Economic growth, international trade, and environmental degradation in Sub-Saharan Africa

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Abstract

Purpose – This study investigates the relationship between economic growth, international trade, and environmental degradation in Sub-Saharan Africa (SSA), focusing on the validity of the environmental Kuznets hypothesis (EKC), the pollution havens hypothesis (PHH), and the factor endowment hypothesis (FEH).

Design/methodology/approach – The study uses annual data for 41 SSA countries between 1990 and 2017 and employs the bias-corrected least square dummy variable (LSDVC) estimation techniques. Environmental degradation is indicated by carbon dioxide (CO_2), delicate particulate matter (PM2.5) emissions, and deforestation.

Findings – The results confirm the validity of the EKC hypothesis for PM2.5 emissions and deforestation but not for CO_2 emissions. The results also indicate that international trade reduces deforestation and that both the PHH and FEH are valid for CO_2 emission but not for PM2.5 emissions and deforestation.

Practical implications – In this paper, the authors are able to illustrate that both economic growth and international trade can harm the environment if unchecked. Therefore, the conclusion of this study offers policy options through which SSA countries can achieve desired economic growth goals without affecting environmental quality. The study can be a benchmark for environmental policy in the region.

Originality/value – The authors provide an in-depth discussion of the growth-trade-environmental degradation nexus in SSA. The EKC, PHH, and FEH's validity confirm that economic growth remains a threat to the local natural environment in SSA. Hence, the need for a trade-off between economic growth needs and environmental degradation and understanding where to compromise to achieve SSA's economic development priorities.

Keywords Environmental degradation, Economic growth, Sub-Saharan Africa, Environmental Kuznets curve

Paper type Research paper

1. Introduction

Environmental degradation, defined as air pollution, is the contamination of air with the persistent emission of greenhouse gases (GHGs), fumes or odours and dust into the atmosphere (Stern *et al.*, 1996). Data from the World Resources Institute (2019) suggest that carbon dioxide (CO_2) is the most abundant GHG emitted. Between 1990 and 2018, CO_2 emissions in Sub-Saharan Africa (SSA) have remained less than 5% of global CO_2 emissions (IPCC, 2018). Albeit low, SSA's per capita CO_2 emission, estimated at 3.9 tons per capita, is slightly above the recommended 2.6 tons per capita level (IPCC, 2018). Therefore, the region's emissions growth rate is among the highest globally and if unchecked, SSA countries may turn into significant emitters (Wang and Dong, 2019). However, most SSA countries are low-income countries that lack the required financial resources to mitigate the consequences of environmental degradation. Furthermore, according to Amegah and Agyei-Mensah (2017),

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urban air quality in SSA is deteriorating due to increased concentration of particulate matter in the atmosphere. Data from the Health Effects Institute (2020) suggest that at around 45 µg/m3 annual average exposures in 2019, PM2.5 concentrations in SSA exceeded the WHO-recommended 10 µg/m3. Nigeria experienced the highest PM2.5 exposure at 70.4 µg/m3 in 2019. Lastly, deforestation as a form of environmental degradation involves the loss of a country's natural forested area without afforestation (Joshi and Beck, 2018). According to FAO (2020), over 420 m hectares of forest area have been lost since 1990. Although, the rate of deforestation is gradually declining in other regions, it is increasing in SSA. FAO (2020) suggests that between 2010 and 2020, Africa (to which SSA belongs) had the highest annual net forest loss at around 3.9 m hectares, up from 3.4 m hectares per year lost between 2000 and 2010 and 3.3 m hectares between 1990 and 2000. Deforestation in other regions like South America declined from 5.2 m hectares per year lost between 2000 and 2010 to 2.6 m hectares per year lost between 2010 and 2020. Therefore, the gradual increase in environmental degradation (CO_2 and PM2.5 emission and deforestation) in SSA over the past 3 decades highlights the motivation of this study.

Several factors have been attributed to the increase in environmental degradation. However, empirical evidence has usually highlighted economic growth as a leading factor for increase in environmental degradation. Empirical evidence on the nexus between economic growth and environmental degradation indicates that achieving economic growth is both a cause and solution to environmental degradation. This is explained by the environmental Kuznets curve (EKC) hypothesis, which suggests that at low levels of income, a positive relationship exists between economic growth and environmental degradation. However, environmental degradation starts to decline as more income is attained. Hence beyond a turning point, the nexus follows a negative relationship (Bah *et al.*, 2020). Therefore, the nexus between economic growth and environmental degradation follows an inverted U-shaped curve.

