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Article

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The role of economic growth, financial development, globalization, renewable energy and industrialization in reducing environmental degradation in the economic community of West African States

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ABSTRACT

Since the ECOWAS region is most susceptible to climate change, factors driving climate change and policy processes are pressuring authorities in the region to take more action in the fight against climate change. In light of this, the paper investigates the role of financial development, globalization, renewable energy, economic growth, and industrialization in reducing environmental degradation in the framework of the N-shaped environmental Kuznets curve hypothesis. Second generation econometric techniques, the Driscoll-Kraay panel regression approach and panel quantile estimation techniques were developed based on a panel dataset of 10 ECOWAS countries from 1990 to 2019. From the analyses, the N-shaped EKC is validated for the ECOWAS region. Moreover, the empirical analysis suggests that lower levels of environmental degradation are associated with increased financial development and renewable energy usage. Globalization and industrialization have a deleterious impact on environmental quality. The results from the *U*-test estimation also reveal that the shape of the EKC is contingent on the nation under study. On the other hand, the panel quantile estimation results show that the N-shaped EKC holds for low and medium emitters but not for high emitters. Globalization and industrialization significantly promote environmental degradation in all quantiles, while renewable energy homogeneously reduces environmental degradation. Financial development was found to hinder environmental degradation in low and high emitters while having a neutral effect in medium emitters. The paper offers valuable policy directions for policymakers in the ECOWAS region based on the findings.

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Introduction

Greenhouse gas emissions (GHGs) from human activities significantly contribute to climate change and global warming, leading to adverse weather patterns, including floods, hurricanes, droughts, wildfires and intense heat waves (Umar & Safi, 2023). Climate change and global warming have dire consequences on population health and must be tackled as a public health emergency. The adverse effects of climate change and global warming on health, food and water security, prosperity and safety are already being felt and are on the rise due to the continuous deterioration of the environment (Hayat et al., 2023). To mitigate this global crisis, the Paris Agreement (COP21) was established in 2015 to build an all-encompassing response strategy to put the world on a pathway to avert climate change by lowering global warming to 2°C over pre-industrial levels and implementing further measures to restrict it to 1.5°C (Crippa et al., 2019). The agreement aims to attain net zero greenhouse gas emissions by the end of this century. As a result, reducing carbon emissions and creating a low-carbon economy have received significant attention globally.

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The ECOWAS region comprises 15 nations, covers an area of 5.2 million square kilometres, and contributes approximately 1.8% of global greenhouse gas emissions. All ECOWAS nations emit, on average, a ton of CO₂ per capita yearly. Despite the comparatively low greenhouse gas and CO₂ emissions in ECOWAS, the West African Science and Service Centre on Climate Change and Adapted Land Use (WASCAL) forecast that GDP would decline by either 3.7% or 11.7% by 2050, depending on whether low or high global warming levels. Agriculture and infrastructure will account for a greater portion of the economic losses caused by climate change. Infrastructure-related economic repercussions are projected to be most severe for coastal nations. Beyond the economic impacts, there could be dire health and social impacts, such as impacts on food security due to a decrease in agricultural yields, extreme weather conditions and render most of the poverty alleviation programmes ineffective. Due to their roles as set by society and culture, women and young people frequently are and will remain more susceptible. According to the ECOWAS Regional Climate Strategy Report 2022,¹ the West African Region is among the most vulnerable in the world because of the critical sectors' high sensitivity to climate change and their limited capacity to adapt. In light of this, ECOWAS authorities must be proactive and pragmatic in addressing climate change. Enhancing environmental quality is one approach to do this. The United Nations (UN) Sustainable Development Agenda 2015 states that environmental quality is critical to sustainable development.

Over the years, environmental degradation in ECOWAS has increased due to increased CO₂ emissions. Figure 1 shows that, from 1990 to 2019, CO₂ emissions in the ECOWAS region tended to increase, with few instances of decreases. The rising economic growth (EG) and energy consumption (EC) in the region may explain this pattern. Rising EC and EG usually drive environmental degradation (ED). The role of EG and EC in ED cannot be over-emphasized. Although they are major determinants of ED, most studies limit their studies to ED, specifically CO₂ emissions, associated with EG and EC (Zhu et al., 2016). However, changes in EG and EC alone may not be able to account for the total variation in CO₂ emissions (Chien et al., 2021; Kishwar et al., 2023; Yan et al., 2023). Consequently, we must consider additional factors associated with ED.

The association between ED and EG (income) is well established in ED literature as the environmental Kuznets curve (EKC). Theoretically, the EKC hypothesis posits that the environmental impact of EG is not static but rather dynamic. Thus, these impacts are expected to vary with time, and it is critical to comprehend the factors influencing these variations. According to the EKC hypothesis, high CO₂ emissions levels are typical of the early phases of economic development, but as EG reaches a specific income level threshold, CO₂ emission levels decline (Grossman & Krueger, 1991). Increased natural resource extraction during the early stages of EG is associated with higher waste production (Panayotou, 1993). If there is an inverted U-shaped EKC, at higher rates of EG, strict environmental laws, technological advancements, and structural shifts away from industries that produce large amounts of pollution and toward services lessen ED (Aminu et al., 2023; Villanthenkodath et al., 2021; Q. Wang, Sun, et al., 2023). Some empirical studies have also argued that the association might be N-shaped (Aljadani et al., 2023;

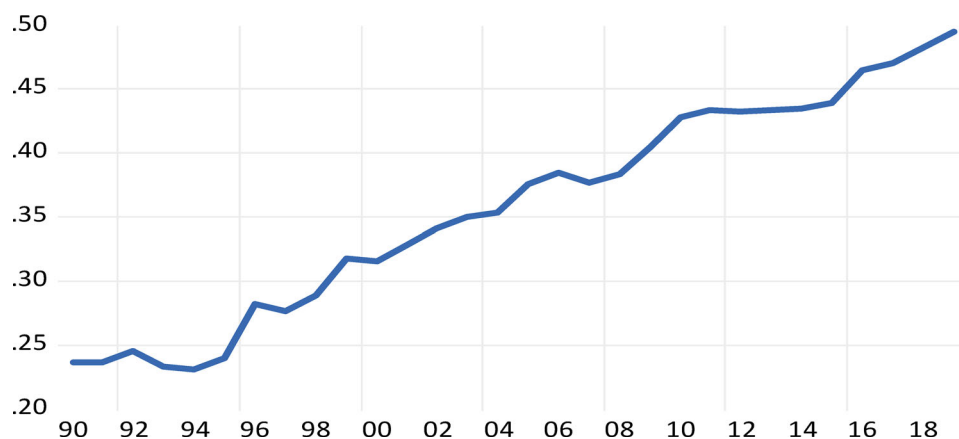


Figure 1. The trend of CO₂ emissions (measured by emissions per capita) in ECOWAS from 1990 to 2019.
Source: Figure created by Author.

Balsalobre-Lorente et al., 2023; Numan et al., 2022) which suggests that ED will start to rise again beyond a certain income level. In addition, some studies failed to validate the EKC hypothesis (Demissew Beyene & Kotosz, 2020; Effiong & Iriabije, 2018; Wencong et al., 2023). These studies contend that additional patterns, such as monotonically rising, U-shaped, N-shaped, and inverted N-shaped patterns, suggest that ED cannot be automatically resolved by rising EG.

