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Zero-pollution effect and economic development: standard and nested environmental Kuznets curve analyses for West Africa

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Abstract

The Economic Community of West African States has keyed into the various international agreements that seek to protect the environment and reduce gaseous emissions. This study investigated the relationship between CO_2 emissions and economic development for West Africa, between 1990 and 2014. Standard and nested-EKC models were estimated using the panel ARDL approach. Both models validate the U-shaped EKC hypothesis, but perceptible more in the long-run and require per capita incomes of $4958 and $853 to produce zero-pollution effects. While the manufacturing and industrial sectors are not significantly large enough to cause environmental degradation even though the volume of trade has increased significantly, the technology-CO_2 relationship is monotonic in all the models. This implies that West African countries have not fully explored and employed the different forms of technology required for per capita income to either produce a zero-pollution effect or to start decarbonising the environment. For now, economic development leads CO_2 emissions and can be abated by policies that encourage natural agricultural practices and the use of renewable sources of energy.

1 Introduction

Environmental degradation is becoming a major threat to humanity and an economic burden to both developed and developing nations. The rate of degradation is increasingly being abetted by pollution-intensive activities and a concomitant rise in global economic development, which are key drivers of economic growth, and major determinants of environmental quality. Invariably, economic development and environmental

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quality are inextricably related. This relationship is predicated on the Environmental Kuznets Curve (EKC), which hypothesizes an inverted U-shaped income inequality/per capita income relationship (Kuznet, 1995) and implicitly relates economic growth to environmental quality. Reinforcing this hypothesis, Grossman & Krueger (1995) submit that pollution increases at early stages of economic growth and decreases under high-income levels (from an agrarian clean-economy to industrialized dirty economy and ends up in a service clean-economy). Empirically, the EKC has an inflection point where economic development neither increases nor reduces environmental degradation (zero-pollution effect) (Selden & Song, 1994; Chucku, 2011; Aduebe, 2013; Sugiawan & Shunsuke, 2016; Cialani, 2007). Thus, GDP per capita below the inflection point corresponds to positive gains in economic development and vice versa.

The Economic Community of West African States (ECOWAS) is experiencing high growth because their respective economies are increasingly becoming more industrialized due to advancements in development and technology. World Bank Development Index (2016) shows that between 1990 and 1994, West Africa experienced a regional growth of approximately 2.2%. This increased steadily to 3.9% between 1995 and 2004 and to 4.5% and 5.2% between 2005 and 2009; and between 2010 and 2014, respectively, but slowed down to 4.5% between 2015 and 2019. The increase in growth was marked by a corresponding increase in gaseous emissions. For instance, the total regional greenhouse gas (GHG) emissions between 1990 and 2014 was 182.61 $MtCO_2e$ with per capita emissions of approximately 4.22 metric tons of carbon dioxide-equivalent (tCO_2e) (see USAID, 2014), which increased to 5.9 tCO_2e between 2015 and 2016 (World Development Index, 2017). An economic implication of this rising trend is that GHG emissions will reduce crop production in West Africa by 0.13% by lowering crop yields (Osabohien et al., 2019). This is in conformity with an earlier submission from a United Nations Conference (2006) that climate change will reduce food production and ultimately threaten suitable development in Africa in the near future.

Due to the rising trends of economic growth and gaseous emissions, it became incumbent on West African countries to adopt the various international agreements that seek to protect the environment and reduce gaseous emissions especially through the use of renewable sources of energy. For instance, the Paris Agreement of 2015, which requires all countries to set emission-reduction pledges (see, Maizland, 2021) and the Nairobi Programme of Action for the Development and Utilization of New and Renewable Sources of Energy (see, Parker, 2016). Sequel to these agreements, the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) was created with the mandate to sustain the economic, social and environmental development of West Africa. The aim of this strategy is to improve access to modern, reliable and affordable energy services, energy security and reduce energy related externalities (GHG & local pollution); ECOWAS Conference (2015).

Despite the adoption of these agreements among other strategies, West African countries are still engaged in pollution-intensive activities and the use of non-renewable sources of energy (fossil fuels), which portend great danger to the environment and ultimately requiring huge capital to sustain the gains of economic development. Therefore, the objective of this study is to examine the effect of CO_2 emissions on the economy of West African states and to deduce an approximate capital that will render a zero-pollution effect on the entire region.

The paper is structured as follows. Section 1 presents the introduction. Section 2 summarizes the literature review. Section 3 describes the methodology. Section 4 reports and analyses the results, while Sect. 5 presents the conclusion and recommendations.