Besides, there is evidence that international trade drives both economic growth and environmental degradation (Asongu *et al.*, 2019). According to Bataka (2021), international trade contributes to economic growth. However, environmental degradation is the opportunity cost for trade-induced economic growth (Bataka, 2021). Therefore, developing countries are willing to lower environmental standards to encourage economic growth. Dinda (2006) suggests that the differences in environmental costs in total production between developed and developing is what pollution-intensive industries target. With free movement of capital amongst countries due to international trade, pollution-intensive industries can quickly shift their activities from the developed countries with strict environmental regulation, which increases the total production costs, to less developed countries with relatively lax environmental regulation, which lower total production costs. This makes less developed countries a haven for pollution-intensive production. This notion is referred to by Cole and Elliott (2003), Antweiler *et al.* (2001), among others, as the "Pollution Havens Hypothesis" (PHH). In addition, Antweiler *et al.* (2001) suggest that countries usually specialise in production based on their relative abundance and endowment of factor inputs. Therefore, because pollution abetment as a factor of production is low in developing countries, this factor endowment attracts pollution-intensive production to developing countries. This is the factor endowment hypothesis (FEH) (Managi *et al.*, 2008). As such, Twerefou *et al.* (2019) suggest that such trade-induced economic growth leads to trade-induced environmental degradation, which originates from differences between the countries' economic growth, factor endowments and environmental regulations. Therefore, the main objective of this study is to examine the empirical relationship between economic growth, international trade and environmental degradation in SSA, focusing on the validity of the EKC, the PHH and the FEH.

SSA has amplified its efforts to spur economic growth over the last 3 decades (Zeufack *et al.*, 2021) with average annual gross domestic product (GDP) growth of 3.5% between 1990 and 2019, which is higher than the global annual average of 2.8% in the same period (World Bank, 2020). Nevertheless, according to Tenaw and Beyene (2021), the downside of rapid economic growth, especially in developing countries like SSA, is environmental degradation (Kong and Khan, 2019). However, Bah *et al.* (2020) suggest that SSA countries can simultaneously continue their efforts to spur economic growth while minimizing environmental damage. Besides, considerable evidence from studies on the relationship between economic growth and environmental degradation in SSA is still inconclusive (Tenaw and Beyene, 2021). Therefore, this study helps us to understand the relationship between economic growth and environmental degradation in SSA, and it is essential in guiding policymakers to design policy options that achieve sustainable economic growth.

2. Literature review

2.1 The EKC hypothesis

Among the earliest studies to examine the economic growth–environmental degradation nexus is Grossman and Krueger (1991), who studied the environmental impacts of the North American Free Trade Agreement (NAFTA). They suggested that the relationship between economic growth and environmental degradation is translated through three effects: scale, technique and composition. According to Nkengfack *et al.* (2019), the scale effect (scale of economic activity) suggests that other factors are constant. An increase in the size of the economy (the scale effect) raises the level of environmental degradation. On the other hand, the technique effect explains the positive impacts of income growth on environmental degradation. This implies that income growth may influence peoples' demand for better environmental standards and protection (Cole and Elliott, 2003). In the presence of the EKC, the technique effect is expected to be negative and significant (Dinda, 2005). Lastly, the composition effect explains how a country's capital and labour structure can affect the country's environment. Given the dynamic structure of the economy and the production structure, changes in the composition of capital and labour used in the production of output will determine whether the composition effect has a positive or negative impact on environment quality (Cherniwchan *et al.*, 2017).

Looking at empirical literature on the EKC hypothesis, Grossman and Krueger (1991) use data from the Global Environmental Monitoring System from several cities in 42 countries between 1977 and 1988. They found evidence for the EKC relationship to exist for sulfur oxide (SO_2) and dark matter with a turning point estimated to be between USD4,000–USD6,000 per capita GDP. In addition, Cropper and Griffiths (1994), Cole *et al.* (1997) and Barbier (1997) are among the early studies that provide evidence for the EKC hypothesis. For SSA, Ntow-Gyamfi *et al.* (2020), Bah *et al.* (2020), Tenaw and Beyene (2021), Asongu and Odhiambo (2020), Sun *et al.* (2020), Nkengfack *et al.* (2019), Abid (2017), Ssali *et al.* (2019), and Ogundari *et al.* (2017) confirm the validity of the EKC hypothesis using different environmental degradation indicators. On the contrary, Beyene and Kotosz (2020) find a bell-shaped relationship and conclude no evidence of the EKC in East Africa. Similarly, Ogundari *et al.* (2017), Ojewumi and Akinlo (2017), Amuakwa-Mensah and Adom (2017) and Zerbo (2017) fail to confirm the validity of the EKC hypothesis for CO_2 in SSA.

2.2 International trade, the PHH and FEH

From the literature, international trade can induce economic growth, and trade-induced economic growth directly affects environmental degradation (Cherniwchan *et al.*, 2017).

