reduced pollution emission in the production process (Pal & Mitrab, 2017; Salmanzadeh-Meydani & Ghomi, 2019). While technological advancement is still low in the region, the source of energy for production process is seen to have serious policy implications for pollution emission (Ang, 2008). Thus, an empirical strategy to unravel the dynamic connection among energy use, pollutant emission and real output capita is considered plausible for policy advisory in the region's oil-rich and oil-poor countries. Currently, global warming and climate change are "twin evils" becoming the greatest threats to human existence and survival in recent times (Acheampong, 2018; Adedoyin, Gumede, Bekun, Etokakpan, & Balsalobre-Lorente, 2020). However, pollution emissions have been identified as the primary source of global warming and climate change and this has attracted global concerns with respect to policies and programmes for mitigating pollution emissions (Adedoyin et al., 2020).

Similarly, it is estimated that the damage attributed to climate change as a result of pollution emission is about 5.0% of global GDP each year going forward and any delay of action will cause a climb of the statistics to 20.0% of GDP (Acheampong, 2018). It is therefore imperative to curb the current trend of pollution emissions globally but this invariably necessitate a reduction in energy use thus threating current global growth trajectories as energy is a crucial production input. These conflicting issues make policies and programmes focusing on spurring growth, energy use and pollution emissions to be at variance with each other (Acheampong, 2018; Nathaniel & Adeleye, 2021; Okoye et al., 2021).

The literature is replete with mixed and imprecise empirical results around four strands of literature. The first are studies focusing on the link between economic growth and emissions (Adeel-Farooq, Raji, & Adeleye, 2020; Ardakani & Seyedaliakbar, 2019; Hanif, Raza, Gago-de-Santos, & Abbas, 2019; Munir, Lean, & Smyth, 2020; Parker & Bhatti, 2020; Yazdi & Dariani, 2019) testing the existence of the Environmental Kuznets Curve (EKC) hypothesis, the second strands focussed on the link between energy consumption and real output (Bekun, Emir, & Sarkodie, 2019; Eluwole, Akadiri, Alola, & Etokakpan, 2020; Nathaniel, Barua, Hussain, & Adeleye, 2020; Rahman & Velayutham, 2020; Salmanzadeh-Meydani & Ghomi, 2019; Soytas & Sari, 2006), the third strand of literature are on dynamic relationship among energy consumption, emission and economic growth (Adeel-Farooq et al., 2020; Ang, 2008; Chontanawat, 2020; Hdom & Fuinhas, 2020; Nepal & Paija, 2019; Mikayilov, Galeotti, & Hasanov, 2018; Mensah et al., 2019; Acheampong, 2018; Pal & Mitrab, 2017; Esso & Keho, 2016; Jafari, Othman, & Nor, 2012) and lastly, on the relationship between energy consumption and pollution emissions (Eluwole et al., 2020; Khan, Khan, & Rehan, 2020; Pandey, Dogan, & Taskin, 2020).

A cursory look at the literature showed that most studies that combined energy consumption, real output and emission adopted granger causality approach only to test the causality among the three variables. But, Acheampong (2018) argued on the need to combine two of the strands of literature (energy consumption and economic growth dynamics as well as energy consumption, economic growth and pollution emissions) in a proper empirical specification cum analysis as excluding any of the two will be missing important policy intuition in their dynamic connections.

Ozturk and Saygin (2020) also pointed out that the behaviour of the relationship differs across countries. Surprisingly with the plethora of studies on these four strands, there is still dearth of studies especially in a panel of Sub-Saharan African countries examining the two strands in a single study with a view to gauging specific policy advisory. Thus, this study bridges this gap by focusing on examining these two strands of literature to unravel evidence-based policy advisory for Sub-Saharan Africa countries.

A number of policy issues can be inferred considering the current socio-economic statistics in the region. For instance, about 634 million people representing approximately 53% of the population have no access to energy in the region, average per capita GDP is around $1,596 with biomass accounting for more than 80% of the population's access to energy, and around 40% of the population are in poverty (representing roughly 66% of global extreme poor population) amidst fragile growth trajectories (UNEP, 2017). Unfortunately, the region has diverse sources of unutilised abundance of renewable energy such as solar (10 TW), hydro (350 GW), wind (110 GW) and geothermal (15 GW). The current investment per annum to the energy sector is around $8 billion whereas the region needs roughly $43 billion investment annually from now till 2030–2040 (UNEP, 2017).

Consequently, the study focusses on drawing policy intuition from a more specific dimension by disaggregating Sub-Saharan Africa (SSA) into oil-rich and oil-poor countries. This is because energy generation and consumption patterns differ between the oil-rich and oil-poor SSA countries (Adedoyin et al., 2020). Also, growth trajectories and the production complexities differ in these two categories in informing policy advisory. The rest of the study is as follows: Section 2 reviews the literature; sections 3 and 4 focus on the methodology and empirical analysis respectively while section 5 concludes the paper with policy directions.