The World Bank acknowledges that financial development (FD) is critical for attaining 7 out of the 17 sustainable development goals. FD has been argued to be the significant cause and solution to ED exacerbated by greenhouse emissions (Aluko & Obalade, 2020; Jianguo et al., 2022). FD supports the formation of credit, investments, and economic growth, which increases energy consumption and subsequently lowers environmental quality (Patel & Mehta, 2023). For instance, a robust and efficient financial system enables people and businesses to obtain credit at reasonable rates. It allows households to buy energy-consuming equipment and companies to improve their operations by investing in energy-consuming equipment that drives ED. On the other hand, FD mitigates the deleterious impacts of GHGs on the environment by providing adequate finance for adopting eco-friendly technologies and switching to renewable energy (RE) sources (Prempeh, 2023; Qamruzzaman & Jianguo, 2020). Financial development can also reduce environmental degradation by promoting good corporate governance (Ao et al., 2023). Businesses adopting good corporate governance are more likely to use better environmental management approaches. Also, by stimulating FDI, which is often linked to promoting R&D activities, FD may lessen environmental degradation (Frankel & Romer, 1999; Prempeh, 2022). In addition, numerous recently published studies have highlighted the significance of digitally reforming the financial sector to reduce carbon intensity (Fareed et al., 2022).

Renewable energy (RE) is a realistic option for achieving carbon neutrality, as studies have shown that its use can reduce CO₂ emissions and nations reliance on energy imports (Chen et al., 2023; Li et al., 2021; Qamruzzaman & Jianguo, 2020; Sun et al., 2023). Countries must switch to RE instead of fossil fuels and maximize energy efficiency to achieve carbon neutrality by 2050. Therefore, efforts must be made to implement a global energy transition to achieve sustainable development goal (SDG) 7, which consists of three key objectives: to create dependable, cost-effective, and accessible modern energy services; to increase the proportion of RE in energy systems; in addition to accelerating the rate of energy efficiency development worldwide. The switch to RE sources is crucial since about 76% of all GHGs are caused by CO₂ emissions from fossil fuels. However, the panacea to these issues would need sizable investments in RE technologies, necessitating financial institution support. Consequently, a robust financial sector is required (Prempeh, 2023). A developed financial system can channel investments toward renewable energy projects while reducing costs and promoting the quest for eco-friendly energy (Habiba et al., 2023; Li, Li, et al., 2022; Prempeh, Kyeremeh, et al., 2023).

Recently, researchers have focused on exploring the association between globalization (GL) and environmental degradation. The theoretical underpinning is that as nations become more globalized, trade barriers decrease and income increases, causing a rise in output, thereby increasing energy demand (F. Chien et al., 2021; Q. Wang, Zhang, et al., 2023a). Globalization often facilitates the growth of polluting industries in underdeveloped countries with lax environmental regulations (Sabir & Gorus, 2019). It is feasible that domestic laws may encourage businesses to adopt environmentally friendly technology and renewable energy sources and that globalization drives businesses towards nations with weak environmental regulations. Environmental degradation occurs from transferring polluting industries from advanced to emerging economies. The pollution haven hypothesis is the name given to this phenomenon. Therefore, we may conclude that developed nations are improving their environmental quality at the expense of developing nations such as ECOWAS member nations. For instance, several ECOWAS countries have relaxed their environmental regulations to compete globally and draw FDI inflows for economic growth. The demand for energy generated from many sources, including coal and fossil fuels, rises due to industrialization, a consequence of globalization. By increasing GHG and global warming, industrialization promotes environmental degradation.

Industrialization (IND) is often addressed and seen as one of the main remedies for underdevelopment in the ECOWAS sub-region economic policy debate (Opoku & Aluko, 2021). For example, the African Development Bank views industrialization as one of the critical sectors for reshaping Sub-Saharan Africa's economy. Additionally, industrialization is vital to the African Union's Agenda 2063,

which will deliver Africa's required development and change by that year. Further, most ECOWAS leaders endorsed industrialization as a key strategy for economic growth and poverty reduction. In line with this, ECOWAS nations have implemented several policies to spur their industrialization drive. As ECOWAS nations strive to achieve economic growth and consider industrialization as one of the key strategies, they must be wary of the potentially harmful effects of industrialization on environmental quality. The process of industrialization might result in increased energy usage, the depletion of natural resources, and the unceasing use of the environment as a sink for industrial wastes, all of which would deteriorate the environment (Opoku & Aluko, 2021; Q. Wang et al., 2022).

Considering the possible effects of EG, FD, GL, RE, and IND on the environment in ECOWAS countries, this research question guides our approach to this investigation: Do EG, FD, GL, RE, and IND have heterogeneous effects on ED? To better understand the research discourse, we explore different second generation methodological approaches to respond to this question. First, unlike previous studies that overlooked the effect of cross-sectional dependence (CSD) and slope heterogeneity in their estimation, the Driscoll-Kraay panel regression model, which is resilient to CSD and slope heterogeneity and performs better as the time dimension increases, is used in this paper. Additionally, this paper uses panel quantile regression (PQR) by Powell (2022) to account for the distributional heterogeneity, as most prior studies ignored it, which might impact the outcomes. Lastly, to the best of our knowledge, no studies have explored the role of financial development, economic growth, globalization, renewable and industrialization in the context of ECOWAS using the N-shaped EKC framework. Thus, this might be the pioneering work in contributing to the global discourse on environmental degradation regarding the role of FD, EG, GL, RE and IND in the context of ECOWAS using the N-shaped EKC framework.

The remainder of the article is as follows. "Literature review" section presents the literature review. The methodology is described in "Data source and methodology" section, while the empirical outcomes and discussion are presented in "Empirical results" section. The conclusions and policy ramifications are captured in "Conclusions and policy ramifications" section.

Literature review

The literature review demonstrates that the associations among ED (CO₂ emissions), EG, FD, GL, RE and IND may be classified into five major strands. The first strand of empirical studies, which focused on the association between ED and EG, explored the validity of the EKC hypothesis. The second strand of studies focused on the FD – ED nexus, while the third strand focused on GL - ED nexus. The fourth strand of studies focused on the link between RE and ED. Lastly, the fifth strand of studies concentrated on the connection between IND and ED. Nevertheless, for ECOWAS nations, a limited number of studies are available.

Under the title of the EKC hypothesis, various studies have explored the correlation between EG and ED since the pioneering work of Grossman and Krueger (1995), for instance, Javid and Sharif (2016), Charfeddine and Ben Khediri (2016); Mrabet and Alsamara (2017), Sencer Atasoy (2017) and Du et al. (2018). However, recent investigations seem to provide conflicting empirical outcomes on the validity of the EKC hypothesis. For instance, Balsalobre-Lorente et al. (2023) conducted a study using the FMOLS, DOLS and panel quantile techniques to investigate the N-shape EKC hypothesis for European emerging economies. The empirical outcomes validated the existence of the N-shape EKC hypothesis. However, the quantile regression suggested that the N-shape EKC hypothesis is invalid for high-emission quantiles. In the case of G-20 economies from 1993 to 2017, Awan and Azam (2022) validated the N-shape EKC hypothesis using the panel Driscoll-Kraay standard error approach. Similarly, Abbasi et al. (2023), using the Driscoll Kraay standard errors model, confirmed the N-shape for a global sample consisting of 107 countries covering the period 1996 to 2014. The findings of Hatmanu and Cautisanu (2023) for EU15 nations confirmed a monotonic rising shape for Austria and Greece, a reducing monotonic shape for Luxembourg, an inverted U-shape for Finland, Germany and Ireland and an N-shape for Sweden after applying the ARDL technique to data covering the period 1960-2019. Similarly, Udeagha and Breitenbach (2023) focusing on South Africa from 1960 to 2020, confirmed the EKC hypothesis and the pollution haven hypothesis, lending support to the findings of Alsayed and Malik (2020) for African countries. On the contrary, Villanthenkodath et al. (2021) using the ARDL, found no evidence of the EKC

for India for the period 1971 to 2014. Similarly, Bakirtas and Cetin (2017) failed to confirm the EKC hypothesis for the MIKTA (Mexico, Indonesia, South Korea, Turkey, and Australia) nations for the period 1982 to 2011 using a panel vector autoregressive (PVAR) method. In the case of 46 SSA countries, Acheampong (2019) failed to confirm the existence of the EKC hypothesis, which contradicts the findings of Acheampong et al. (2019), which found support for the EKC hypothesis in 46 SSA countries.