This means that international trade may fundamentally affect how scale, technique and composition effects determine environmental degradation (Bataka, 2021). Holding other factors constant, income gains arising from an opportunity to trade can positively induce the scale of economic activities through increased production to satisfy the newly opened markets, which will most definitely increase environmental degradation. Trade-induced economic growth can also be regarded as "trade-induced scale effect" (Cole, 2004). However, economic growth may encourage cleaner production techniques and provide funds for public expenditure in environmental abatement technologies leading to a cleaner environment (Dinda, 2005). This is regarded as the "trade-induced technique effect", which exhibits a negative relationship between economic growth and environmental degradation (Cole and Elliott, 2003). As such, Dinda (2006) suggests that the PHH is only possible due to international trade. Hence, trade has indirect effects on environmental degradation through the inflow of pollution-intensive industries into countries with relatively lenient environmental regulations.

Furthermore, when an economy participates in the global trade system, free movement of factor inputs may also change the relative capital and labour structure that represents the composition effect. Antweiler *et al.* (2001) suggest that free movement of factors of production means that production goes to places where resources are abundant. Because resources in developing countries are generally untouched, openness to trade attracts more exploitation and hence more production activities, leading to increased environmental pollution and damage, which explains the FEH (Managi *et al.*, 2008).

Empirical studies such as Antweiler *et al.* (2001), Cole and Elliott (2003), Copeland and Taylor (2003) and Solarin *et al.* (2017) confirm the validity of the PHH and FEH. For SSA, Bataka (2021), Tenaw and Beyene (2021), Twerefou *et al.* (2019), Adams and Opoku (2020), Gulistan *et al.* (2020), Wang and Dong (2019), Sun *et al.* (2020) and Bissoon (2018) are among others that provide empirical evidence on the relationship between international trade and environmental degradation.

3. The model and methodology

3.1 The model

The empirical model adopted in this research starts with environmental degradation as a function of real per capita income as suggested by Antweiler *et al.* (2001). It is written as:

$$ED_{it} = \alpha_i + \theta_t + \beta_1 M_{it} + \beta_2 M_{it}^2 + \varepsilon_{it} \tag{1}$$

where; i and t indicate country and year, respectively, for $i = 1, 2, \ldots\ldots N; t = 1, 2, \ldots\ldots T$. ED_{it} indicates environmental degradation, α denotes country-specific intercepts, θ represents time-specific intercepts, and M represents real per capita income. ε_{it} is the error term that is assumed to be independently and identically distributed (iid). We include the square of real per capita income to allow for diminishing marginal effects (Antweiler *et al.*, 2001). Besides, Nkengfack *et al.* (2019) suggest that both M_{it} and M_{it}^2 capture the scale effect and the technique effects. For the validity of the EKC hypothesis, it is expected that $\beta_1 > 0$ and $\beta_2 < 0$ (Dinda, 2005). We follow Cole and Elliot (2003) to include the composition effect and international trade as well as the interaction terms for the trade-induced income effects and trade-induced composition effects to examine the PHH and FEH, respectively. Other control variables include foreign direct investment (FDI) as suggested by Demena and Afesorgbor (2020), energy consumption as suggested by Kwakwa (2020) and Gulistan *et al.* (2020). Lastly, following Udeagha and Ngepah (2019), we include ratifying the Kyoto Protocol (KPR) to indicate political commitment towards combatting environmental degradation. Therefore, the empirical model becomes

$$LED_{it} = \alpha_i + \theta_t + \beta_1 LM_{it} + \beta_2 LM_{it}^2 + \beta_3 KL_{it} + +\beta_4 TI_{it} + \beta_5 TI * KL_{it} + \beta_6 LTI * M_{it} + \beta_7 LFDI_{it} + \beta_8 KPR + \beta_9 LEU + \varepsilon_{it} \quad (2)$$

where L at the beginning of some variables indicates a natural log. KL_{it} is the capital-labour ratio which is used to indicate the composition effect. TI_{it} represents international trade intensity. Further, following Cole and Elliot (2003), we also use interaction terms of trade intensity and income $(TI * M)_{it}$ to capture the trade-induced income gains as a proxy for the PHH. We also use the interaction term of the trade intensity and the capital-labour ratio $(TI * KL)_{it}$ to capture the trade-induced composition effect which represents the FEH. The control variables include FDI (*FDI*), the ratification of the Kyoto Protocol (*KPR*) and energy consumption (*EU*).

3.2 Description of variables

We use three indicators for environmental degradation. First, we follow Tenaw and Beyene (2021) and Bataka (2021) to use per capita CO_2 emissions *(LCO)* to represent global air pollution. The CO_2 Information Analysis Centre (CDIAC) obtains data from Global Carbon Atlas. Second, we follow Wu (2017) to use the natural log of fine particulate matter (PM2.5) emissions *(LPM)* as a local air pollutant (Schwela, 2012). Finally, we follow Cropper and Griffiths (1994) and Bhattarai and Hammig (2001, 2004) to use the natural log of deforestation *(LFO)* as an indicator of environmental degradation. Deforestation is calculated using

$$FO = \frac{F_{i,t-1} - F_{it}}{F_{i,t-1}} \quad (3)$$

where FO is deforestation, F_{it} and $F_{i,t-1}$ are the total forest area (sq. km) in the current and previous periods, respectively. Data for both *LPM* and *LFO* are obtained from World Bank's World Development Indicators (WDI).