2 Theoretical underpinning/empirical review

2.1 Theoretical underpinning

As earlier stated, the relationship between economic development and environmental quality is premised on the Environmental Kuznets curve (EKC) postulated by Simon Kuznet in 1995. The main thrust of the EKC hypothesis is that at the early stages of a nation's growth process, inequality in income distribution rises and starts declining when per capita income attains an inflection point. Implicitly, environmental quality and economic development follow the same trajectory (Beckerman, 1992; Dinda, 2004), with greater economic activities inevitably harming the environment due to advances in technology, resource use and investments (International Bank for Reconstruction & Development's World Development Report, 1992). Reinforcing the EKC hypothesis, Grossman and Krueger (1991) identifies three distinct channels through which economic development affects environmental quality: the scale effect, the composition effect and the technique effect. Summarily, environmental quality deteriorates at early stages of development—scale effect, and ameliorates when developments shift from pollution-intensive primary activities to tertiary activities—composition effect, and at later stages of development when the use of clean and new technologies tends to improve environmental quality (technique effect). In line with Grossman and Krueger's (1991) submission, other proponents of the EKC hypothesis (Andreoni & Levinson, 2001; Arrow et al., 1995; Ausubel, 1996; Komen et al., 1997; Panayotou, 1993; Stern (2004); Suri & Chapman, 1998; assert that environmental degradation can be reduced at higher levels of development, through resource-saving, structural and technological changes in the extractive and manufacturing sectors, trade liberalization and through environmentally friendly policies.

In a nutshell, the EKC hypothesis simply postulates that economic development begins with an agrarian 'clean' economy free from pollutants, and gradually progresses to an industrialized 'dirty' economy, which is responsible for pollution and depletion of natural resources, and ends up in a service 'clean' economy characterized by awareness and the willingness of people to spend more income on improving environmental quality.

Despite the plethora of claims and empirical evidence that have validated the EKC hypothesis, critics have argued that the postulation is not universally applicable. For instance, Shafik (1994) provides empirical evidence of a monotonic increasing relationship between economic development and environmental quality. Similarly, He (2007) also observed that no one-fit-for-all inverted U-shaped curve can adequately describe the relationship between growth and pollution. Recent studies have even shown that the EKC follows an N-shape (Chuku, 2011) or an S-shape (Friedl & Getzner, 2003) unlike the standard U-shaped EKC.

2.2 Empirical review

The debate to either validate or justify the true nature of the EK-curve is ongoing. A flurry of studies has ended up with confounding results due to the different proxies that characterize air quality (CO_2, SO_2, PM_{10}, CO, NO_2, etc.), as well as the different functional forms, specifications and analytical techniques employed. The true nature of the EKC curve was initially investigated by (Grossman & Krueger, 1991; Panayotou, 1993; Selden & Song, 1994; Shafik & Bandyopadhyay, 1992). Grossman and Krueger (1991) used the global

environmental monitoring system (GEMS) data set for SO_2, dark matter (smoke) and suspended particles to analyse the relationship between air quality and GDP per capita. Similarly, Shafik and Bandyopadhyay (1992) specified three different functional models using ten different indicators for the EKC. They found that lack of clean water and lack of urban sanitation declined monotonically with increasing income over time. However, local air pollutant concentrates validated the EKC hypothesis with turning points between $3000 and $4000. Finally, both municipal waste and carbon emissions per capita increased unambiguously with rising income.

Panayotou (1993) employed a log quadratic model for USA and found an EKC relationship with a per capita turning point of $5,500. Selden and Song (1994) tested the EKC hypothesis using four important air pollutants: suspended particulate matter, sulphur dioxide, nitrogen dioxide and carbon monoxide. They found that per capita emissions for all the four pollutants displayed inverted-U relationships with turning points of approximately $7,114.

Recent studies have found high turning points with profound policy implications. For instance, Aduebe (2013) arrived at turning points of $1235.85 and $952.53 in the short and long runs in Nigeria; Sugiawan and Shunsuke (2016) established a value of $8,000 for Indonesia and Cialani (2007) concluded that the per capita turning point in Italy is approximately $26,900.