The second strand of studies focused on the FD-ED nexus. Tao et al. (2023) found that FD significantly hampers ED in OECD countries. Shang et al. (2023), using the ARDL approach, found that FD substantially reduces CO₂ emissions in China. Ofori et al. (2023) concluded that the impact of FD on ED is contingent on the indicator of FD. Their study demonstrated that domestic credit to the private sector (financial development index) as a measure of financial development significantly increases (reduces) environmental pollution. Yang et al. (2021) using a panel of BICS nations, found a deleterious impact of FD on environmental quality for the period 1990–2016. Qalati et al. (2023) using a panel of developed countries, concluded that low ecological quality is associated with high FD after exploring the nexus for developed and emerging economies covering the period 1990–2019. Habiba et al. (2023) investigated the association between FD and CO₂ emission for a panel comprising E-7 nations for the period 1990–2020. Using the augmented mean group (AMG) estimator, they concluded that FD increases CO₂ emissions. Acheampong et al. (2019) show that FD contributed substantially to CO₂ emissions in SSA from 1980 to 2015 based on the fixed and random effect regression estimates. However, Acheampong (2019) using a panel of 46 SSA countries, found that FD has a neutral impact on ED. Similarly, Charfeddine and Kahia (2019) concluded that FD does not influence ED in the MENA region.

The third strand of literature is on the globalization–carbon emission nexus. Patel and Mehta (2023) using yearly time series data and the NARDL, found that GL considerably reduces environmental pollution in India. Ebaidalla and Abusin (2022) using mean group (MG) and augmented mean group (AMG) techniques and data spanning 1995–2018, concluded that GL reduces ED in the GCC countries. A study by Weimin et al. (2022) highlighted the beneficial influence of GL on ecological quality by curbing CO₂ emissions. Sultana et al. (2023) examined how GL influenced CO₂ emissions in N-11 countries from 1990 to 2019. Using the method of moments PQR, it was found that GL significantly harms environmental quality by increasing CO₂ emissions. Likewise, Sadiq et al. (2023) established the deleterious impact of GL on CO₂ emissions. Kostakis et al. (2023) demonstrated that GL is negatively associated with ED in the MENA. In the case of Indonesia, Rasool et al. (2023) concluded that economic GL promotes ED, while social GL impedes ED. However, political GL has a neutral impact on ED. Studies such as Rani et al. (2022), Acheampong (2022), Primbetova et al. (2022) and Taiwo et al. (2021) further demonstrated the deleterious impact of GL on environmental quality.

The fourth strand of literature explores the association between RE usage and ED. In a recent study, Sun et al. (2023) examined the impact of RE on ED in China. The outcome of the generalized method of moments (GMM) model demonstrated that RE reduced ED. Chen et al. (2023) used the ARIMA (Autoregressive Integrated Moving Average) regression model to investigate the role of RE usage in reducing CO₂ emissions in China from 1990 to 2022. The outcomes of the analysis suggest that RE lowers CO₂ emissions. Muhammad and Khan (2021) discussed the influence of RE consumption on CO₂ emissions. Analyzing a panel of 31 developed and 155 developing nations from 1991 to 2018 revealed a negative interaction between ED and RE consumption in developed and developing countries. Using the panel quantile regression, Hayat et al. (2023) concluded that RE usage significantly promotes environmental quality, and the impact is much more pronounced in higher quantiles in OECD from 1990 to 2020. Similarly, Chien et al. (2021), Yan et al. (2023), Peng et al. (2023), Hussain et al. (2023), and Khan et al. (2023) confirmed that RE usage substantially improves environmental quality. However, Dong et al. (2020) discovered that RE did not impact CO₂ emissions utilizing a global panel of 120 countries.

Lastly, the fifth strand of literature examines the impact of industrialization on environmental degradation. Aluko and Obalade (2020) utilizing a panel of 35 SSA economies found that lower environmental quality is linked to a rise in industrialization. On the contrary, Ayad et al. (2023) showed that industrialization significantly hinders environmental degradation in the USA. Opoku and Aluko (2021) employed the PQR to investigate the effect of industrialization on the environment from 2000 to 2016 using data from 37 African countries. Their findings demonstrated that industrialization increased ED in low-emission countries and reduced ED in medium to high-emission countries. Using a sample of 21 MENA and

34 OECD countries, Wang and Taghvaei (2023) concluded that industrialization increases environmental pollution in MENA and developing nations but reduces environmental pollution in OECD and developed nations. Musah et al. (2022) using a balanced panel of 16 West African countries for the period 1990–2016, found that industrialization has a deleterious impact on environmental sustainability. Daniyal et al. (2023), focusing on Pakistan from 1960 to 2018, found that industrialization has a neutral effect on ED. Ali et al. (2023), using the quantile-on-quantile model, concluded that industrialization is negatively associated with ED in Saudi Arabia.

From the literature discussed, it is clear that there are some divergent and inconclusive results regarding the associations among ED, EG, FD, GL, RE and IND. Indeed, the evidence for the EKC hypothesis and the role of EG, FD, GL, RE and IND in reducing ED on the African continent, specifically the ECOWAS region, is limited. In addition, most prior studies have accounted for the impact of EC and EG on ED. In contrast, only a few studies have shed light on the relationship between FD, GL, RE and other determinants of ED in the EKC framework. Furthermore, to the best of our knowledge, no studies have employed parametric and non-parametric studies to investigate the impact of EG, FD, GL, RE and IND on ED. To address this lacuna in the literature, this study uses the Driscoll-Kraay covariance estimator that does not restrict the limiting behaviour of the panels and produces robust standard errors and is also robust to CSD and slope heterogeneity. The study addresses the issue of distributional heterogeneity using the PQR model suggested by Powell (2022) with nonadditive fixed effects since most earlier studies overlook it, which might have a negative impact on the results. As shown by Kishwar et al. (2023) and Aljadani et al. (2023), the association between ED and its determinants is sensitive to outliers in the data. To ensure the robustness of the estimations, the PQR coefficients were determined using the dynamic Markov Chain Monte Carlo (MCMC) algorithm. This approach will allow empirical analyses to observe the validation of the EKC at different quantiles. Therefore, the paper offers new insights into the existing literature on ED in the context of ECOWAS concerning EG, FD, GL, RE and IND. Moreover, our study incorporated FD, GL, RE and IND in the framework of the EKC.

Data source and methodology

Data and descriptive statistics

To achieve the stated objectives of this paper, we used a balanced dataset for ten Economic Community of West African States (Benin, Burkina Faso, Cabo Verde, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Sierra Leone, and Togo) covering the period 1990–2019. Only nations that had data for the chosen variables were selected. CO₂ (emissions per capita) was adopted as a measure of environmental degradation (ED) (Q. Wang & Zhang, 2021), and financial development (FD) is proxied by domestic credit to the private sector by banks (% of GDP) (Prempeh, Yeboah, et al., 2023), GDP per capita (constant 2015 US\$) measures economic growth (EG) (Li, Wang, et al., 2022). Renewable energy consumption (RE) is measured by renewable energy consumption (% of total usage) (Q. Wang, Zhang, et al., 2023b). Industrialization (IND) is the contribution of the industry sector (including construction) value added (% of GDP) (Opoku & Aluko, 2021). Data on the mentioned variables are obtained from the World Development Indicators (WDI) database. In addition to these variables, globalization was measured by the KOF globalization index, which captures economic, political and social globalization. The KOF Swiss Economic Institute's database serves as the source of information for the KOF globalization index (Kishwar et al., 2023). All variables have been transformed into their natural logarithmic forms for easy analysis and interpretation of results. Table 1 presents descriptive statistics for the variables.