For M_{it} and M_{it}^2 we use real per capita GDP and the square of real per capita GDP as suggested by Nkengfack *et al.* (2019). For KL_{it} the capital-labour ratio for the respective country is used as a proxy of the composition effect (Cole and Elliot, 2003). Data for both *M* and *KL* are obtained from Penn World Tables (PWT). We also use the composite trade intensity (*TI*) measure suggested by Squalli and Wilson (2011). This *TI*-based measure offers a broader consideration in regard to a country's participation in global trade and the country's significance in the global economy because *TI* is adjusted by the share of a country's trade level in relation to the average international trade. TI_{it} is calculated as:

$$TI_{it} = \frac{(X_{it} + I_{it})}{\frac{1}{n}\sum_{j=1}^{n}(X_{jt} + I_{jt})}\left(\frac{(X_{it} + I_{it})}{Y_{it}}\right) \quad (4)$$

where X_{it}, I_{it} and Y_{it} are exports, imports and real GDP, respectively. Also, i denotes a country in SSA and j represents a country's major trading partner. The first part of the equation captures world trade, while the second part represents each county's trade openness. Data from the World Trade Organisation (WTO) is used to compute TI.

For *FDI,* we use FDI inflow, and data are obtained from the World Bank's WDI. For *EU*, we use "fossil fuels energy use (*FFEU*)" as a proxy for energy consumption when *CO* and *PM* are used as the dependent variables. When deforestation is used as the dependent variable, we use "firewood energy use (*FWEU*)" as an energy consumption indicator. This is because fossil fuels are direct emitters of CO_2 and PM2.5, while fuelwood is a direct product of deforestation. Data for *FFEU* are obtained from World Bank's WDI while that of *FWEU* are obtained from UNDATA. Finally, we create a dummy variable *KPR* that takes the value of one from the year in which the SSA country ratified the Kyoto Protocol onwards, otherwise zero.

3.3 Data and methods

For this study, we use annual panel data of 41 SSA countries between 1990 and 2017. As such, the data suggests that ($T = 28$) is less than ($N = 41$). To estimate equation (2), we start with a panel vector autoregressive (VAR) model in the first differences expressed as:

$$Y_{i,t} = \alpha_i + \gamma \Delta Y_{i,t-1} + \beta \Delta X'_{i,t} + \Delta \varepsilon_{it} + d_t \tag{5}$$

where Δ is the first difference operator, $Y_{i,t}$ is a vector of the logs of dependent variables, $X'_{i,t}$ is a vector of the independent variables, ε_{it} is a vector of idiosyncratic errors and d_t is the time dummy. The panel VAR model in the first difference allows us to estimate the underlying dynamic relationships without applying any *a priori* restrictions. In equation (5), the lagged dependent variable on the right-hand side correlates with the new differenced error term, causing a possible simultaneity problem. Besides, the dynamic panel specification in equation (2) implies an endogeneity problem where the independent variable becomes endogenous if it is correlated with the error terms (Baltagi, 2013). This is the called Nickell's bias (Nickell, 1981) which means that the non-zero correlation between the lagged dependent variable and the individual-specific effects render the estimation of equation (2) using traditional panel data estimation approaches (Fixed effects and random effects) biased for data samples with small T regardless of the size of N. However, when N is finite, the variance of the estimates may asymptotically increase, thereby generating considerable bias. As such, several N-consistent estimators such as the instrumental variable (IV) approach by Anderson and Hsiao (1982) and the generalised method of moments (GMM) estimators including the difference GMM by Arellano and Bond (1991) and the system GMM by Arellano and Bover (1995), and Blundell and Bond (1998) are possible alternatives. Albeit versatile, these estimators may suffer distinctive weaknesses. The IV and difference GMM suffer finite-sample bias in panels with small N as well as a weak instruments bias in the presence of highly persistent data (Bruno, 2005b). The system GMM can also be affected by the proliferation bias in case the number of instruments is larger than the number of cross-sectional units (Bruno, 2005b).