Another strand of studies has presented results indicating that the EKC hypothesis is not valid in all countries. For example, Tomi et al. (2001); Azomahou, Laisney and Van (2005); Richmond and Kaufmann (2006); Aslanidis and Iranzo (2009); Ozturk and Acaravci, (2010); Koçak (2014); Cederborg and Snöbohm (2016); Abdalla et al. (2017); Fakhri et al. (2019) established no relationship between air quality and per capita income, while few studies like (Shafik & Bandyopadhyay, 1992; Lise, 2006; Akbostanci, Turut-As & Tunc, 2009; Fodha & Zaghdoud, 2010a, 2010b) established a monotonically increasing linear relationship. This kind of relationship often occurs when environmentally friendly techniques are not employed as economic growth leads CO_2 emission (Aye & Edoja, 2017). Shahbaz and Sinha (2020) arrived at inconclusive results for a single-country and cross-country contexts, after a thorough survey of empirical literature. They attributed the inconclusiveness to the choice of contexts, time period, explanatory variables and methodological adaptation. Furthermore, some studies have provided evidence of an N-shaped EKC derived from a cubic function (Aye & Edoja, 2017; Chuku, 2011; Friedl & Getzner, 2003; Martinez-Zarzoso & Bengochea-Marancho, 2004).

Recent studies have argued that the homogeneity of countries' economic activities validated the EKC hypothesis. For instance, Pilatowska and Wldarczyk (2018) used an asymmetric framework to model the dynamic link between per capita income and CO_2 emissions for 14 European Union countries. They divided the selected countries into three groups depending on a category of knowledge-advanced economies. Their finding confirmed the EKC hypothesis, which showed some similarities with countries belonging to the same category of knowledge-advanced economies. Using quantile regression analysis on a short-run panel of 138 countries, Yunpeng et al. (2014) found that the concentration of air pollutants and Gross Regional Product per capita provided strong evidence of the EKC hypothesis in the provincial capitals of mainland China. A similar approach by Allard et al. (2017) showed an N-shaped EKC for 74 countries on the contrary. In a related study, Saqib and Benhmad (2020) arrived at a quadratic relationship between income growth and ecological footprint, which validated the EKC hypothesis, after using efficient estimation tools like the pooled mean group and augmented mean group to estimate the long-run parameters for 22 European countries. In their most recent study, Saqib & Benhmad (2021a, b)

synthesized the existing findings in the EKC literature and conducted a meta-regression analysis using quantitative methods on a broad level. They found a strong evidence in support of EKC after reviewing 101 research papers published from 2006 to 2019, and concluded that the EKC is a long-run phenomenon, which is always established irrespective of the data used or the econometric tool employed.

A handful of studies has shown that the EKC can likely produce different shapes due to heterogeneity of economic activities. For example, Choi, Heshmati and Cho (2010) found different EKC patterns for some Asian countries. China showed an N-shaped curve, while Japan displayed a U-shaped curve. Korea and Japan showed an inverted U-shaped curve, while China displayed a U-shaped curve. Earlier studies by List and Gallet (1999), Koop and Tole (1999), and Halkos (2003) ended up with different countries having different turning points, implying that there is no 'one-form-fits-all' EKC curve for a group of countries using panel models. Correcting for heterogeneity using the Method of Moments' quantile regression, Ike, Usman et al. (2020) concluded that the dynamic effect of oil production on carbon emissions in 15 oil-producing countries validates the EKC and pollution halo hypotheses.

Few empirical studies have examined the EKC hypothesis in African using panel time series data. Ojewumi (2015) validated the EKC hypothesis for solid emission and composite factor of emission in selected Sub-Saharan African countries, but maintained that other pollutants: CO_2, emissions, industrial emissions and liquid emissions did not follow the EKC path. Out of 19 African countries, Shahbaz et al. (2016) confirmed the EKC hypothesis for only 6 countries. Sarkodie (2018) validated the EKC hypothesis in 17 African countries with a turning point of US\$ 5702 GDP per capita. Osabuohien et al. (2014) provide evidence of a long-term relationship between CO_2 and particulate matter emissions with per capita income and other variables in a panel of 50 African countries. Other studies have invalidated the EKC hypothesis in Africa due to income heterogeneity (Ogundipe et al., 2014; Nasr, Gupta & Sato, 2014; Boqiang et al., 2016; Adu & Denkyirah, 2017; Bissoon, 2018; Beyenez, & Kotosz, 2019).

Few studies have specifically nested the ARDL model with energy consumption to investigate the EKC hypothesis. For example, Attari et al. (2016) for Pakistan; Asongu, Montasser, Ghassen and Toumi (2015) for 24 selected African countries; Tingtiing et al. (2016) for 26 provinces in China; Fazli and Abbasi (2018) for selected developing countries; Chng, 2019 for six ASEAN countries and Saqib & Benhmad, 2021a, b) All these studies have confirmed that the EKC hypothesis is a long-run phenomenon.