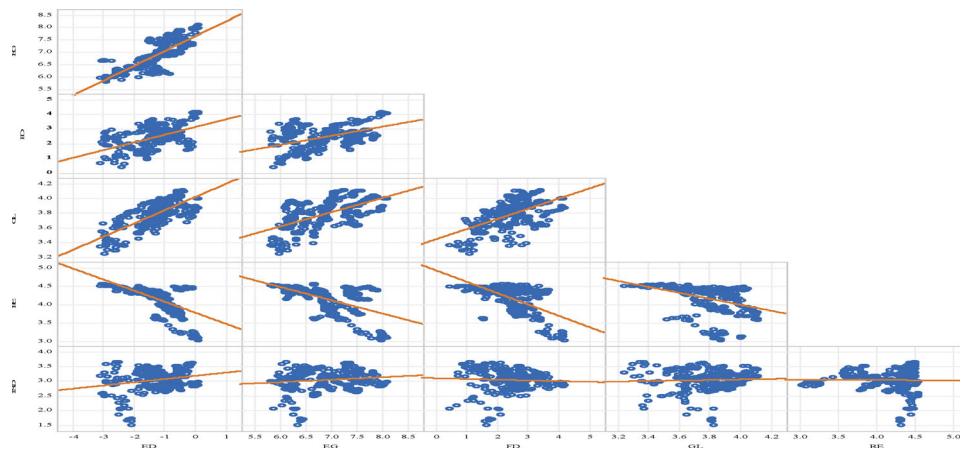
Table 1 unveils the descriptive statistics of the variables, and it can be seen that the EG mean value is the highest, followed by RE, GL, IND, FD and ED. The standard deviation illustrates how robust the data are around the mean; the smaller the standard deviation, the more concentrated the data around the mean. Based on this assumption, GL is more concentrated around its mean, followed by IND, RE, EG, FD and ED. Except for EG, all the variables are negatively skewed. All the variables except RE and IND, which have a leptokurtic distribution, can be seen to have a platykurtic distribution. The Jarque-Bera test statistics suggest that all the variables under study except FD are non-normal, necessitating a non-linear estimation approach that can produce robust results. So, this paper is motivated to use the PQR

Table 1. Descriptive statistics and pairwise correlation matrix.

	<i>lnED</i>	<i>lnEG</i>	<i>lnFD</i>	<i>lnGL</i>	<i>lnRE</i>	<i>lnIND</i>
Mean	−1.294	6.867	2.465	3.786	4.169	3.043
Median	−1.206	6.868	2.529	3.813	4.323	3.093
Maximum	0.119	8.107	4.179	4.114	4.554	3.659
Minimum	−3.108	5.809	0.420	3.246	3.034	1.516
Std. Dev.	0.779	0.580	0.766	0.189	0.371	0.357
Skewness	−0.444	0.190	−0.103	−0.553	−1.397	−1.342
Kurtosis	2.510	2.009	2.738	2.861	4.162	6.141
Jarque-Bera	12.836***	14.086***	1.388	15.537***	114.402***	213.448***
Observations	300	300	300	300	300	300
ED	1					
EG	0.801***	1				
FD	0.531***	0.468***	1			
GL	0.739***	0.594***	0.558***	1		
RE	−0.630***	−0.564***	−0.634***	−0.412***	1	
IND	0.239***	0.137**	−0.053	0.049	−0.012	1

Note. *** and ** indicates 1% and 5% significance, respectively.

Source: Computed by Author.

**Figure 2.** Scatter plots of the lower triangular matrix.

Source: Figure created by Author.

approach, which offers comprehensive insights into the model. Since the regressors have modest correlation coefficients, with the maximum correlation coefficient being 0.634, multicollinearity among the regressors was ruled out in conformity with Gujarati (2004). Figure 2 graphically depicts the scatter plots of the lower triangular matrix of the variables under study, while Figure 3 displays the trend of the variables.

Theoretical framework

The N-shaped EKC served as the main source for the theoretical foundation model employed in this work. The general structure for assessing different N-shaped EKC types is as follows:

$$ED = f(EG, EG^2, EG^3, Z) \quad (1)$$

where *ED* represents environmental degradation, *EG* denotes economic growth or GDP per capita, EG^2 is the square of GDP per capita, EG^3 is the cube of GDP per capita, and *Z* symbolises the other variables. In this investigation, CO_2 emission was taken as the measure of environmental degradation; thus, the N-shaped EKC is expressed in the expanded form with the other critical variables as:

$$ED = f(EG, EG^2, EG^3, FD, GL, RE, IND) \quad (2)$$

where *FD* is financial development, *GL* represents globalization, *RE* is renewable energy consumption, and *IND* is industrialization. *EG* is economic growth, and EG^2 and EG^3 are the square and cube of the measure of economic growth to support the existence of the N-shaped EKC assumption in the

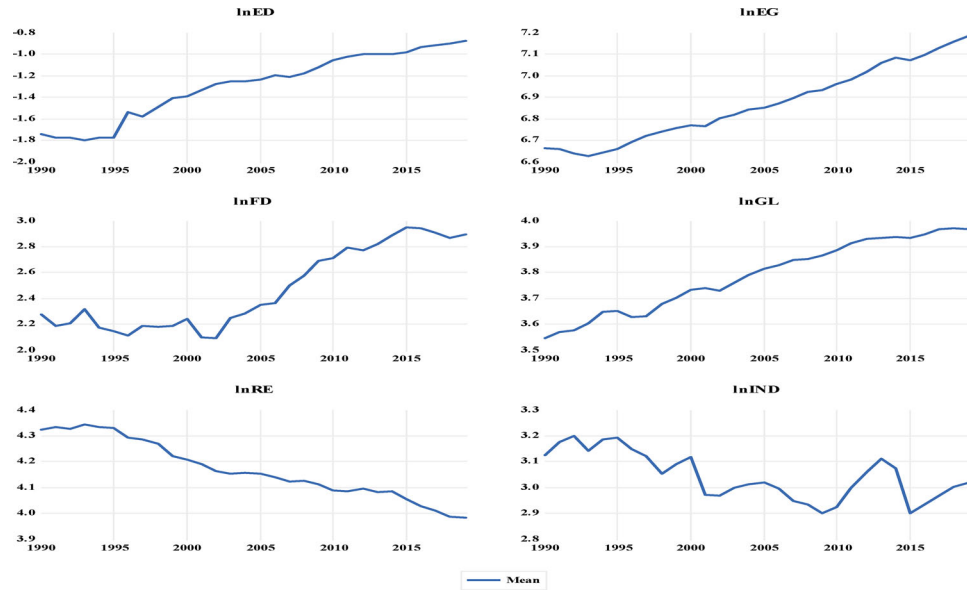


Figure 3. Trends of variables employed in the analysis.

Source: Figure created by Author.

framework. We then convert Eq. (2) into the natural log format to generate Eq. (3):

$$\ln ED_{it} = \mu_{it} + \alpha_1 \ln EG_{it} + \alpha_2 EG_{it}^2 + \alpha_3 EG_{it}^3 + \alpha_4 \ln FD_{it} + \alpha_5 \ln GL_{it} + \alpha_6 \ln RE_{it} + \alpha_7 \ln IND_{it} + \varepsilon_{it} \quad (3)$$

where μ is the intercept in the model, i represents the nations in the panel, and t is the period. ε_{it} is the stochastic error term. The significant positive, negative and positive coefficients of EG , EG^2 and EG^3 will validate the N-shaped EKC hypothesis as demonstrated by Eq. (3).