Therefore, as time becomes infinite ($T \rightarrow \infty$), the least-squares dummy variable (LSDV) estimator is more consistent (Nickell, 1981). Nevertheless, when $T < 30$, Judson and Owen (1999) show that the LSDV estimator has a bias of up to 20% of the time value coefficient of interest. Kiviet (1995) suggests an asymptotic expansion technique for correcting the bias. The bias-corrected LSDV (LSDVC) is further extended by Judson and Owen (1999), and Bun and Kiviet (2003). Depending on the bias approximation chosen, Bun and Kiviet (2003) demonstrate that the LSDVC estimator can be initialised through three N-consistent estimators (the IV, the difference GMM and the system GMM estimator) in terms of bias and root mean square errors for a balanced panel (Meschi and Vivarelli, 2009). Bruno (2005a, b) further illustrate that that the LSDVC estimator approach can be performed similarly efficiently using unbalanced panel data. According to both root mean squared error and bias criteria, regardless of the initialising estimator and the accuracy of the bias approximation are similar (Bruno, 2005b). Monte Carlo analysis by Bruno (2005b) demonstrates that the LSDVC outperforms other estimators when $T < 30$. Hence, the LSDVC estimation procedure is the most appropriate for this study.

4. Empirical results, findings and discussions

4.1 Descriptive statistics and cross-sectional dependence

Before estimating the models, we look at the descriptive statistics as well as examine the presence of cross-sectional dependence (CSD) following Pesaran (2004). The results are presented along with the descriptive statistics in Table 1. The CSD test statistics for all the variables are significant at 1% level. Therefore, we reject the null hypothesis (H_o) of cross-section independence. The descriptive statistics show that the number of observations varies, with the highest at 1,148 and the lowest at 1,060. We also conduct the correlation test amongst the independent variables, and the correlation matrix is presented in Table 2. Based on the correlation matrix, we can conclude that there is multicollinearity amongst the independent variables.

4.2 Presentation of findings

We estimate equation (2) using the LSDVC estimation, which is initialised by dynamic panel data estimates of the difference GMM by Arellano and Bond (1991) in this case AB. To ensure the robustness of our estimates, we also include the estimates when the LSDVC estimator is initialised by the system GMM by Blundell and Bond (1998) in this case BB and the IV techniques by Anderson and Hsiao (1982) in this case AH. We rely on a recursive correction of

Variables	CSD test statistic	OBS	Mean	SD	MIN	MAX
LCO	35.07***	1,148	1.2526	1.4191	0.5353	2.2861
LFO	45.08***	1,148	10.5046	2.0738	5.8966	14.2878
LPM	46.95***	1,148	3.4885	0.3965	2.6635	4.5439
LM	34.72***	1,148	8.2969	0.4613	7.8658	10.0413
LM^2	7.99***	1,148	16.8714	0.6183	16.5386	19.8931
KL	7.99***	1,120	38431.9553	46647.4119	1,468.5403	296585.1250
TI	128.98***	1,148	0.5165	4.0734	0.0000	69.3345
LFDI	73.00***	1,060	18.2307	2.4139	4.6052	23.0287
LFFEU	20.15***	1,148	1.9321	0.6341	0.4000	4.0602
LFWEU	14.38***	1,148	7.8915	2.1909	1.0886	12.0895
TI*KL	25.53***	1,120	18.0294	0.5577	17.8733	22.7807
LTI*M	54.80***	1,148	6.5018	1.2151	4.4449	11.3870
KPR	124.22***	1,148	0.5000	0.5000	0.0000	1.0000

Note(s): * indicates *p*-values which represent the level of significance, where *** is at 1 percent, ** is at 5 percent and * is at 10 percent level of significance. OBS is the total number of observations, SD is the standard deviation, MIN is the minimum value and MAX is the maximum value

Table 1. CSD test and descriptive statistics of the data used

	LM	LM^2	KL	TI	LFDI	Lffeu	Lfweu	TI*KL	LTI*M	KPR
LM	1									
LM^2	0.691	1								
KL	0.612	0.638	1							
TI	0.182	0.171	0.099	1						
LFDI	0.323	0.265	0.225	0.507	1					
LFFEU	−0.508	−0.415	−0.487	−0.214	−0.110	1				
LFWEU	−0.366	−0.325	−0.433	0.123	0.301	0.501	1			
TI*KL	−0.009	−0.037	0.013	0.500	0.209	−0.066	0.087	1		
LTI*M	0.518	0.512	0.753	0.416	0.422	−0.526	−0.275	0.517	1	
KPR	0.156	0.172	0.100	0.536	0.449	−0.122	0.047	0.255	0.247	1

Table 2. Correlation matrix amongst the independent variables

the bias of the estimator suggested by Bruno (2005a). Further, the statistical significance of the LSDVC coefficients was tested using bootstrapped standard errors with 200 iterations following Bruno (2005b). The results from the LSDVC estimation are presented in Table 3 and arranged in columns following how the LSDVC estimator is initialised. In columns (1)–(3), (4)–(6) and (7)–(9), the LSDVC estimator is initialised by AB, BB and AH, respectively.