3 Methodology

3.1 Data source

This study employed secondary data from 1990 to 2014 extracted from World Development Indicators (World Bank, 2019). The scope of the study ends in 2014 because data for all variables are available till 2019 except for renewable energy consumption. The data set constitutes a balanced panel of 14 West African countries (Benin, Burkina Faso, Cape Verde, Ghana, Guinea, Guinea Bissau, Liberia, Nigeria, Niger, Mali, Senegal, Sierra Leon, The Gambia, Togo), while Mali, Liberia and Niger were excluded from the sample because of the paucity of data. CO_2 per capita emissions measure air pollution. GDP per capita is used to capture economic development as provided by the literature: (Panayotou, 1993;

Ogundipe et al., 2014; Nasr, Gupta & Sato, 2014; Boqiang et al., 2016; Adu & Denkyirah, 2017; Bissoon, 2018; Beyenez, & Kotosz, 2019; etc.) To measure the Grossman-Krueger effect, i.e. from a clean agrarian economy to a dirty industrialized economy and to a clean service economy, trade openness and value addition in agriculture, industry and services are included in the nested-EKC model.

3.2 The standard or non-nested environmental Kuznets curve model

The standard EKC model focuses on the relationship between per capita income and environmental degradation. Air pollution (CO_2 emissions) is a form of environmental degradation, which exhibits an inverted U-shaped relationship with per capita income expressed as a quadratic function. The standard quadratic EKC model with a set of income and non-income regressors is presented as follows:

$$(CO_2/P)_{it} = \alpha_o + \alpha_1 t_1 + \alpha_2 \left(GDP/P \right)_{i,t} + \alpha_3 \left(GDP/p \right)_{i,t}^2 + \tau Z_{i,t} + \varepsilon_{i,t} \tag{1}$$

where $(CO_2/P)_{it}$ is per capita CO_2 emissions, which captures environmental pollution and $\left(GDP/P \right)_{i,t}$ is a proxy for economic development in country i at time t, respectively. P is population size, τ is a vector of coefficients of other non-income explanatory variables, t is the deterministic time trend, which is a proxy for technological progress and $\varepsilon_{i,t}$ is white noise. α_2 and α_3 are the parameters of the first- and second-order per capita income, showing the nature of (CO_2/P)- (GDP/P) relationship after estimation. If $\alpha_2 > 0$, and $\alpha_3 = 0$, then, we have a monotonic increasing function where per capita emission is always increasing with respect to per capita income. If $\alpha_2 > 0$, and $\alpha_3 < 0$, then, pollution and per capita income will exhibit an inverted U-shaped relationship. A standard EKC, models per capita emission in function of per capita income only, implying that $Z_{i,t} = 0$. The zero-point source emission is a turning point of per capita income for which per capita emission is maximum (better still approximates point of inflection) calculated as $\left(\frac{GDP}{P} \right)_{max} = \left(\frac{-\alpha_2}{2\alpha_3} \right)$.

3.3 Nested-EKC model

Technically, both the standard and nested-EKC models have identical terms with the latter having one or more extra terms. Stern (2000) exemplified a simple nested-EKC model, where per capita emission is modelled in function of per capita income and other variable inputs, $Z_{i,t} \neq 0$ as follows:

$$(CO_2/P)_{it} = f_i \left(A_i, \left(GDP/P \right)_{it}, Z_{i,t} \right)$$

where $(CO_2/P)_{it}$ is per capita CO_2 emissions, A_i is level of technology, $\left(GDP/P \right)_{it}$, is per capita income, $Z_{i,t}$ is infinite number of inputs that influence per capita emission. f_i represents a function where the inputs are homogenous of degree one:

$$(CO_2/P)_{it} = \rho_i \frac{A_t}{TFP_{it}} b_{it} \frac{GDP_{it}}{P_{it}} \left(\frac{y_{it}}{GDP_{it}} \right)^{-\sum_{j-1}^{Jj-1} a_j} \prod_{k-1}^{J-1} \left(\frac{y_{it}}{GDP_{Tit}} \right)^{\sigma_j} \sum_{k=1}^{k} \beta_k \frac{z_{it}}{Z_{it}} \varepsilon_{it} \tag{2}$$

where $\frac{y_{it}}{GDP_{it}}$ is the scale effect, A_t represents level of technology, $\frac{1}{TFP_{it}}$ is the overall technological progress b_{it} the abatement effect, $\left(\frac{y_{it}}{GDP_{Tit}}\ldots\frac{y_{it}}{GDP_{Tjit}}\right)$ and $\left(\frac{z_{it}}{Z_{it}}\ldots\frac{z_{it}}{Z_{jit}}\right)$ represents the output and input mix, respectively. Logging and simplifying the above model leads to the following nested-EKC models:

$$(CO_2/P)_{it} = \alpha_o + \alpha_1 t_1 + \alpha_2\left(GDP/P\right)_{i,t} + \alpha_3\left(GDP/p\right)_{i,t}^2 + \alpha_4 AGRIC_{it} + \varepsilon_{i,t} \qquad (3)$$

$$(CO_2/P)_{it} = \alpha_o + \alpha_1 t_1 + \alpha_2\left(GDP/P\right)_{i,t} + \alpha_3\left(GDP/p\right)_{i,t}^2 + \alpha_4 RENERGY_{it} + \varepsilon_{i,t} \qquad (4)$$

$$(CO_2/P)_{it} = \alpha_o + \alpha_1 t_1 + \alpha_2\left(GDP/P\right)_{i,t} + \alpha_3\left(GDP/p\right)_{i,t}^2$$
$$+ \alpha_4 Man_{it} + RENEGY_{it} + Trade_{it} + INVEST_{it} + SERV_{it} + \varepsilon_{i,t} \qquad (5)$$

where $AGRIC_{it}$, $RENEGY_{it}$, Man_{it}, $Trade_{it}$, $INVEST_{it}$, $SERV_{it}$ represent the value added to GDP of agriculture, manufacturing, trade and services in country i at time t. A dynamic multivariate autoregressive distributed lag panel (PARDL) model with an error correction term (ECT) is therefore applied to analyse the long and short runs EKC hypothesis. The dynamic PARDL (p, q) with an error correction term for the standard EKC model is as follows:

$$\Delta(CO_2/P)_{it} = \alpha_0 + \alpha_1 t_1 - \theta\left(\Delta(CO_2/P)_{it-j} - \mu(CO_2/P)_{it-j}\right) + \sum_{i=1}^{p-1} \alpha_{ij}\Delta(CO_2/P)_{it-j}$$
$$+ \sum_{i=0}^{q1-1} \beta_{ij}\Delta\left(GDP/P\right)_{i,t-j} + \sum_{i=0}^{q2-1} \beta_{ij}\Delta\left(GDP/p\right)_{i,t-k}^2 + \varepsilon_{i,t} \qquad (6)$$

where $(CO_2/P)_{it-k}$ is the lagged dependent variable with p lags, α_0, is constant term, t_1 is a time trend which represent technology, $\left(GDP/P\right)_{i,t-k}$, $\left(GDP/p\right)_{i,t-k}^2$, are the lagged independent variables with q lags. The optimal lags are selected using the Akaike information criterion. The long-run coefficient is $\frac{\sum_{j=0}^{q} \beta_{ij}}{\theta}$, and the error correction term has a speed-of-adjustment $\theta = (1 - \sum_{j=1}^{p} \alpha_{ij})$, which shows how quickly such an equilibrium distortion is attained or corrected. Basically, the sign of the adjustment coefficient, θ, governs the convergent/divergent trajectories of the dependent variable, $(CO_2/P)_{it}$ towards/from the long-run pollution–income relationship (Wang, 2012). The beauty of the nested-EKC model is that captures the Grossman-Krueger effect, not mentioned in the standard EKC model.

3.4 Panel unit root test

The inclusion of the difference operator (Δ) in Eq. 6 shows that $[\Delta(CO_2/P)_{it}$, $\Delta(CO_2/P)_{it-j}$, $\Delta\left(GDP/p\right)_{i,t-k}^2]$ must be integrated of order one. However, ARDL estimations allow a mixture of I(1) dependent/independent variables and I(0) strictly independent variables (see, Pesaran et al. 2001). For a panel unit root test, Levin et al.

(2002); Breitung (2002) and Hadri (2000) tests assume that there is a common unit root process such that ρ_i is identical across cross sections. The first two tests employ a null hypothesis of a unit root while Hadri's test uses a null of no unit root.

$$\Delta Y_{it} = \alpha Y_{it} + \sum_{j-1}^{pi} B_{ij} \Delta Y_{it-j} + X'_{it} \delta + \varepsilon_{it} \tag{7}$$

where we assume a common $\alpha = \rho - 1$, which allows the lag order for the difference terms, to vary across cross sections. Thus, the null and alternative hypotheses are written as: $H_0 : \alpha = 0, H_0 : \alpha < 0$.