2. Literature review

From policy advisory perspective, the connection among energy use, pollutant emissions and real output growth has remained the core of several empirical studies to engender evidence-based policy direction over the years. However, depending on the scope of research, variables incorporated into the model(s), and estimation techniques deployed, the outcomes remain contentious and debatable. Hence, without claiming to be exhaustive, an attempt is made to review some recent studies on the interwoven nexus of emissions, real output per capita and energy use. The empirical literature is awash with diverse results for both panel data (Awodumi & Adewuyi, 2020; Nathaniel et al., 2020; Parker & Bhatti, 2020; Wang & Wang, 2020; Adedoyin et al., 2020; Rahman & Velayutham, 2020; Qisheng, Shuwang, Pengcheng, & Lei, 2020; Munir et al., 2020; Eluwole et al., 2020; Acheampong, 2018) and country specific (Hdom & Fuinhas, 2020; Khan et al., 2020; Mikayilov et al., 2018; Ozturk & Saygin, 2020; Pal & Mitrab, 2017; Salmanzadeh-Meydani & Ghomi, 2019; Jafari et al., 2012; Ang, 2008; Soytas & Sari, 2006) studies. Table 1 provides a summary of these studies with their respective scope, estimation techniques and empirical findings.

From Table 1, it is clear that the literature has not given ample attention to disaggregating SSA into oil-rich and oil-poor in gauging the empirical connection among energy use, pollution emission and per capita output. We found this disaggregation interesting as the sources of energy is crucial for growth and environmental sustainability. Thus, the main thrust of this study is to pay attention to these two subgroups for policy advisory.

Table 1
Summary of carbon emissions, economic growth and energy use (EU) studies.

S/No.	Author(s)	Technique(s)	Outcomes
1	Awodumi and Adewuyi (2020) Top 10 oil-producing economies, Africa, 1980–2015	NARDL	Asymmetric effect of EU on EG and CE
2	Nathaniel et al. (2020) 15 African countries, 1990–2014	FGLS, PCSE, GMM	EU has a positive effect on EG; CE has a negative lag effect on EG.
3	Khan et al. (2020) Pakistan, 1965–2015	ARDL	EG and EU significantly contribute to emissions in the long- and short-run.
4	Parker and Bhatti (2020) 14 Asian countries, 1971–2017	Sequential Method	EG is the crucial driver of CE, but the behaviour is not uniform across countries.
5	Wang and Wang (2020) 186 countries, 1990–2014	Decoupling index model and the decomposition approach	Effects of energy transition on decoupling EG from CE vary at the global and national levels.
6	Ozturk and Saygin (2020) Turkey, 1974–2016	ARDL, T-Y Causality	Positive and bidirectional causality between EG and CE.
7	Adedoyin et al. (2020) BRICS, 1990–2014	PMG-ARDL	Coal rents have a significant but negative impact on carbon emissions.
8	Rahman and Velayutham (2020) 5 Asian countries, 1990–2014	Panel Cointegration, DOLS, FMOLS, D-H Causality	Positive impact of REN and NRE on EG.
9	Qisheng et al. (2020) 810 China Municipals, 2005–2015	Probit Model	Increase in EG, EU, and CE significantly increase the promotion probability of municipal party secretaries.
10	Munir et al. (2020) ASEAN, 1980–2016	CSD, Granger Causality	EKC hypothesis holds, various causal relations among the countries
11	Eluwole et al. (2020) 37 Developed countries, 1995–2014	Panel ARDL Techniques	EG, EU, tourism and FDI are significant determinants of environmental degradation.

Table 1 (*Continued*)

S/No.	Author(s)	Technique(s)	Outcomes
12	Dogan, Tzeremes, and Altinoz (2020) 17 African countries, 1971–2014	Quantile Analysis	Strong causalities between the variables in the middle-lower, middle-upper and middle quantiles.
13	Danish and Ulucak (2020) BRICS, 1992–2014	CUP-FM; CUP-BC	REN and NRE exhibit asymmetric impact on green growth.
14	Acheampong (2018) 116 countries, 1990–2016	PVAR, GMM	CE, EU, and EG exhibit varying interactions on the global sample and at regional levels.
15	Esso and Keho (2016) 12 African Countries, 1971–2010	Bounds Cointegration, Granger Causality	Mixed causal relations across countries. But in the long-run, EC and EG cause CE to rise.
16	Ahmad et al. (2019) 30 Chinese Provinces, 2000–2016	SIRPAT Model	Construction sector-augmented EKC exists.
17	Ardakani and Seyedaliakbar (2019) MENA, 1995–2014	Multivariate Linear Regression	EKC hypothesis holds.
18	Bekun et al. (2019) South Africa, 1960–2016	Bounds Cointegration; Granger Causality	Unidirectional causality from EU to EG; energy-led growth hypothesis; inverted U-shaped pattern between EU and EG in the long run.
19	Chontanawat (2020) ASEAN, 1971–2015	Cointegration and Causality Models	Long-run relationship and there is causality among EC, EG, and CE.
20	Adeel-Farooq et al. (2020) ASEAN, 1985–2012	MG, PMG	EKC hypothesis holds. EG causes CE to decrease while EU has deteriorating environmental effect.
21	Nepal and Paija (2019) Nepal, 1975–2013	Augmented VAR	Long-run unidirectional Granger causality from EG to EU, and a unidirectional Granger causality from CE to EG.
22	Hdom and Fuinhas (2020) Brazil, 1975–2016	FMOLS; DOLS	EG has negative effects on CE while CE exhibit positive impact EG.
23	Hanif et al. (2019) 15 Asian Countries, 1990–2013	ARDL	EG leads to increase in CE, and that fossil fuel engenders environmental deterioration.