4.3 Discussion of findings

Table 3 shows the results for *L.LED* are all significant at 1%. Further, for all the columns, the coefficients for *LM* are positive and significant in all columns. The positive and significant coefficients for *LM* mean that other factors are held constant. Per capita income growth leads to an increase in environmental degradation in SSA. This echoes the findings by Gulistan *et al.* (2020), Bah *et al.* (2020) and Ssali *et al.* (2019). Further, the coefficients for *LM* are larger than all other significant coefficients regardless of the indicator used. This indicates that economic growth is the largest contributor to SSA's environmental degradation, which justifies the findings by Aliyu and Ismail (2015). It also explains the primacy of scale effects in determining environmental degradation in SSA, Nkengfack *et al.* (2019) suggested.

Besides, the coefficient for LM^2 is negative and significant in columns when *LPM* and *LFO* are used as dependent variables. This means that *LPM* and *LFO* exhibit an inverted U-shaped curve, confirming the EKC hypothesis's validity. Therefore, we can confirm that in SSA, the EKC hypothesis is valid for PM2.5 emissions and deforestation but not for CO_2 emissions. While we fail to find relevant studies that examine the EKC hypothesis for SSA using PM2.5 emissions, the validity of the EKC hypothesis for deforestation is comparable to the findings by Bissoon (2018), Cropper and Griffiths (1994) and Bhattarai and Hammig (2001, 2004) but in contrast with Ogundari *et al.* (2017). The implication for this result is similar to that discussed by Chiu (2012) who suggests that when countries have low per capita income, deforestation rates increase as income increases due to the transformation of forest and woodland areas into arable land as well as fuelwood. However, deforestation reduces as per capita income increases to a certain level, coupled with the adoption of modernised agricultural technology and advanced sources of energy and fuels (Barbier, 2004). This can also stem from the encouragement to engage in sustainable forest management, afforestation and natural expansion of forests, as well as the consciousness of the effects of climate change (Chiu, 2012).

Further, the turning points for PM2.5 emissions are USD 1356 (US Dollars), USD 1397 and USD 959.8 in columns (2), (4) and (8), respectively. However, between 1990 and 2017, the average annual per capita GDP (constant 2010 US Dollar) for SSA was USD 1304.5 in 1990 and USD 1667.4 in 2017 with the lowest at which at USD 1173 in 1994. Therefore, the turning points for PM2.5 below USD 1000 are unrealistic, but those at USD 1356 and USD 1397 are more realistic and were probably achieved between 2004 and 2005. On the other hand, the turning points for deforestation are USD 1206, USD 1195, and USD 2045.1 in columns (3), (6) and (9), respectively. The turning points for deforestation in columns (3), (6) are more realistic and probably achieved between 1995 and 1996. Besides, the turning points for deforestation were achieved before those for PM2.5, which may suggest that SSA countries experienced a reduction in deforestation before they experienced a reduction in PM2.5 emission. The findings confirm that the evidence of the EKC hypothesis in the empirical literature is mixed (Kong and Khan, 2019), and the results vary from one study to another based on the selection of variables, the data, the model specification and methodology used (Harbaugh *et al.*, 2002). Specifically, the mixed results of the EKC hypothesis in this study are due to using different dependent variables.

Furthermore, Cole and Elliott (2003) suggest that the coefficient for the composition effect can be either positive or negative. From the findings, the coefficients for *KL* are significant for both PM2.5 emissions and deforestation. The relationship between *KL* and PM2.5 emissions

Table 3. The LSDVC estimates for economic growth-environmental degradation nexus in SSA