4 Empirical results

4.1 Unit root test

Table 2 presents the results of the panel unit root tests for all the variables. The test results show that agriculture (AGRICULTURE) is stationary at levels, i.e. integrated of order zero I(0), while all the other variables are non-stationary at their levels. However, they become stationary after their first difference, i.e. integrated of order one I(1). First, the dependent variable is an I(1) series, and second, the variables are a mixture

Table 1 Panel unit root and stationarity tests. Source: Authors computation using EViews 9

	Levin, lin and chu t*		Breitung t-stat		Order of Integration
	Level	1st Difference	Level	1st Difference	
CO_2	− 0.1021 (0.4594)	− 6.5.14 (0.000)***	0.0634 (0.525)	− 5.560 (0.000)***	I(1)
GDPPC	− 0.368 (0.356)	− 1.089 (0.123)	3.214 (0.999)	− 3.098) (0.0010)**	I(1)
RENCON	− 0.0461 (0.482)	− 7.728 (0.000)***	− 0.245 (0.403)	− 4.465 (0.000)***	I(1)
AGRIC	− 2.027 (0.0213)**		− 4.216 (0.000)***		I(0)
MAN	2.532 (0.994)	− 3.36136 (0.0004)***	0.121 (0.548)	− 1.06071 (0.1444)**	I(1)
INDUS	1.74901 (0.9599)	− 5.962 (0.000)***	− 1.419 (0.0780)	− 5.3977 (0.000)***	I(1)
SERV	− 0.538 (0.295)	− 8.476 (0.000)***	− 1.318 (0.094)	− 6.517 (0.000)***	I(1)
TRADE	0.245 (0.597)	− 5.843 (0.000)***	0.029 (0.5117)	− 3.982 (0.000)***	I(1)

*, **, ***Indicates1%, 5% and 10% levels of significance. The values in brackets show the probability values for the relevant test statistic

Table 2 Estimates of standard environmental Kuznets curve. Source: Authors computation using EViews 9

ARDL (1,1,1)—Dependant variable: CO_2 per capita			
Short run		Long run	
C	0.0366 (0.013)		
T	0.00235** (0.00085)		
D(GDPPC)	0.00114 (6.02E-07)	GDPPC	0.000236** (9.00E-05)
D(GDPPC^2)	−6.63E-07 (0.001)	$GDPPC^2$	−2.38E-08 (5.95E-08)
ECT(−1)	−0.457 ** (0.032)		
Inflection point ($-\beta 1/2\beta 2$)	$860		$4958

NB: **Denotes 5%, level of significance based on the values in the brackets and represent standard errors for the estimated parameters

of I(1) and I(0) series. Hence, the variables can be modelled using an ARDL approach (Table 1).

4.2 Empirical analysis of standard environmental Kuznets curve

The results establish short-run and long-run relationships between CO_2 emission, agriculture, renewable energy and economic activities in twelve West African Countries based on the panel ARDL approach. The suitability of the ARDL approach is premised on the fact that the estimation can involve a mixture of I(0) and I(1) series. Lag lengths of the estimated models were selected based on the Akaike information criterion (AIC) and the dependent variable which must be I(1).

Table 2 presents the quadratic regression results for the standard EKC models. The estimated models validate the EKC hypothesis, since the first- and second-order coefficients of GDP per capita in the two periods alternate between positive and negative values. Hence, economic development and CO_2 emissions exhibit an inverted U-shaped EKC in West Africa with inflection (turning) points of approximately $860 and $4958 where economic development neither increases nor reduces environmental quality (zero-pollution effect) both in the short and long runs. In economics sense, this simply means that GDP per capita below these turning points corresponds to positive gains in economic development, while GDP per capita above these points corresponds to further gains in economic development due to improvements in economic activities that reduce gaseous emissions. The time trend in the short run is positive and significant, implying that technological progress increases per capita emission in West Africa. The error correction term is negative and statistically significant. This implies that in the long run, GDP per capita and CO_2 per capita will rise at an average speed of approximately 46% reaching an inflection point of $ 4958 where the effect of CO_2 emission (pollution) is zero and thereafter, CO_2 per capita will start decreasing as GDP per capita further increases due to improvements in technology.