Panel regression

To explore the EKC hypothesis in ECOWAS, the paper employed the Driscoll-Kraay panel regression model and the coefficients were computed using the fix effects algorithm. One of the critical issues associated with panel data is CSD (spatial) and temporal dependence, which, if not addressed, might lead to spurious estimates. Consequently, the study used the Driscoll and Kraay (1998) approach, which has been applied in comparable studies (Awan & Azam, 2022; Özokcu & Özdemir, 2017; Prempeh, Yeboah, et al., 2023). The approach considers CSD and produces resilient and reliable estimates. According to the Driscoll-Kraay technique, the standard errors are autocorrelated, heteroscedastic up to a certain lag, and correlated across the groups in the panel. Additionally, it is non-parametric, which allows for greater flexibility without imposing any limitations and is most suitable as the time dimension increases; thus, this technique works with both balanced and unbalanced panel data and can accommodate missing data values. This study employs Driscoll-Kraay standard errors for pooled ordinary least squares (OLS) estimation by considering a linear model expressed as:

$$y_{i,t} = X'_{i,t} \delta + \varepsilon_{i,t}, i = 1, \dots, N, t = 1, \dots, T \quad (4)$$

where $y_{i,t}$ is the dependent variable ($\ln ED$) and is a scalar, $X_{i,t}$ represents the regressors ($\ln EG$, $\ln EG^2$, $\ln EG^3$, $\ln FD$, $\ln GL$, $\ln RE$ and $\ln IND$) with a $(K + 1) \times 1$ vector, whose initial value is 1, and δ is the unidentified parameters with $(K + 1) \times 1$ vector, i denotes the individual nations at time t .

After adding each observation, the following equation is derived:

$$y = [y_1, t_{1,1}, \dots, y_1 T_1 \quad y_2, t_{2,1}, \dots, y_N T_N]' \text{ and } X = [x_1, t_{1,1}, \dots, x_1 T_1 \quad x_2, t_{2,1}, \dots, x_N T_N]' \quad (5)$$

For any s, t (strong exogeneity), it is presumed that $X_{i,t}$ are uncorrelated with the scalar error term ε_{is} . However, $\varepsilon_{i,t}$ might display CSD, autocorrelation, and heteroscedasticity. According to the stated

assumptions, δ may be reliably predicted via OLS regression, yielding (Hoechle, 2007):

$$\hat{\delta} = (X'X)^{-1}X'y \quad (6)$$

For simplicity, the square roots \hat{S}_T of the diagonal components of the asymptotic covariance matrix are used to compute the Driscoll-Kraay standard error coefficients, which are then represented as follows in accordance with Driscoll and Kraay (1998):

$$V(\hat{\delta}) = (X'X)^{-1}\hat{S}_T(X'X)^{-1} \quad (7)$$

The EKC hypothesis is tested in each country singly using the U test (see Lind & Mehlum, 2010) after estimating the Driscoll-Kraay panel regression.

Panel quantile regression (PQR)

This part offers the Powell (2022) PQR estimator that preserves the non-separable noisy term for PQR estimation while using nonadditive fixed effects. With the premise that time-varying elements only impact the variance of parameters, this estimate approach differs from traditional PQR estimators by including additive fixed-effects and discrete noisy terms in the quantile estimation (Sarkodie & Strezov, 2019; Zhu et al., 2016). The distribution of the dependent variable $Y_{i,t}$ is estimated using PQR for independent variables $D_{i,t}$. To keep the non-separable noisy term often associated with PQR estimation, the study models the result using a nonadditive fixed effect, which is written as follows:

$$Y_{i,t} = D'_{i,t}\delta(Z^*_{i,t}), Z^*_{i,t} \sim Z(0,1) \quad (8)$$

where $D'_{i,t}\delta(\tau)$ strictly increases in quantile τ , $Z^*_{i,t}$ represents the function of the disturbance terms. Equation (8) is then expressed in quantile form as:

$$Q_Y(\tau/d) = d'\delta(\tau), \tau \in (0,1) \quad (9)$$

Equation (9) describes the quantile of the implicit response variable $Y_d = d'\delta(Z^*)$ for randomly chosen $Z^* \sim Z(0,1)$ and a constant possible value of the treatment effect d . Grounded on Eq. (9), the paper specifies the conditional quantile function to investigate the impact of EG, FD, GL, RE and IND on ED as follows:

$$\begin{aligned} \ln ED_{i,t}(\tau|\varphi_i, \beta_t, x_{i,t}) = & \varphi_i + \beta_t + \delta_{1,\tau} \ln EG_{i,t} + \delta_{2,\tau} \ln EG^2_{i,t} + \delta_{3,\tau} \ln EG^3_{i,t} + \delta_{4,\tau} \ln FD_{i,t} + \delta_{5,\tau} \ln GL_{i,t} \\ & + \delta_{6,\tau} \ln RE_{i,t} + \delta_{7,\tau} \ln IND_{i,t} \end{aligned} \quad (10)$$

where φ_i is the nonadditive fixed effects, x represents the matrix of regressors at individual nations i at time t . We perform a numerical optimization through the adaptive MCMC sampling using multivariate normal proposal distribution by Baker (2014) to improve the robustness of the PQR estimates. Depending on the sign of the individual γ parameters related to ED, the EKC will assume different shapes (Aljadani et al., 2023; Allard et al., 2018).

- If $\delta_1 > 0$, $\delta_2 < 0$ and $\delta_3 > 0$, then we will observe the classical N-shaped EKC.
- If $\delta_1 < 0$, $\delta > 0$ and $\delta_3 < 0$, then we will observe an inverted N-shaped EKC
- If $\delta_1 < 0$, $\delta_2 > 0$ and $\delta_3 = 0$, then we will observe a U-shaped EKC
- If $\delta_1 > 0$, $\delta_2 < 0$ and $\delta_3 = 0$, then we will observe the classical inverted U-shaped EKC

We specify the cointegrating associations as follows:

$$\ln ED_{i,t} = \vartheta_i + \delta_1 \ln EG_{i,t} + \delta_2 \ln EG^2_{i,t} + \delta_3 \ln EG^3_{i,t} + \delta_4 \ln FD_{i,t} + \delta_5 \ln GL_{i,t} + \delta_6 \ln RE_{i,t} + \delta_7 \ln IND_{i,t} + \varepsilon_{i,t} \quad (11)$$

where ϑ_i represents the panel-specific fixed effect, $\delta_1, \dots, \delta_7$ are the cointegrating parameters constant across the panel, and ε denotes the error term. The study utilized three cointegration approaches, namely Kao (1999), Pedroni (1999, 2004) and Westerlund (2005)² to investigate the cointegration associations among the variables.

Empirical results

In most cases, studies using panel data fail to consider the issue of CSD and slope homogeneity, which may result in biased estimations and conclusions. Therefore, the paper used four distinct CSD approaches, namely Breusch- Pagan LM, Pesaran scaled LM, and Pesaran CSD tests, to investigate the presence of CSD. Table 2 demonstrates the existence of CSD in all the variables. This indicates that the residual terms contain common shocks across cross-sections due to economic integration. The study further applied the slope homogeneity test developed by Pesaran and Yamagata (2008) and a recent one by Blomquist and Westerlund (2013) which is robust to heteroskedastic and serially correlated errors (HAC). The two tests failed to confirm slope homogeneity in the model, as demonstrated in Table 3. This suggests that the coefficients of the model are heterogeneous, and the slope varies depending on the nation under consideration. Thus, the model suffers from heterogeneity problems and wrong conclusions might be drawn if analysis techniques that assume strict slope homogeneity are used. The CSD and slope heterogeneity results suggest that the second-generation panel unit tests would be more appropriate in exploring the unit root properties of the variables compared to the first generation.

The next step in our econometric analysis is to check the stationarity properties of the variables as it has been observed in literature that non-stationary data may lead to spurious regression results. To ascertain the stationarity properties of the data, the study employed three second-generation panel stationarity tests named Breitung and Das (2005), Pesaran CADF and CIPS stationarity tests proposed by Pesaran (2007). Table 4 reports the outcome of the panel unit root tests which shows that all the tests failed to reject the null hypothesis at level except for IND, where the null was rejected by the Breitung and Das and CIPS tests. However, after the first differencing, all the variables became stationary in all three tests. Thus, we can proceed to check if the variables are cointegrated.