Variables	(1) LCO_AB	(2) LPM_AB	(3) LFO_AB	(4) LCO_BB	(5) LPM_BB	(6) LFO_BB	(7) LCO_AH	(8) LPM_AH	(9) LFO_AH
L.LED	0.7410***	0.7489***	1.0200***	0.7739***	1.0662***	1.0243***	0.7316***	0.7621***	1.0199***
	(0.0387)	(0.0576)	(0.0092)	(0.0359)	(0.0411)	(0.0060)	(0.0460)	(0.1253)	(0.8883)
LM	3.0562***	1.1396**	1.9981**	2.1240**	0.9892*	1.6753**	2.9388***	1.0822*	2.0049*
	(0.0136)	(0.0017)	(0.0323)	(0.0140)	(0.0659)	(0.0142)	(0.0112)	(0.0179)	(0.0161)
LM^2	0.0516	−0.0790*	−0.1408**	0.0202	−0.0683***	−0.1182*	0.0838	−0.0788*	−0.1315**
	(0.2708)	(0.0028)	(0.0093)	(0.2513)	(0.0029)	(0.0046)	(0.3704)	(0.0029)	(0.0063)
KL	−0.0321	−0.0210*	0.2181***	−0.0313	−0.0186	0.0626**	−0.0128	−0.192	0.0316
	(0.0486)	(0.0170)	(0.0407)	(0.0442)	(0.0191)	(0.0315)	(0.0561)	(0.0199)	(0.0331)
TI	0.0051	−0.0009	−0.0014*	0.0053	0.0004	−0.0017*	0.0004	−0.0017	0.0006
	(0.0083)	(0.0028)	(0.0005)	(0.0078)	(0.0048)	(0.0005)	(0.0017)	(0.0045)	(0.0005)
LTIM	0.4155***	0.0302	0.0145	0.4228***	0.0205	0.0133	0.1610	0.0382	0.0132
	(0.1272)	(0.0449)	(0.0148)	(0.1253)	(0.1071)	(0.0136)	(0.1848)	(0.0905)	(0.0134)
TIKL	0.4140***	−0.0324	0.0073	0.1209	−0.0248	0.0069	0.4354**	−0.0417	0.0073
	(0.1267)	(0.0451)	(0.0067)	(0.1242)	(0.1097)	(0.0065)	(0.1895)	(0.0838)	(0.6560)
LFDI	0.0035	0.0094**	−0.0015**	0.0037	0.0091*	−0.0026***	0.0037	0.0026	−0.0032*
	(0.0065)	(0.0022)	(0.0004)	(0.0062)	(0.0027)	(0.0008)	(0.0085)	(0.0029)	(0.0009)
LEU	0.1311**	0.0233*	0.0059***	0.1434**	0.0210**	0.0059***	0.1113*	0.0259	0.0025
	(0.0666)	(0.0131)	(0.0014)	(0.0654)	(0.0159)	(0.0013)	(0.0855)	(0.0473)	(0.0025)
KPR	0.0031	−0.0028	−0.0267**	0.0041	−0.0107	−0.0201*	0.0046	−0.0054	−0.0235
	(0.0354)	(0.0116)	(0.0191)	(0.0331)	(0.0143)	(0.0193)	(0.0469)	(0.0148)	(0.0275)
YDs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OBS	998	998	998	998	998	998	998	998	998
C_ID	41	41	41	41	41	41	41	41	41

Note(s): For ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, standard errors in parentheses. The LSDVC initialised by Arellano and Bond (1991) (AB), Blundell and Bond (1998) (BB), and Anderson and Hsiao (1982) AH consistent estimators and the standard errors are bootstrapped with 200 iterations. *L.LED* is the lagged dependent variable, YDs represents the year dummies, OBS is the number of observations and C_ID is the number of countries used is negative which suggests that as SSA becomes more capital intensive, there is a reduction in PM2.5 emissions. Because the majority of the population in SSA is employed in labour-intensive agriculture where forest and bush burning are common practices (Rudel, 2013), PM2.5 emissions are high. With more capital, agriculture modernisation is inevitable, leading to a fall in PM2.5 emissions. On the other hand, *KL* has a positive relationship with deforestation which means that as SSA countries become more capital intensive, the deforestation in the region increases. We can argue agriculture plays a huge role in most SSA economies, and the adoption of more capital may lead to a transformation from subsistence to commercial agriculture which requires more land for agricultural expansion thereby increasing deforestation (Soaga and Kolade, 2013).

The findings also show that international trade has a negative relationship with deforestation which means that as SSA countries become more open to international trade, deforestation decreases. This is because openness to international trade provides SSA countries with access to modernised technologies and factor inputs that substitute and reduce the dependence on forests for raw materials thereby reducing deforestation in SSA (Saggi, 2002). Such technologies may include agriculture technologies and fertilisers that can improve crop yield on existing farmland without the need to cut down more forests to provide new lands for agriculture.

Furthermore, *LTI*M* has a positive and significant relationship with *LCO* in columns (1) and (4) which confirms the validity of the PHH for CO_2 emissions in SSA. This means that openness to international trade facilitates pollution-intensive industries to relocate to SSA which leads to both trade-induced per capita income gains and increase in CO_2 emissions in the region. According to Twerefou *et al.* (2019) and Sun *et al.* (2020), the relocation of pollution intensive industries can be attributed to poor environmental regulation because SSA countries are among the lowest-ranked countries on the environmental performance index (EPI) (Wendling *et al.*, 2018) with only five countries were ranked in the top 100. This is in addition to lax environmental regulations that lower production costs and increase profit margins. Besides, SSA countries are also willing to welcome pollution-intensive production because it creates more jobs and increases economic growth at the cost of the environment. In the end, such trade-induced income growth can lead to high CO_2 emissions, thereby validating the PHH.

For the FEH, the findings show a positive relationship between *TI*KL* and CO_2 emissions in columns (1) and (7) which means that openness to international trade induces capital growth in SSA which in turn increase CO_2 emissions in the region. Because, capital moves to where it has a comparative advantage and the comparative advantage is driven by factor abundance, factor endowments including cheap and abundant labour and natural resources in SSA attract more capital especially extractive industries that emit more CO_2.