Table 1 (*Continued*)

S/No.	Author(s)	Technique(s)	Outcomes
24	Rahman, Saidi, and Mbarek (2020) 5 Asian Countries, 1990–2017	Panel Cointegration	CE negatively affect EG and Granger causality results show bidirectional causality between EG and CE.
25	Zaman, Shahbaz, Loganathan, and Raza (2016) Panel of 3 diversified regions, 2005–2015	PCA	EKC evidence; EC induces CE.
26	Yazdi and Dariani (2019) Asia, 1980–2014	PMG; Panel Cointegration	Bidirectional causal relationship exists between EG and CE.
27	Sharif, Raza, Ozturk, and Afshan (2019) 74 Countries,	FMOLS; Panel Cointegration	NRE has a positive effect on ED; RE has a negative impact on ED.
28	Mikayilov et al. (2018) Azerbaijan, 1992–2013	Cointegration Analysis	No EKC evidence; EG has a positive impact on CE in the long-run.
29	Pandey et al. (2020) Asia, 1971–2014	SUR	EC increases ED, and the EKC hypothesis is validated for only the supply-side analysis.
30	Mensah et al. (2019) 22 African Countries, 1990–2015	PMG	Long- and short-run causal relations between EC and EG and between EC and CE.

Table 1 (*Continued*)

S/No.	Author(s)	Technique(s)	Outcomes
31	Soytas and Sari (2006) China, 1971–2002	T-Y, Causality, and IRF	No causal relation between EG and EU.
32	Ang (2008) Malaysia, 1971–1999	VECM	CE and EU are positively related to output in the long-run; strong causality from EG to EU in the short-run and long-run.
33	Jafari et al. (2012) Indonesia, 1971–2007	T-Y, Causality	No causal relation between EG, EU, and CE.
34	Pal and Mitrab (2017) India and China, 1971–2012	ARDL	Short-run effect of EU on CE; N-shaped relationship between CE and EG which is a departure from the EKC hypothesis.
35	Salmanzadeh-Meydani and Ghomi (2019) Iran, 1975–2011	VAR	Bi-directional long-run causality between ELC and EG and a unidirectional long-run causality from ELC to CS

Notes: CE = carbon emissions; EU = energy use; EG = economic growth; ELC = electricity consumption; CS = capital stock; T-Y = Toda-Yamamoto; D-H = Dumitrescu-Hurlin; DOLS = dynamic ordinary least squares; FMOLS = fully modified ordinary least squares; ASEAN = Association of Southeast Asian Nations; REN = renewable energy; NRE = non-renewable energy; BRICS = Brazil, Russia, India, China, South Africa; MG = mean group; PMG-ARDL = pooled mean group-autoregressive distributed lag model; ARDL = autoregressive distributed lag model; NARDL = nonlinear autoregressive distributed lag model; PCSE = panel corrected standard errors; FGLS = feasible generalised least squares; GMM = generalised method of moments; FDI = foreign direct investment; CUP-FM = continuously updated fully modified; CUP-BC = continuously updated bias-corrected; SIRPAT = Stochastic Impacts by Regression on Population, Affluence, and Technology; EKC = environmental Kuznets curve; VAR = vector autoregressive; VECM: vector error correction model; PCA = principal component analysis; ED = environmental degradation; SUR = seemingly unrelated regression; IRF = impulse response function.
Source: Authors' Compilation.

3. Method

3.1. Models and variables

In gauging policy direction via evidence-based empirical strategy on the connection among energy use, pollutant emission and real output per capita, several theoretical and empirical strategies exist. However, Grossman and Krueger (1991) Environmental Kuznets Curve (EKC) provided earlier theoretical underpinning for modelling per capita GDP and the environment. But, a number of empirical modifications have ensued over the years. Considering extensively the empirical strategies on the various determinants of pollution emissions, our empirical strategy is guided by harnessing and harmonising the various drivers as espoused from the specifications by Adeel-Farooq et al. (2020); Awodumi and Adewuyi (2020); Eluwole et al. (2020); Ahmad, Zhao, and Li (2019); Ardakani and Seyedaliakbar (2019); Hanif et al. (2019); Mikayilov et al. (2018) and Pal and Mitrab (2017). Since the EKC proposes that indicators of environmental degradation first rise, and then fall with increasing income per capita, model 1 is specified as:

$$\begin{aligned} PEM_{it} = \theta_0 + \theta_1 gY_{it} + \theta_2 (gY_{it})^2 + \theta_3 ENGY_{it} + \theta_4 GFCF_{it} + \theta_5 FDI_{it} + \theta_6 OPENX_{it} \\ + \theta_7 POPG_{it} + \varepsilon_{it} \end{aligned} \tag{1}$$

Where; *PEM* = pollution emissions represented by carbon emission per capita; *gY* = real output per capita; *ENGY* = non-renewable energy use per capita, *GFCF* = gross capital formation as a ratio of GDP, *POPG* = population growth , *FDI* = foreign direct investment inflow as share of GDP. This is included because FDI inflows to sub-Saharan Africa are resources seeking and due to SSA environmental regulatory laxity and low demand for quality life, multinational companies mostly shift their production plants so as not to internalise emission abatement into their production function. *OPENX* = trade openness as trade flows via dumping may affect the environment in SSA.

To address one of the core objectives of the study, Eq. [1] assumes homogeneity for the parameters θ_1, and θ_2 which depend neither on a specific country nor on the time period. It is assumed that all countries take on the same shape of the functional relation of the pollutant-output paradox. More importantly, Eq. [1] allows for testing the various forms of pollutant-output relationships *viz*: (i) $\theta_1 < 0, \theta_2 > 0$ reveals a U-shaped relationship; (ii) $\theta_1 > 0, \theta_2 < 0$ reveals an inverse U-shaped connection, representing the EKC. The growth turning point of this curve is computed by $\hat{\tau} = \exp\left(0.5^{\hat{\theta}_1/\hat{\theta}_2}\right)$; (iii) $\theta_1 > 0, \theta_2 > 0$ reveals a monotonically increasing linear relationship; (vi) $\theta_1 < 0, \theta_2 < 0$ reveals a monotonically decreasing linear relationship; and (vii) $\theta_1 = 0, \theta_2 = 0$ reveals a level relationship. In general, the turning point is when the first derivative of Eq. [1] with respect to real output is equated to zero. Therefore, to ensure that this turning point is within the minimum and maximum values of real output that is, within the observed range of the data, the real output per capita variable is estimated in its *level* form while other variables are transformed into their natural logarithms with the exception of the population growth rate.