As the panel unit root tests suggest, the variables are $I(1)$. We proceed to explore the possibility of a long-run association among these variables using the Kao, Pedroni and Westerlund cointegration tests. It is worth noting that the Kao and Pedroni first-generation cointegration test does not consider the presence of CSD in the series, whereas the Westerlund second-generation cointegration test considers the presence of CSD in the series. Notwithstanding, all three cointegration tests, as shown in Table 5, validate the cointegrated associations among the variables.

The paper first estimates the panel regression using Driscoll-Kraay standard errors to allow for comparison. Table 6 reports the outcome of the level-log panel data with the Driscoll-Kraay standard errors estimated by fixed-effect regression and the average marginal effect of post-estimation. The results suggest that all the coefficients of the EKC hypothesis are significant at the 5% level. The nexus between EG and ED is initially positive; thus, increases in ED are associated with increases in EG until it reaches the turning point in EG, where a further rise in EG decreases ED and increases ED afterwards. Hence, the Driscoll-Kraay panel regression validates the classical N-shaped EKC hypothesis for the ECOWAS region as the predicted signs of the coefficients attached to EG, EG^2 , and EG^3 are positive, negative and positive, respectively. Thus, the empirical analysis confirms the nonlinear connection between EG and ED. In the early stage of development, the observed outcome demonstrates that efforts to raise income levels in low-income countries lead to increased ED as the scale and composition effect prioritizes EG over environmental quality, thereby achieving EG at the expense of environmental quality. After attaining middle income, further increase in EG decreases ED due to technical effects, which puts much emphasis on environmental quality. This is followed by the rise in ED due to the technical obsolesce effect at high-income levels. The findings corroborate the findings of Balsalobre-Lorente et al. (2023), Aljadani et al. (2023) and Sarkodie and Strezov (2019) for developing economies. Figure 3 illustrates how the

Table 2. Cross-sectional dependency test results.

Test	$\ln ED$	$\ln EG$	$\ln FD$	$\ln GL$	$\ln RE$	$\ln IND$
Breusch-Pagan LM	757.979***	742.276***	443.557***	1142.536***	595.853***	342.900***
Pesaran scaled LM	75.155***	73.499***	42.012***	115.690***	58.065***	31.401***
Bias-corrected scaled LM	74.982***	73.327***	41.839***	115.518***	57.893***	31.229***
Pesaran CSD	15.714***	25.453***	16.975***	33.763***	22.092***	13.196***

Note. *** indicates 1% significance.

Source: Computed by Author.

Table 3. Outcome of slope coefficient homogeneity test.

Test	Test statistic	p-value
$\tilde{\Delta}$	10.956	0.000
$\tilde{\Delta}_{adj.}$	13.245	0.000
$\tilde{\Delta}$ (HAC)	−2.715	0.007
$\tilde{\Delta}_{adj.}$ (HAC)	−3.245	0.001

Note. H_0 : slope coefficients are homogenous.

Source: Computed by Author.

Table 4. Panel unit root tests.

	<i>ln</i> ED	<i>ln</i> EG	<i>ln</i> FD	<i>ln</i> GL	<i>ln</i> RE	<i>ln</i> IND
<i>Level</i>						
Breitung and Das test	3.876	7.466	−0.381	4.411	3.912	−1.855**
CADF test	−1.847	−1.574	−1.321	−1.255	−1.589	−1.761
CIPS test	−1.492	−1.430	−1.726	−1.253	−1.691	−2.438**
<i>1st difference</i>						
Breitung and Das test	−7.921***	−6.371***	−7.615***	−6.171***	−8.828***	−8.849***
CADF test	−2.767 ***	−3.752***	−3.169***	−3.004***	−2.456**	−3.250***
CIPS test	−5.100***	−4.104***	−4.399***	−5.083***	−4.882***	−5.825***

Notes: ***, **, and * indicate significance at 1, 5, and 10% levels, respectively.

Source: Computed by Author.

Table 5. Results of panel cointegration tests.

	Statistic	p-value
<i>Panel A: Kao test for cointegration</i>		
Modified Dickey-Fuller t	−3.0683	0.0011
Dickey-Fuller t	−3.0617	0.0011
Augmented Dickey-Fuller t	−3.3836	0.0004
Unadjusted modified Dickey-Fuller t	−5.2281	0.000
Unadjusted Dickey-Fuller t	−3.8348	0.0001
<i>Panel B: Pedroni test for cointegration</i>		
Modified Phillips-Perron t	3.120	0.001
Phillips-Perron t	−2.169	0.015
Augmented Dickey-Fuller t	−2.487	0.006
<i>Panel C: Westerlund cointegration test</i>		
Variance ratio	2.394	0.008

Source: Computed by Author.

Table 6. Regression with Driscoll-Kraay standard errors and average marginal effects.

	Coefficient	std. err	t	$P > t $	dy/dx	std. err	z	$P > z $
<i>ln</i> EG	54.486	16.972	3.21	0.011	54.486	16.972	3.210	0.001
<i>ln</i> EG ²	−7.706	2.468	−3.12	0.012	−7.706	2.468	−3.120	0.002
<i>ln</i> EG ³	0.360	0.118	3.05	0.014	0.360	0.118	3.050	0.002
<i>ln</i> FD	−0.078	0.026	−2.98	0.015	−0.078	0.026	−2.98	0.003
<i>ln</i> GL	0.448	0.149	3.01	0.015	0.448	0.149	3.000	0.003
<i>ln</i> RE	−2.556	0.255	−10.01	0.00	−2.556	0.255	−10.010	0.000
<i>ln</i> IND	0.093	0.038	2.48	0.035	0.093	0.038	2.480	0.013
_cons	−119.718	38.247	−3.13	0.012				
R-squared	0.843							
Prob > F	0.000							

Source: Computed by Author.

association between EG and ED moves from low to high income in the case of the selected ECOWAS nation, transitioning from the scale effect to the technical obsolescence stage.

FD significantly mitigates ED. This result supports previous studies conducted by Tao et al. (2023) for OECD countries, Shang et al. (2023) for China and Aluko and Obalade (2020) for SSA countries. They argued that FD improves ED by channelling investment/funds towards eco-friendly projects. Also, developed financial sectors attract FDI inflows from multinational companies with eco-friendly technologies to the host nations, reducing ED, which is well explained by the pollution halo hypothesis. However, this result contradicts the findings of Jianguo et al. (2022), Yang et al. (2021) and Aljadani et al. (2023), who argued that FD promotes ED by providing credit to households or companies, which enables them to expand or acquire energy-intensive appliances and equipment.

In terms of the influence of GL on ED, the results suggest that GL significantly promotes ED in ECOWAS. GL increases human needs, resulting in greater resource utilization and atmospheric pollution, while it can introduce energy-intensive technologies leading to ED. As GL leads to growing demand, the resultant impact is increased manufacturing activity. However, greater output is associated with higher resource usage and energy use. Indirectly, this contributes to ED and the depletion of natural resources (Sun et al., 2021). Also, the results suggest that GL policies implemented by ECOWAS nations do not promote environmental quality. The positive asocial between GL and ED in this paper aligns with those of Chien et al. (2021), Sultana et al. (2023), Rani et al. (2022), Acheampong (2022), Primbetova et al. (2022) and Taiwo et al. (2021). Our findings, however, contradict that of Patel and Mehta (2023) and Shahbaz et al. (2021), who argued that with an increase in GL, there would be a faster inflow of knowledge, capital and green technologies that help improve environmental quality. Also, GL encourages global trade and FDI inflows from developed economies to developing economies for investments in eco-friendly technologies.