Among the control variables, we find that FDI has a positive relationship with PM2.5 emissions and a negative relationship with deforestation. This suggests that in SSA, PM2.5 emissions increase as FDI inflow increases which is similar to the findings by Demena and Afesorgbor (2020), and Bissoon (2018). On the other hand, deforestation falls as the inflow of FDI increases. We can argue that FDI inflow reduces overall dependence on natural forests for survival and provides alternative raw materials and technologies that substitute forest-based raw materials and goods. We also examine the relationship between energy consumption with environmental degradation. The findings suggest that both *FFEU* and *FWEU* have a positive impact on air pollution and deforestation respectively which is in line with the findings of Gulistan *et al.* (2020), Wang and Dong (2019) and Ssali *et al.* (2019). Finally, our findings suggest that ratification of the Kyoto Protocol has no impact on CO_2 and PM2.5 emissions in SSA, and we can say that the finding is valid is because, by the time SSA ratified the Kyoto protocol, GHGs emissions in the region were still very low and thus, had not so much effect (Le Quéré *et al.*, 2015). However, based on the findings, the ratification of the

Kyoto Protocol is effective in reducing deforestation in SSA. This is because, under the Kyoto protocol, the clean development mechanism (CDM) proposes carbon credits and establishes international carbon markets for within which these carbon credits can be traded (Olsen, 2007) and because SSA has usually emitted less GHGs compared to other regions, companies have bought carbon credits from countries in the region leading to a fall in the deforestation rate thereby indirectly improving the air quality (Cushing *et al.*, 2018).

5. Conclusions and recommendations

In this study, we examine the empirical relationship between economic growth and environmental degradation in SSA focussing on the validity of the EKC hypothesis, PHH and FEH in SSA. Our findings confirm the existence of the EKC for PM2.5 emissions and deforestation but not for CO_2 emissions despite CO_2 emissions having a positive relationship with economic growth. We also find a negative relationship between trade openness and deforestation which means that SSA countries increase their participation in international trade as deforestation falls. Also, the PHH is valid for CO_2 emission suggesting that trade-induced economic growth leads to an increase in CO_2 emissions. This is owed to the fact that trade increases technology transfer which in turn increases production leading to more economic growth. However, due to lax environmental regulations in SSA, more pollution-intensive industries are attracted which also increases emissions. Besides, our findings also show that the validity of the FEH in SSA for CO_2 emissions but not for PM2.5 emissions and deforestation.

Whereas the validity of the EKC illustrates that PM2.5 emissions and deforestation will fall as per capita income increases, and it is not the same for CO_2 emissions. The positive relationship between per capita income and environmental degradation indicators illustrates that in the processes of achieving high economic growth, SSA bears the consequence of environmental degradation in the form of CO_2 and PM2.5 emissions as well as deforestation. In addition, the validity of the PHH and FEH means that SSA countries should tighten their environmental standards and enforcement of the standards. This can be through instituting regional environmental standards to act as benchmarks for individual country's environmental standards and establishing a regional body to monitor and enforce the agreed standards. Besides, policymakers in SSA countries should encourage green investments and the adoption of environmentally friendly technologies, which increase economic growth but cause less environmental damage. This can be done by increasing government spending on research and development on green technologies to boost the motivation to create and innovate environment-friendly technologies. In addition, offering tax waivers, exemptions and subsidies to both local and foreign investors bringing green investments to SSA. Further, SSA governments should facilitate the transition from fossil fuels and fuelwood to renewable energy, which causes less harm to the environment. Similarly, SSA governments should improve access to information on the environment as well as encourage knowledge management strategies as a means of creating awareness on environmental issues.

Furthermore, policymakers in SSA should encourage green investments and the adoption of environmental friendly technologies which increase economic growth without degrading the environment. This can be through offering tax waivers, exemptions and subsidies on green technologies for both local and foreign investors. In addition, SSA governments should increase spending on research and development on green technologies to boost the innovation of eco-friendly tools. SSA governments should also facilitate the transition from environmentally damaging fossil fuels and fuelwood energy to environmentally friendly renewable energy use. Further, the creation of easily accessible knowledge management strategies as a means of creating civil awareness about the consequences of environmental degradation amongst all sectors through different media is a vital way for all citizens to change attitudes towards environmental protection.

This study contributes to the literature on the EKC hypothesis in SSA by using several indicators environmental degradation and confirming that the validity of the EKC, PHH and FEH hypotheses depends on the type of indicator for environmental quality used. We also acknowledge not examining the relationship between economic growth and water pollution because countries in SSA do not have reliable data for water pollution indicators such as dissolved oxygen (DO) and biochemical oxygen demand (BOD). This is a gap in the literature that may be closed in the future when data for such indicators are made publicly available.

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