On energy use and real output per capita dynamics, the existing empirical specifications are guided by both production function approach and growth theories. Thus, taking a comprehensive look at the several empirical strategies, our model follows the works of Mensah et al. (2019); Adedoyin et al. (2020); Awodumi and Adewuyi (2020); Acheampong (2018); Esso and Keho (2016); Ang (2008). Thus, model 2 is specified as:

Table 2
Variables description and expectations.

Variables	Definition	Model 1	Model 2
PEM	Proxied by CO2 emissions (metric tons per capita)	NA	+
gY	Real GDP per capita (constant 2010 US$)	+	NA
ENGY	Energy use (kg of oil equivalent per capita)	+	+
DCB	Domestic credit provided by banks (% of GDP)		+
POPG	Population growth (annual %)	+	+
FDI	Foreign direct investment, net inflows (BoP, current US$)	+	+
OPENX	Trade (% of GDP)	+	+
GFCF	Gross fixed capital formation (% of GDP)	+	+
HUM	Proxied by School enrolment, primary (% gross)		+

Source: Authors' Compilations from World Bank (2020) World Development Indicators.

$$gY_{it} = \gamma_0 + \gamma_1 PEM_{it} + \gamma_2 GFCF_{it} + \gamma_3 ENGY_{it} + \gamma_4 HUM_{it} + \gamma_5 FDI_{it} + \gamma_6 OPENX_{it} + \gamma_7 POPG_{it} + \gamma_8 DCB_{it} + \mu_{it} \quad (2)$$

Where; *HUM* = captures human capital (enrolment rate), *DCB* = domestic credit provided by banks. The study employs an unbalanced panel data of 19 Sub-Saharan African countries classified into 14 oil-rich[1] and 5 oil-poor[2] countries from 1980 to 2019. Hence, to estimate Eqs. [1] and [2], the models are first estimated for the aggregate sample thereafter the countries in the sample are classified into oil-rich and oil-poor countries. Table 2 details the variables used in both models and expected signs.

3.2. *Estimation techniques*

Before engaging the econometric analyses, it becomes imperative to subject the data to some pre-estimation checks such as (1) cross-sectional dependence, (2) stationarity and (3) cointegration tests. Failure to control for cross-sectional dependence (CSD) can result in biased estimates due to high dependence across countries (Pesaran, 2004, 2015). The CSD test is suited for both balanced and unbalanced data. The null hypothesis is either strict cross-sectional independence (Pesaran, 2004) or weak cross-sectional dependence (Pesaran, 2015). In the event of cross-sectional dependence in the data, the study applies the *t*-test for unit roots in heterogeneous panels with cross-section dependence, proposed by Pesaran (2004)[3] . The null hypothesis which assumes that all series are non-stationary removes dependence across the panels, and the regressions are augmented with the cross-section averages of lagged levels and first-differences of the individual series using the augmented Dickey-Fuller approach (CADF). Correspondingly, the second-generation Westerlund (2005) cointegration test suited for heterogeneous and cross-sectionally dependent panels is applied.

In the event of cross-sectional dependence in the data and cointegration among the variables, the Prais-Winsten regression model with panel-corrected standard errors (PCSE) which also controls

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[1] Angola, Botswana, Cameroon, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Gabon, Ghana, Mozambique, Nigeria, South Africa, Tanzania, Zambia, Zimbabwe.

[2] Benin, Kenya, Mauritius, Senegal, Togo.

[3] Due to the unbalanced nature of the sample coupled with several missing observations, we were unable to apply the cross-sectionally Im, Pesaran and Shin (IPS, 2003) test.

for heteroscedasticity and serial correlation is used to estimate Eqs. [1] and [2]. Since we used 37 observations for 19 SSA countries, the first-order autocorrelation, $AR(1)$ within panels is controlled for in addition to controlling for time-specific disturbances. For robustness checks and to observe the consistency of the results, we deploy the panel spatial correlation consistent (PSCC) standard errors using a period lag of the regressors to control for reverse causality and endogeneity. This estimator uses the Driscoll and Kraay (1998) robust standard errors technique and corrects the standard errors of the coefficient estimates for possible dependence (Cameron & Trivedi, 2005; Hoechle, 2006). The underlying algorithm routines the OLS/WLS[4] and fixed effects (within) regression and computes spatial correlation consistent (PSCC) standard errors for linear panel models.

4. Results and discussions

This section presents empirical findings and raises the corresponding evidence-based policy implications on the connection among energy use, pollutant emissions and real output per capita. Analyses begin with pre-estimations results followed by estimations of model 1 for the full and sub-samples, and thereafter estimation of model 2. Both results in Tables 6 and 7 incorporate robustness checks and discussions are taken in terms.