In addition, the empirical results suggest that shifting from fossil fuel usage to RE mitigates ED. RE offers alternative sources of energy that may enable economies to attain their development agenda while maintaining environmental quality. RE has a statistically significant link with ED, as a 1% rise in RE results in a 2.56% drop in ecological degradation. Embracing RE discourages the use of fossil fuels in the energy mix. For instance, by substituting renewable power for electricity produced from fossil fuels, emissions from energy production may be reduced. RE may also indirectly assist lower ED by decreasing energy usage. For example, energy-efficient appliances and buildings consume less energy, which may help decrease energy requirements. As a result, lower fossil fuels will be used to produce energy, hence reducing emissions. Moreover, there is a dire need to introduce modern energy sources to regulate emissions levels to enhance environmental quality and EG. The results confirm the results of Chien et al. (2021), Muhammad and Khan (2021), Fareed et al. (2022), Sun et al. (2023), Hayat et al. (2023), Peng et al. (2023), for different periods and economies. However, our findings contradict the findings of Menyah and Wolde-Rufael (2010) and Apergis et al. (2010). Apergis et al. (2010) argue that RE supply cannot be relied on to meet peaks in demand. Consequently, a backup to traditional energy sources is required, and this would typically make use of fossil fuels.

Lastly, IND is directly linked to ED as the industrial sector heavily depends on energy input derived from fossil fuels responsible for CO₂ emissions. Several industrial and manufacturing operations cause ED. For example, making cement, steel, and aluminium consumes a great deal of energy and releases GHGs into the atmosphere. Our findings buttress the claims of Aluko and Obalade (2020), Opoku and Aluko (2021), Musah et al. (2022) and Wang and Taghvae (2023). Ahmed et al. (2022) opine that as developing nations such as ECOWAS countries transform from agrarian economies to industrialization, pollution-intensive industrial production initially increases and substantially contributes to environmental degradation.

To determine the validity of the panel regression results, the paper applies the average marginal effects as a post-estimation technique; the findings are shown in columns 6 to 9 of Table 6. With some or all covariates fixed, this post-estimation technique estimates and publishes values based on a fitted model. The average marginal effects estimation yields coefficients identical to those in the panel regression estimates but have resilient *p*-values, consequently corroborating the earlier results at a 1% significance level.

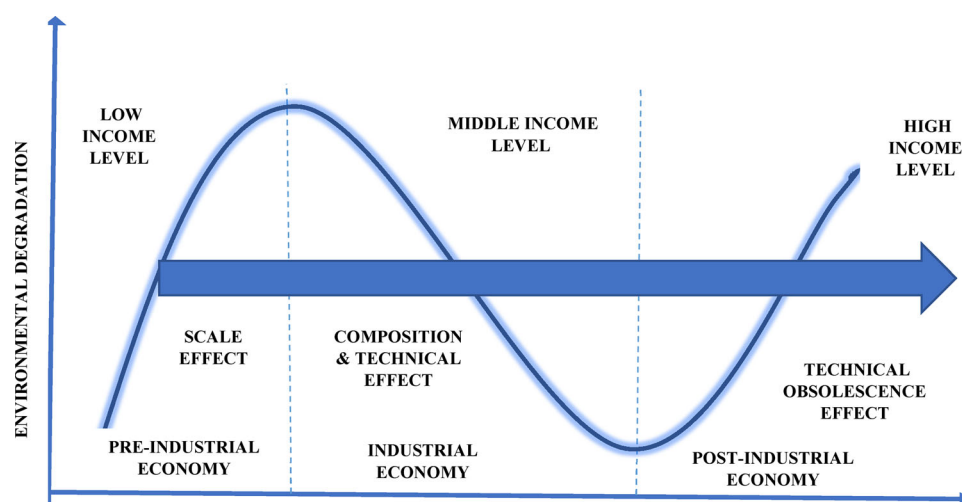
We explore the EKC hypothesis for each country using the *U* test estimation approach to support the findings of the Driscoll-Kraay panel regression. The outcomes of the *U* test estimates are shown in Table 7, demonstrating three distinct associations between ED and EG. First, the inverse U-shape EKC only holds for Nigeria at a turning point of US\$ 2628.24 at the 5% significance level. As shown in Figure 4, ED gradually declines at higher levels of economic development due to increased environmental cognizance, the implementation of environmental regulations, laws and policies, substantial ecological cost, technological advancements, and structural shifts toward energy- and carbon-intensive industries and services. A U-shape association holds for Benin, Ghana, Senegal and Togo at inflexion points of US\$ 1084.25, US\$ 1949.29, US\$ 1345.25 and US\$ 523.07, respectively. Lastly, a monotone association between EG and ED for Burkina Faso, Cabo Verde, Cote d'Ivoire, Guinea and Sierra Leone at a turning point of US\$ -1167.76, US\$ 4257.04, US\$ 1374.36, US\$ 1258.14 and US\$ -865.21. The negative turning point for

Table 7. U test estimation results.

Benin			Burkina Faso		
	Lower bound	Upper bound		Lower bound	Upper bound
Interval	771.076	1153.726	Interval	333.172	716.012
Slope	0.015	−0.003	Slope	0.004	0.005
t-Value	1.122	−0.288	t-value		
P > t	0.135	0.388	P > t		
Turns ^a	1084.249		Turns	−1167.758	
Shape ^b	U shape		Shape	Monotone	
Cabo Verde			Cote d'Ivoire		
Lower bound		Upper bound	Lower bound		Upper bound
Interval	780.689	3318.933	Interval	1507.090	2289.377
Slope	0.001	0.000	Slope	0.0001297	0.001
t-Value			t-Value		
P > t			P > t		
Turns	4257.042		Turns	1374.362	
Shape	Monotone		Shape	Monotone	
Ghana			Guinea		
Lower bound		Upper bound	Lower bound		Upper bound
Interval	852.431	1981.636	Interval	547.272	937.703
Slope	0.002	−0.00006	Slope	0.002	0.00106
t-Value	0.536	−0.015	t-value		
P > t	0.298	0.494	P > t		
Turns	1949.285		Turns	1258.135	
Shape	U shape		Shape	Monotone	
Nigeria			Senegal		
Lower bound		Upper bound	Lower bound		Upper bound
Interval	1429.012	2679.555	Interval	957.688	1409.971
Slope	−0.001	0.00003	Slope	0.005	−0.00076
t-Value	−0.303	0.011	t-value	0.616	−0.104
P > t	0.382	0.496	P > t	0.271	0.459
Turns	2628.239		Turns	1345.249	
Shape	Inverse U shape		Shape	U shape	
Sierra Leone			Togo		
Lower bound		Upper bound	Lower bound		Upper bound
Interval	356.295	744.070	Interval	398.027	618.491
Slope	0.002	0.00268	Slope	0.004	−0.00314
t-Value			t-value	0.149	−0.128
P > t			P > t	0.441	0.450
Turns	−865.207		Turns	523.067	
Shape	Monotone		Shape	U shape	

^aRepresents a turning point.^bRepresents the interpretation.

Source: Computed by Author.

**Figure 4.** N-shaped EKC for the ECOWAS region.

Source: Figure created by Author.

Table 8. Outcome of panel quantile analysis.

Quantile	Model	$\ln EG$	$\ln EG^2$	$\ln EG^3$	$\ln FD$	$\ln GL$	$\ln RE$	$\ln IND$
25	Coef	11.660***	−1.512***	0.069***	−0.144***	1.529***	−0.716***	0.305***
		[0.667]	[0.094]	[0.004]	[0.010]	[0.061]	[0.019]	[0.011]
50	Coef	36.2.6***	−4.990***	0.232***	−0.023	1.169***	−0.629***	0.201***
		[12.768]	[1.798]	[0.084]	[0.019]	[0.128]	[0.024]	[0.022]
75	Coef	−20.049***	2.958***	−1.422***	−0.117***	1.181***	−0.571***	0.172***
		[2.444]	[0.349]	[0.017]	[0.025]	[0.098]	[0.055]	[0.050]

Source: Computed by Author.

Burkina Faso and Sierra Leone indicates an economic recession, shocks associated with international economic sanctions or political instability emanating from coup d'états. The monotone association between EG and ED confirms the scale effect. Extraction of minerals and agricultural productivity rise as EG intensifies. EG boosts IND, which adds value to exploited natural resources and agricultural production, depletes natural resources faster and increases waste volume and toxicity (Sarkodie & Strezov, 2018).