Table 3 Nested environmental Kuznets curve with agriculture. Source: Authors Calculation using EViews 9

ARDL(1,1,1,1)—dependant variable: CO_2 per capita			
Short run		Long run	
C	0.066 (0.014)		
T	0.0017** (0.00057)		
D(GDPPC)	0.0012 (0.0011)	GDPPC	0.00016 (8.54E-05)
D(GDPPC^2) D(Agriculture)	−7.54E-07 (5.95E-07) −0.0027 (0.0098)	GDPPC^2 Agriculture	−9.13E-09 (4.57E-08) −0.0012** (0.00054)
ECT(−1)	−0.439** (0.0513)		
Turning point ($−β1/2β2$)	\$1591	\$8762	

NB: **Denotes 5%, level of significance based on the values in the brackets and represent standard errors for the estimated parameters

4.3 Empirical analysis of nested environmental Kuznets curve

Table 3 presents the regression results of the nested-EKC model including only agriculture. The results show an inverted U-shaped curve with agriculture significantly reducing CO_2 emissions only in longrun attaining an inflection (turning) point of approximately \$8762. This implies that a clean agrarian economy is environmentally friendly (scale effect) to West African countries. A flurry of studies in line with the above findings has shown that natural agricultural practices are less harmful to the environment than greenhouse farming (see, Xiong et al., 2016; Carbonell-Bojollo et al., 2019; Rodríguez, 2019, etc.). The significance of the error correction term suggests that in the long run, GDP per capita and CO_2 per capita will rise at an average speed of approximately 46% reaching an inflection point of \$8762 where the effect of CO_2 emission (pollution) is zero, and thereafter, CO_2 per capita will start decreasing as GDP per capita further increases due to improvements in technology and agriculture.

Table 4 reports the regression results of the nested-EKC models including only renewable energy. The estimated results establish an inverted U-shaped curve in the short and long runs. However, renewable energy will significantly increase environmental quality only in long-run. Hence, a clean economy due to the use of renewable energy is environmentally friendly (scale effect) to West African countries. This finding is in line with that of (Attari et al., 2016; Asongu, Montasser, Ghassen & Toumi, 2015; Tingtiing et al., 2016; China; Fazli & Abbasi, 2018; Chng, 2019 and Saqib & Benhmad, 2021a, b). The error term is significant implying that in the long-run, GPD per capita and CO_2 will rise at an average speed of approximately 38.2% attaining an inflexion point of \$113 (zero effect of pollution on the economy), and thereafter, CO_2 per capita will start decreasing as GDP per capita further increases due to improvements in technology and renewable energy.

Table 5 shows that the overall nested model is U-shaped in the short run similar to what Khanna (2002) found in the case of India and inverted U-shaped in the long run. In the short-run, renewable energy significantly reduces CO_2 emissions, while agriculture and renewable energy significantly reduce CO_2 emissions (improve environmental quality) in

Table 4 Nested environmental Kuznets curve with renewable energy. Source: Authors Computation using EViews 9

Dependant variable: CO_2 per capita

Short run		Long run	
C	0.335		
	(0.00096)		
T	0.00089		
	(0.0009)		
D(GDPPC)	0.00179	GDPPC	8.52E-07**
	(0.00102)		(3.96E-07)
D(GDPPC^2)	− 1.13E-06	GDPPC^2	− 7.51E-09**
D(Renenergy)	(6.67E-07)	RENENERGY	(1.6E-07)
	− 0.0044		− 0.0077**
	(0.0027)		(0.0009)
ECT(− 1)	− 0.382**		
	(0.0752)		
Turning point (− β1/2β2)	$792	$113	

NB: **Denotes 5%, level of significance based on the values in the brackets and represent standard errors for the estimated parameters

Table 5 Nested estimates of environmental Kuznets curve with economic activities. Source: Authors computation using EViews 9

Dependant variable: CO2 per capita

Short run		Long run	
C	0.0048		
	(0.0177)		
T	0.0012		
	(0.0013)		
D(GDPPC)	− 0.0016	GDPPC	0.0012**
	(0.0014)		(0.0004)
D(GDPPC^2)	7.6E-07	GDPPC^2	− 4.26E-07**
D(Agriculture)	(7.99E-07)	Agriculture	(1.79E-07)
D(Renenergy)	0.0033	Renenernergy	− 0.0049**
D(Tradeopenness)	(0.00173)	Tradoponess	(0.0019)
D(Manufacturing)	− 0.0054 **	Manufacturing	− 0.00449**
D(Industry)	(0.0026)	Industry	(0.00118)
D(Service)	8.25E-05	Service	0.00092**
	(0.0004)		(0.00036)
	0.00036		0.0028
	(0.0018)		(0.0027)
	0.0021		0.00091
	(0.0022)		(0.00153)
	− 0.0050		− 0.0017
	(0.0042)		(0.0013)
ECT (− 1)	− 0.286**		
	(0.0865)		
Turning Point (− β1/2β2)=	$1053	$853	