4.1. Summary statistics and correlation analysis

The summary statistics of the interest variables that characterize the relationship between energy use, emissions and real aggregate output in the trichotomies of the selected SSA countries within the sample period is presented in Table 3. Comparing the mean value of emissions (*PEM*), per capita output (*gY*) and energy use (*ENGY*) within the full sample, oil-rich and oil-poor sub-classifications, we observe the following: *PEM*, gY and *ENGY* have mean values 1.23, 2439 and 682.3 respectively in the full sample, 1.44, 2670.11 and 770.45 for oil-rich countries, 0.66, 1802.07 and 437, respectively in the oil-poor countries.

More volatile, are carbon emissions in the oil-rich countries with an average value of 1.44 relative to the full sample (1.23) and oil-poor countries (0.66). This means that on average, more pollutions due to energy generation is experienced in the oil-producing countries than in their non-oil producing counterparts. Income per head across the trio follows a similar pattern. On average, per capita income is highest in the oil-rich (US$2670.11) and lowest in oil-poor countries (US$1802.07). In the same vein, energy use per capita in the oil-rich countries are higher on average (with an average value of 770.45 relative to oil-poor countries with a mean value of 437). For the rest of the variables, their statistics are as shown in Table 3.

The pairwise correlation matrix displayed in Table 4 shows the strength of statistical relationships among the variables using their natural logarithmic transformation. Cursory observation shows that with the exception of *POPG* which shows a negative but statistically significant association with emissions at the 1% level, others exhibit positive and statistically significant relationships at the 1% level. In other words, higher levels of income, domestic credit, foreign investment, trade, capital availability and education can contribute to increased carbon emissions which pollute or degrade the environment. Relative correlation coefficients among the regressors

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[4] Weighted least squares.

Table 3
Summary statistics.

Variables	PEM	gY	ENGY	DCB	POPG	FDI	OPENX	GFCF	HUM
Full Sample									
Mean	1.233	2439.051	682.262	19.679	2.634	5.49E + 08	71.526	21.711	95.928
Std. Dev.	2.152	2693.191	591.072	17.570	0.782	1.40E+09	29.268	9.742	20.080
Minimum	0.008	164.192	208.123	0.449	−0.222	−7.12E+09	6.320	0.000	43.152
Maximum	9.979	12724.890	3129.079	106.260	4.425	1.00E+10	165.646	89.386	148.185
Oil-Rich Countries									
Mean	1.439	2670.112	770.445	16.557	2.691	7.04E+08	70.195	22.619	96.971
Std. Dev.	2.429	2848.197	656.566	15.678	0.713	1.60E+09	30.205	11.168	19.101
Minimum	0.008	164.192	226.984	0.449	−0.222	−7.12E+09	6.320	0.000	53.374
Maximum	9.979	12724.890	3129.079	84.052	4.425	1.00E+10	165.646	89.386	148.185
Oil-Poor Countries									
Mean	0.657	1802.072	436.861	27.647	2.474	1.17E+08	74.757	19.549	93.407
Std. Dev.	0.801	2088.215	202.011	19.561	0.933	2.21E+08	26.659	4.184	22.122
Minimum	0.112	445.264	208.123	4.833	0.069	−4.63E+07	37.700	8.748	43.152
Maximum	3.442	9833.613	1111.422	106.260	3.865	1.45E+09	137.112	31.277	132.467

Notes: 5.49E + 08 = 549,000,000.00; CO2PC = carbon emissions per capita; PC = per capita GDP; ENU = energy use per capita; DCB = domestic credit provided by banks; POPG = population growth rate; FDI = net inflows of foreign direct investment; TR = trade openness; GFCF = gross fixed capital formation; HUM = human capital proxied by primary school enrolment.
Source: Authors' Computations.

Table 4
Pairwise correlation analysis.

Variables	lnPEM	lngY	lnENGY	lnDCB	POPG	lnFDI	lnOPENX	lnGFCF	LnHUM
lnPEM	1.000								
lngY	0.887***	1.000							
lnENGY	0.798***	0.698***	1.000						
lnDCB	0.56***	0.419***	0.391***	1.000					
POPG	−0.352***	−0.251***	−0.343***	−0.425***	1.000				
lnFDI	0.191***	0.229***	0.252***	−0.012	−0.025	1.000			
lnOPENX	0.247***	0.357***	0.065	0.274***	−0.177***	−0.015	1.000		
lnGFCF	0.273***	0.376***	0.214***	0.042	0.077*	0.215***	0.135***	1.000	
lnHUM	0.411***	0.425***	0.458***	0.162***	−0.169***	0.22***	0.284***	0.387***	1.000

Notes: ***, and * denote statistical significance at the 1% and 10% levels, respectively; ln = natural logarithm; PEM = pollutant emissions; gY = per capita GDP; ENGY = energy use per capita; DCB = domestic credit provided by banks; POPG = population growth rate; FDI = net inflows of foreign direct investment; OPENX = trade openness, GFCF = gross fixed capital formation; HUM = human capital proxied by primary school enrolment.
Source: Authors' Computations.

show that none exert a linear dependency on another as no coefficient exceed 0.75, hence averting the problem of multicollinearity.

4.2. Cross-sectional dependence (CSD), unit root and cointegration test results

Testing for the presence of cross-sectional dependence among the chosen variables as displayed in Table 5 shows a statistically significant outcome for all variables at the 1 percent level. Hence,

Table 5
Cross-sectional dependence, unit root and cointegration tests.