The PQR estimator created by Powell (2022) is used to assess the distributional and heterogeneous impact of EG, FD, GL, RE, and IND on ED. The analysis is executed by clustering the selected countries in terms of low emitters (25th quantile), medium emitters (50th quantile) and high emitters (75th quantile). The quantile estimates in Table 8 show that the classical N-shape EKC is valid for low and medium emitters. Contrary to our expectation, the inverted N-shape is valid for high emitters. Hence, we do not find support for the existence of the N-shape EKC for high emitters. On the other hand, FD significantly reduces ED in low and high emitters while having a neutral effect on medium emitters. This outcome is incompatible with the conclusions of Kishwar et al. (2023), which demonstrated that FD has promoted EG at the expense of environmental quality. Also, this finding differs from that of Halliru et al. (2020) for West African states. A plausible explanation might be the difference in the period under study, the sample employed, and the econometric approach utilized. GL homogeneously promotes ED in all quantiles. However, as displayed by the magnitude of the impacts, the marginal effects are relatively pronounced for low emitters. This suggests that GL hurts the environmental quality the most in less polluted nations. This resonates with the conclusions of Balsalobre-Lorente et al. (2023) for emerging economies in Europe. The quantile estimates further indicate that RE homogeneously reduces ED in all quantiles. This finding is supported by Chien (2022) and Mujtaba et al. (2022) for N-11 and OECD economies, respectively. However, the impact is relatively higher in low emitters. This finding suggests that promoting environmental quality through RE is more compelling in less polluted countries. It is, therefore, crucial for ECOWAS leaders to develop and implement renewable energy transition policies as soon as possible. However, this result disagrees with the findings of Murshed et al. (2022), who suggested that RE has a neutral impact on CO₂ emissions in E7 countries. They argued that the share of RE in the total energy mix is around 20%; thus, a marginal increase in RE might not be adequate in reducing or increasing the level of CO₂ emissions in E7 nations. Lastly, consistent with economic theory and previous studies (Kirikkaleli & Kalmaz, 2020; Prempeh, Yeboah, et al., 2023; F. Wang & Taghvaei, 2023) we establish that IND has a deleterious impact on environmental quality in all emission quantiles.

Conclusions and policy ramifications

The current paper explored the role of five key variables (FD, EG, GL, RE and IND) in mitigating environmental degradation in the ECOWAS region. In addition, the study also tested the environmental N-shaped EKC hypothesis in the context of ECOWAS nations. The paper applied the Driscoll and Kraay estimator and PQR approach to data from 1990 to 2019 for ten ECOWAS nations. The key conclusions and ramifications for policy are offered based on these analyses.

Conclusions

The empirical results suggest that financial development and renewable energy hinder environmental degradation, while globalization and industrialization accelerate environmental degradation. In addition, we validate the N-shape EKC for the ECOWAS region. Economic growth remains one of the most critical

drivers of environmental degradation. The findings imply that economic development initially causes environmental degradation, but later on, after attaining a certain threshold of development (income), economic activity contributes to reducing environmental degradation. However, following a period of decline, environmental deterioration will increase again if growth reaches a certain level. This shows that economic growth cannot sustain ecological quality in the long run and that there may be a trade-off between environmental quality and economic growth. A probable explanation is that governments start implementing more eco-friendly policies by emphasizing environmental quality at greater levels of development, which may eventually be relaxed as time goes on.

Further, the PQR analysis demonstrates that the N-shape EKC is valid for low and medium emitters, whereas the inverted N-shape EKC holds for high emitters. We found that financial development reduced environmental degradation in high and low emitters but did not influence environmental degradation in medium emitters. Besides, globalization promotes environmental degradation in all quantiles. This suggests that, as part of the process of globalization and their attempts to spur economic growth, ECOWAS states are keen to attract FDI inflows that bring with them pollution by indulging in unhealthy competition, such as weakening environmental regulations. The results further indicated that renewable energy usage improves environmental quality by reducing environmental degradation in all quantiles. Our work supports the claims that renewable energy usage is critical in attaining the carbon neutrality agenda in ECOWAS nations. Finally, even though industrialization is considered a vital factor for economic growth, the study revealed that industrialization increases environmental degradation. Focusing on the individual nations, an inverted U-shape EKC was for Nigeria at a turning point of GDP per capita of US\$2628.239. A U-shape EKC for Benin, Ghana, Senegal and Togo at a turning point of GDP per capita of US\$1084.249, US\$1949.285, US\$1345.249 and US\$523.067. However, a monotonic association was established between economic growth and environmental degradation in Burkina Faso, Carbo Verde, Cote d'Ivoire, Guinea and Sierra Leone.

Policy ramifications

The conclusions elaborated above provide several policy ramifications. First, we observe that financial development mitigates CO₂ emissions. This indicates that financial development promotes carbon neutrality and highlights the need for ECOWAS countries to encourage financial development by putting reforms into place to boost their financial sectors; this could aid in curbing environmental deterioration. To finance R&D efforts, adopt clean technology and find potential low-carbon emission investment projects, the financial industry must ensure that businesses have access to greater funding. While financial development indirectly boosts the severity of carbon emissions by fostering economic development in developing nations, governments in these economies can encourage investment in environmentally sustainable economic sectors. Further, to maximize the potential environmental impact of financial development, policymakers from ECOWAS nations should embrace public disclosure procedures that reveal the environmental performance of industries or companies. Governments should coordinate their growth strategies with sustainable environment goals since economic growth in ECOWAS countries shows an N-shaped relationship with environmental deterioration.

Second, given the deleterious impact of globalization on the environment, authorities in the ECOWAS region should consider globalization while developing and enacting environmental conservation regulations. To successfully combat the damaging effects of globalization, ECOWAS nations must establish and monitor a strict environmental regulatory system.

Third, ECOWAS nations must implement more conservative energy policies for non-renewable energy sources while enhancing their R&D spending to embrace clean energy sources, as renewable energy consumption is found to promote environmental quality by reducing CO₂ emissions. To replace non-renewable energy, it is vital to explore renewable energy sources as they have been found to reduce environmental degradation. Most importantly, given that the cost of renewable energy has decreased significantly due to research and technological advancements, it should progressively replace fossil fuels. Given the abundance of unexplored renewable energy resources in ECOWAS countries and the threat of escalating environmental degradation, renewable energy should be included in the region's energy mix.

Lastly, although industrialization is essential to the growth of the sub-region, the findings suggest that it is the driving force behind environmental deterioration in the ECOWAS region. Therefore, we offer that firms be encouraged to adopt and use more environmentally friendly technologies. Additionally, companies should be subjected to stricter environmental rules. By doing this, the push for industrialization and the objective of promoting environmental sustainability, which is essential to achieving sustainable development, may be balanced.

Despite its substantial empirical and policy contributions, the paper has some limitations worth noting. Our empirical framework does not consider critical variables such as institutional quality, technological innovation, environmental regulation and political stability. Therefore, future studies can extend this study by exploring the role of institutional quality, technological innovation, environmental regulation and political stability in the framework of the N-shaped EKC, pollution haven or halo hypothesis for the ECOWAS region or other economic blocs. Furthermore, although other factors contribute to declining environmental quality, CO₂ emissions are utilised as a stand-in for environmental quality. Further research in the ECOWAS context is needed, with the possibility of including other indicators of environmental degradation.

Notes

1. https://ecowap.ecowas.int/media/ecowap/file_document/2022_Press_kit_-_West_Africa_region_mobilises_for_climate_at_COP27_EN.pdf.
2. The Westerlund (2007) technique in STATA cannot accommodate more than six covariates.

Disclosure statement

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Availability of data and materials

In this investigation, we exclusively used secondary data from public sources. Therefore, in this study, no new data is used or produced.

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