NB: **Denotes 5%, level of significance based on the values in the brackets and represent standard errors for the estimated parameters

the long-run. Trade openness significantly increases the CO_2 emissions (reduces the environmental quality) of West African countries. This is in conformity with Trade theories relating to the inverted EKC hypothesis, which assume that changes in CO_2 emissions are a result of the scale, composition and technical effects of trade liberalization and economic growth (see Grossman & Krueger, 1992; Suri & Chapman, 1998; Heil & Selden, 2001; Copeland & Taylor, 2003). A plausible explanation that justifies this result is that the volume of trade in West Africa has grown steadily over the years due to the growth of the manufacturing and industrial sectors that are engaged in pollution-intensive activities (environmentally unfriendly activities) and also rely heavily on fossil fuels as their primary sources of energy. This is also justifiable because the results on Table 5 indicate that industry increases CO_2 emissions in both periods (industrialized dirty economy) (see, Grossman & Krueger, 1991; Ausubel, 1996; Panayotou, 1993; Arrow et al., 1995; Chuku, 2011). Services have the potentials of improving environmental quality in West Africa because the coefficients are negative though insignificant in both periods. The insignificance of the coefficients suggests that the use of services for economic activities in West Africa is still at its rudimentary stage. The significance of the error term shows that there is a long-run relationship between CO_2 per capita and economic development, and these variables will rise at an average speed of approximately 28.6% before attaining an inflection point of $853 (zero effect of pollution on the economy). Thereafter, CO_2 per capita will start decreasing immediately after the inflection point as GDP per capita further increases due to improvements in technology, renewable energy, agriculture and services.

5 Policy implications

The study has established from the nested-EKC model that economic activities such as manufacturing, industrial and trade tend to reduce the environmental quality of West African States. This portends great danger in the future since these activities keep growing unabatedly. This implies that if proper measures are not put in place to curtail gaseous emissions, respective governments will be forced to budget more to tackle environmental degradation in the long run, especially via extra-budgetary expenditure. This will definitely increase the fiscal burden of the respective governments, either by forcing them to borrow more, thereby, increasing their debt profiles, or by adopting austerity measures that may give less consideration to other sectors of their respective economies.

The turning point in the nested-EKC model is less than that of the standard EKC model (i.e. $853 < $4958). This is plausible because the nested-EKC model shows that different economic activities: manufacturing, industrial and trade have a negative effect on environmental quality. However, agriculture, services and renewable energy are quick to mitigate their effects, which requires less capital (low turning point- $853) intervening at a low speed (28.6%). Agriculture is already the mainstay of most African countries, implying that if West African States invest more in renewable energy and services alongside agriculture, the fiscal burden required to tackle environmental degradation in the long run will be greatly reduced.

5.1 Conclusion and recommendations

The impact of economic development on environmental quality, specifically CO_2 emissions has attracted much attention recently. In this light, this study investigated the effects

of economic development, technology, renewable energy and agriculture on CO_2 emission in West Africa using secondary data from 1990 to 2014. The standard EKC and nested-EKC models were estimated using the panel ARDL approach. The results revealed that the standard and nested-EKC models validate the inverted U-shaped EKC hypothesis. Both models show that West African economies require per capita incomes of \$4958 and \$853 to reduce the effect of pollution to zero. Further results suggest that agriculture, services and renewable energy are environmentally friendly, while the manufacturing and industrial sectors are not significantly large enough to cause environmental degradation even though, the volume of trade has increased significantly over time. Evidently, technology-CO_2 relationship is monotonic in all the models. This simply means that West African countries have not fully explored the different forms of technology required for per capita income to start decarbonising the environment.

Thus, West African governments should provide incentives and environmentally friendly policies that will continuously promote conventional agriculture and the use of renewable energy. This will scale down the quantum of greenhouse gaseous emissions, and at the same time increase the rate of CO_2 absorption during the process of photosynthesis.

Again, respective governments in West Africa should set up a Research and Development (R&D) department that will identify all the potential sources of renewable energy supplies that are efficient and less expensive, and proper ways of investing in the service sector. This in combination with advances and innovations in technology will considerably reduce CO_2 emissions, which will further boost economic development.

Geography/economics studies have shown that afforestation and re-afforestation always improve environmental quality via the process of photosynthesis. Researchers can further extend the nested model by including forest activities in the above models to test the validity of the EKC hypothesis.

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