Variable	CSD-test	CADF Panel Unit Root Test			
		Level	1st Diff.	Decision	Panel Cointegration Test
lnPEM	7.027***	−1.442	−4.503***	*I*(1)	Model 1: No Cross-sectional Means = −1.942**
lngY	18.701***	1.738	−7.365***	*I*(1)	
lnENGY	11.77***	−0.862	−10.089***	*I*(1)	
lnDCB	18.379***	−0.645	−11.328***	*I*(1)	
POPG	14.329***	−4.183***	N/A	*I*(0)	Model 2: No Cross-sectional Means, Trend = −1.956**
lnFDI	44.93***	−3.770***	N/A	*I*(0)	
lnOPENX	4.812***	0.034	−8.634***	*I*(1)	
lnGFCF	6.399***	−1.003***	−10.022***	*I*(1)	
lnHUM	11.774***	−1.774	−5.640***	*I*(1)	

Notes: *** and ** denote statistical significance at the 1% and 5% levels, respectively; ln = natural logarithm; PEM = carbon emissions per capita; gY = per capita GDP; ENGY = energy use per capita; DCB = domestic credit provided by banks; POPG = population growth rate; FDI = net inflows of foreign direct investment; OPENX = trade openness; GFCF = gross fixed capital formation; HUM = human capital proxied by primary school enrolment.; N/A = not applicable; CADF = cross-sectional augmented Dickey-Fuller.
Source: Authors' Computations.

the hypothesis of no cross-sectional dependence is rejected. Therefore, in the analysis that follows, methods that control and correct for the presence of CSD is deployed.

Upon confirmation of the presence of CSD, the CADF panel unit root test is undertaken to check for the presence or otherwise of unit root in the variables. Findings shown in the middle panel of Table 5 reveal that *PEM*, *gY*, *ENGY*, *DCB*, *OPENX*, *GFCF* and *HUM* are all integrated of the first order, that is, they are *I(1)*. *POPG* and *FDI* on the other hand do not contain a unit root; they are *I(0)*. Next, the Westerlund (2005) panel cointegration test accounting for Cross-sectional dependence is used to test for long-run relationship. The outcomes shown in the right panel of Table 5 rejects the null hypothesis no panel cointegrating relationship at the 5% level for models 1 and 2 respectively. Hence, for both models, all variables experience a recovery in the long-run after temporary short-run distortions.

4.3. Model 1 results - full and sub-samples

Table 6 presents the composite results for model 1. Columns [1], [3], and [5] show the main results using the PCSE technique for the full and sub-samples while the rest columns display the robustness checks using the PSCC techniques. Across all model specifications, per capita income (real output per capita) shows a positive relationship at the 1% significant level with pollutant emissions. The policy implication is that industrial related output growth demands extensive use of energy which is mostly not environmental friendly in both oil-rich and poor countries. Previous studies also supported this evidence (Adeel-Farooq et al., 2020; Adu & Denkyirah, 2018; Amin, Dogan, & Khan, 2020; Murshed, Alam, & Ansarin, 2020; Nathaniel & Adeleye, 2021; Nathaniel et al., 2020). For the core argument of the study, the EKC hypothesis holds since an inverted U-shaped relationship exists between per capita real output[5] and pollutant emissions for the SSA

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[5] The actual negative coefficients for the full and sub-samples with respect to the square of real output are: *Full sample:* −3.19e-08 and −3.93e-08; *Oil-rich countries:* −3.61e-08 and −3.78e-08; *Oil-poor countries:* −5.38e-08 and −5.72e-08, respectively.

Table 6
Results for Model 1 (Dep. Var.: Carbon Emissions, log).

Variables	Full Sample		Oil-rich Countries		Oil-poor Countries	
	PCSE Main [1]	PSCC Robustness [2]	PCSE Main [3]	PSCC Robustness [4]	PCSE Main [5]	PSCC Robustness [6]
gY	0.0006***	0.0006***	0.0006***	0.0006***	0.0008***	0.0009***
	(14.73)	(17.76)	(15.05)	(12.37)	(16.56)	(10.91)
gYSQ	−0.0000***	−0.0000***	−0.0000***	−0.0000***	−0.0000***	−0.0000***
	(−11.08)	(−9.39)	(−12.30)	(−9.83)	(−12.56)	(−11.29)
lnENGY	0.4367***	0.4148***	0.4392***	0.4185***	−0.4270***	−0.4148***
	(6.44)	(5.81)	(5.73)	(3.16)	(−5.28)	(−4.53)
lnDCB	0.3443***	0.3263***	0.2934***	0.2806***	0.0087	−0.0122
	(8.28)	(7.69)	(7.39)	(7.41)	(0.12)	(−0.10)
POPG	−0.0823**	−0.0873**	−0.3565***	−0.3501***	0.1234***	0.1020
	(−2.14)	(−2.68)	(−8.10)	(−6.87)	(2.67)	(1.44)
lnFDI	0.0484***	0.0456***	0.0485***	0.0480**	0.0622***	0.0469**
	(3.07)	(2.84)	(3.05)	(2.22)	(3.82)	(2.14)
lnOPENX	−0.1262**	−0.1070	0.0565	0.0724	0.3862***	0.4005***
	(−2.23)	(−1.42)	(0.92)	(0.72)	(4.74)	(3.80)
Oil-rich	−0.0288	−0.0215				
	(−0.47)	(−0.53)				
Constant	−5.3279***	0.0000	−5.1320***	−4.9548***	−2.4900***	−2.4144***
	(−9.32)	(.)	(−7.75)	(−5.60)	(−4.14)	(−3.95)
EKC Turning Point ($)	9,188.59	8,764.16	8,951.46	8,595.74	9,652.62	9,714.80
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. of Obs.	508	508	360	360	148	148
R-Squared	0.866	0.865	0.911	0.908	0.946	0.952
Wald/F Statistic	4214.72***	257.82***	5179.51***	125.79***	4404.25***	55.55***

Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively; lagged regressors used for PSCC model; ln = natural logarithm; gY = per capita GDP; ENGY = energy use per capita; DCB = domestic credit provided by banks; POPG = population growth rate; FDI = net inflows of foreign direct investment; OPENX = trade openness.
Source: Authors' Computations.

general and sub-samples at the 1% significant level. This shows that at the earlier stages of real output, pollutant emissions increase but as real output increases further, the level of emissions decline (see Fig. 1). All models support the EKC behaviours with a turning point, that is, per capita income levels inducing a rising and declining emissions similar to those found in other empirical studies (Adeel-Farooq et al., 2020; Fonkych & Lemper, 2005; Murshed & Dao, 2020; Song, Zheng, & Tong, 2008; Stern, Common, & Barbier, 1996; Stern, 2004). Restricting discussions to the PCSE results, the turning points are US$9,188.59, US$8,764.16, and US$7,847.99 for the SSA generally, oil-rich, and oil-poor countries, respectively. By implication, most of the countries are still far below the average per capita output threshold required to cause a declining pollution emission in the region at the long-run.

The relationships depicted in Fig. 1 are that pollution is inevitable in the early stages of economic development, but that this will be lessening as the economy reaches a certain turning point. But these findings pose some intrinsic policy risks requiring specific policy advisory in SSA region that currently needs some rising growth trajectories to increase per capita output. This is because dire consequences could occur if SSA decides to overlook environmental pro-

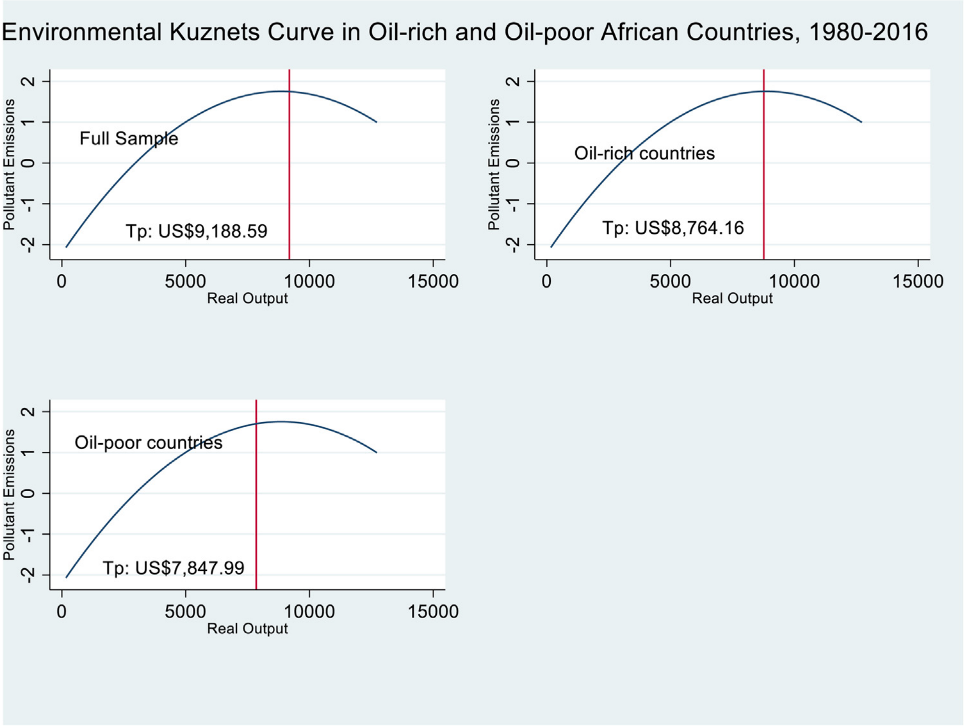

Fig. 1. EKC in Oil-rich and Oil-poor African Countries, 1980–2016. Source: Authors' Computations.

tection by focussing on increasing incomes to abate environmental destruction. It also beholds some pertinent policy concern to ensure emission control without constraining real output per capita. According to Song et al. (2008), three scenarios are possible: (i) the point of irreversible environmental damage may be reached before the turning point for environmental improvement; (ii) a divergent EKC is possible with environmental degradation increasing monotonically with the rise in per capita income; (iii) with per capita income at its peak, environmental protection is achieved.

Energy use shows a statistically significant positive relationship at the 1% level with pollutant emissions such that a percentage change in energy use per capita results in 0.437, 0.439, and −0.427 percent change in pollution for the SSA generally, oil-rich and oil-poor countries, respectively. Currently, SSA relies more on non-renewable energy than renewable source despite expanse opportunity in renewable sources. By implication, this is more striking for oil-rich SSA countries as these countries emitting more pollution due to energy use thereby underscoring lax environmental regulation in energy production and use. For the oil-poor countries, the reverse is the case implying that in regions where energy production is not feasible, cleaner environments are associated with increased energy use. For robustness checks, we estimated Eq. 1 using one period lag of the regressors to correct for endogeneity and reverse causality. The results which are generated from the PSCC technique and as shown in columns [2], [4], and [6] are not significantly different from those of the main analysis.

Table 7
Results for Model 2 (Dep. Var.: gY, log).

Variables	Full Sample		Oil-rich countries		Oil-poor countries	
	PCSE	PSCC	PCSE	PSCC	PCSE	PSCC
	Main [1]	Robustness [2]	Main [3]	Robustness [4]	Main [5]	Robustness [6]
lnPEM	0.5269***	0.6345***	0.6261***	0.6147***	0.8886***	0.9026***
	(23.42)	(26.88)	(19.57)	(17.67)	(20.50)	(12.44)
lnENGY	0.2204***	−0.0645	−0.1867***	−0.1704***	0.5192***	0.5240***
	(3.71)	(−1.24)	(−3.09)	(−2.75)	(6.14)	(3.86)
lnGFCF	0.0352	0.0099***	0.1650***	0.1743***	0.5293***	0.5789**
	(1.11)	(4.27)	(3.26)	(4.42)	(3.96)	(2.32)
lnFDI	0.0030	−0.0076	0.0097	0.0126	−0.0555***	−0.0618*
	(0.56)	(−0.62)	(0.73)	(0.88)	(−3.90)	(−1.96)
lnHUM	0.2044**	0.0297	0.4723***	0.4596**	−0.3488***	−0.3504
	(2.36)	(0.21)	(3.41)	(2.58)	(−3.21)	(−1.68)
lnOPENX	0.1467***	0.3648***	0.2626***	0.2772***	−0.4789***	−0.4893***
	(4.24)	(8.90)	(6.27)	(5.39)	(−5.55)	(−4.21)
Oil-rich	0.0948**	0.1940***				
	(2.28)	(6.10)				
Constant	4.4586***	0.0000	5.0322***	0.0000	7.6967***	7.8248***
	(12.02)	(.)	(6.61)	(.)	(12.86)	(8.81)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. of Obs.	434	434	294	294	140	140
R-Squared	0.994	0.867	0.895	0.897	0.944	0.943
F Statistic		231.989		378.132		251.199

Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively; lagged regressors used for PSCC model; ln = natural logarithm; PEM = carbon emissions per capita; ENGY = energy use per capita; GFCF = gross fixed capital formation; FDI = net inflows of foreign direct investment; HUM = primary school enrolment; OPENX = trade openness.
Source: Authors' Computations.

4.4. Model 2 results - full and sub-samples

Presented in Table 7 are results from the estimation of Eq. [2]. Those for the full sample are shown in columns [1] and [2] while those for the sub-samples are displayed in columns [3] to [6]. For the full ample, pollutant emissions per capita significantly influences real output per capita at the 1% level (Bekun et al., 2019; Liu & Bae, 2018). It indicates that a percentage change in carbon emissions will cause about 0.53 percent rise in aggregate real output. By implication, it underscores much unclean energy inputs in the production process.

Also, energy use per capita shows a positive and statistically significant relationship (at 1 percent) with real output (Cai, Sam, & Chang, 2018; Maji & Sulaiman, 2019). A percentage change in energy use per capita, ceteris paribus, ensures that real output rises by 0.22 percent. This connotes the pivotal role of energy in industrial activities to spur sustainable growth trajectories. The sub-sample analyses also reveal some interesting findings. From the PCSE results, the coefficients of pollutant emissions for both oil-rich and oil-poor countries display positive and statistically significant influence on real output per capita thereby confirming earlier policy intution that production processes in SSA are bedevilled with unclean energy inputs. Thus, the reason for higher emission rates to induce higher per capita out in both oil-rich and oil-poor regions and these two sub-regions need higher per capita out considering the current percentage of the population in poverty.

5. Conclusion and policy implications

Policies focussing on spurring growth, energy use per capita and curbing pollutant emissions are mostly at variance as vast energy is required for industrial expansion that may incentivise emissions. Thus, it is plausible to unravel the dynamic connection among these three important issues for precise policy advisory in SSA's oil-rich and oil-poor countries. While production patterns, energy sources and pollutant emissions differ across oil-rich and oil-poor countries, it is crucial to account for this difference in empirical studies to guide specific policies in the sub-regions. This study therefore examines the dynamic relationships among pollutant emissions, energy use and real output per capita for oil-rich and oil-poor SSA countries for the period 1980−2019. Owing to cross-sectional dependence, the Prais-Winsten model with panel-corrected standard error (PCSE) alongside the panel spatial correlation consistent (PSCC) approach is applied and key findings are established for policy advisory.

First, the EKC hypothesis holds and this is striking for both oil-rich and oil-poor SSA countries. But, the established average per capita output threshold necessary to ensure emissions abatement at the long-run is beyond the current average per capita output of $1596 in the region. The region is classified as one of the poorest regions in the world; hence growth enhancing policies are plausible to spur real output per capita. By implication, the region cannot currently afford policies to put strain on current growth trajectories in order to curtail pollution emissions. The region is endowed with breadth of renewable sources but have not been properly utilised. Therefore, policies should be geared towards promoting and attracting investment into these expanse renewable energy developments in the region for long-run growth. In the meantime, the region can focus on policies to mitigate pollution emission with measures to ensure some balance between growth and the environment.

Second, energy use induces pollutant emissions in oil-rich SSA countries but not in oil-poor SSA countries. This connotes varying source of energy generation and usage across countries in the region. Hence, it calls for policies to ensure strict regulation in the energy production and usage in oil rich countries. Also, because the region is poor and illiteracy rate is high, policies should focus more on awareness campaign to make people more conscious of the hazards of pollution emission during energy use. There is also the need for policies to mitigate emission without affecting the growth enhancing role of energy use in the region. Third, pollutant emissions and energy use are real output per capita enhancing in SSA generally and in oil-poor countries. This is an indication of much use of unclean energy inputs in the production process due to rising demand for industrial expansion in the region. Thus, the need for policy measures to spur carbon trading and ensure efficient optimisation of energy use is imperative for sustainable growth.

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