ASSESSMENT OF THE EFFECT OF ECONOMIC GROWTH ON ENVIRONMENTAL POLLUTION IN WEST AFRICA

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ABSTRACT

This study investigates the effect of economic growth on environmental degradation in West Africa, assessing the applicability of the Environmental Kuznets Curve (EKC) hypothesis. Using annual panel data from 16 West African nations (1996–2022) and a panel autoregressive distributed lag (ARDL) approach, the study explores both long- and short-term effects. The results support the EKC hypothesis, demonstrating that economic expansion initially worsens environmental pollution by 10.985% but subsequently reduces it by 0.564% after crossing a specific income threshold. Additionally, the informal sector exacerbates the ecological damage linked to formal economic operations, whereas renewable energy adoption substantially mitigates pollution levels. Conversely, urbanization drives environmental degradation due to heightened energy demand and industrial output, leading to increased CO_2 emissions. These findings highlight the importance of implementing sustainable policies that strengthen environmental governance, integrate informal economic activities, and expand renewable energy infrastructure. To achieve enduring development, West African leaders must harmonize economic advancement with ecological preservation, ensuring that growth strategies do not compromise environmental integrity.

Keywords: *Pollution, Economic Growth, Environment, CO_2 Emissions and West Africa*

1. Introduction

The nexus between environmental pollution and economic growth has emerged as a central topic in global economic discussions, especially in developing areas such as West Africa. As nations in this region strive to boost their economies, they encounter the complex task of promoting growth while minimizing its environmental impact, particularly in terms of carbon dioxide (CO_2) emissions. Economic expansion typically drives up industrial activity and energy use, which are major contributors to environmental degradation (Apergis et al., 2023). Nevertheless, the Environmental Kuznets Curve (EKC) hypothesis posits that pollution tends to rise in the early stages of economic growth but eventually decreases once a certain income threshold is reached and more sustainable measures are implemented (Grossman & Krueger, 1991, 1995, & 1996). While this theory has been widely explored across various regions, its relevance to the West African context remains an open and important area of investigation.

One important factor that may affect the relationship between environmental pollution and economic growth is the size of the informal sector, which holds substantial influence in West African economies. This sector includes unregulated and untaxed economic activities, many of which have notable environmental impacts, such as illegal logging, mining, and energy use (Baloch et al. 2022). Because these activities operate outside formal regulations, they often contribute to higher levels of environmental pollution. The nexus between the formal and informal sectors, and their combined effects on environmental outcomes, presents a complex dynamic that requires careful analysis.

Urbanization is another factor contributing to environmental pollution in West Africa. As cities in the region expand, driven by rapid population growth and migration from rural areas, the demand for energy, infrastructure, and transportation increases (Onifade, 2022). Urban expansion frequently results in increased CO2 emissions, largely driven by the dependence on fossil fuels for electricity, heating, and transportation. As policymakers strive to achieve economic growth, the environmental consequences of urbanization remain a critical factor that must be taken into account (Chu & Hoang, 2022).

Renewable energy has become a key factor in addressing climate change worldwide. In West Africa, shifting to renewable sources like hydropower, solar, and wind presents a viable way to cut carbon emissions while fostering economic development. Despite this potential, progress remains sluggish due to institutional, financial, and infrastructural barriers. Examining the effects of renewable energy use on environmental health in the region is crucial for shaping effective sustainability policies (Adu & Denkyirah, 2019). However, the paper is structured into five sections. Section one deals with introduction, section two focuses on the literature review, section three discusses the methodology of the paper, section four deals with the result and discussion of findings and section five discusses the conclusion and recommendations.

2. Literature Review

This section examines key literature, covering conceptual frameworks, theoretical foundations, and empirical insight.

2.1 Conceptual Review

Environmental pollution denotes the deterioration of natural ecosystems due to the release of harmful contaminants, largely resulting from human activities (Onifade, 2022). This research focuses on CO_2 emissions as a proxy for environmental pollution, given their substantial role in driving global warming and climate change. These emissions predominantly originate from fossil fuel combustion in industries, transportation, and energy generation, making them a vital measure of ecological impact (Apergis & Ozturk, 2015).

Economic Growth: Economic growth is commonly assessed using gross domestic product (GDP), representing the aggregate market value of goods and services generated within an economy during a specified timeframe (Dada et al. 2023). As a key measure of national economic health, GDP signals productivity, capital formation, and developmental progress (Chu & Hoang, 2022). However, while economic expansion is vital for enhancing societal welfare, it frequently entails environmental trade-offs, as heightened industrial output and consumption patterns exacerbate emissions and natural resource degradation (Churchill et al., 2018).

The Shadow Economy: This encompasses all economic operations that evade governmental oversight and remain unaccounted for in formal GDP calculations (Medina & Schneider, 2019). This sector typically includes informal commerce and undocumented business operations. Of particular significance is the environmental impact of these clandestine activities, as their unregulated nature often leads to elevated emission levels and environmental degradation due to the absence of compliance with ecological regulations (Medina & Schneider, 2019). Collectively, these elements establish a framework for analyzing the interplay between formal and informal economic sectors and their environmental consequences in West Africa.

2.2 Theoretical Review

This study adopts the Environmental Kuznets Curve (EKC) hypothesis as its conceptual framework to analyze the complex relationship between economic growth and environmental quality in West Africa. The EKC proposition holds particular relevance for the region, as many West African nations currently experience rapid economic growth alongside worsening environmental indicators. According to this framework, pollution levels typically rise during early industrialization phases (a pattern observable in West Africa's expanding extractive industries and urban centers) but may eventually decline as economies reach higher income levels and implement cleaner technologies (Grossman & Krueger, 1991, 1995, 1996).

2.3 Empirical Review

The reviewed literature highlights the growing interest in how formal economic growth, the shadow economy, and other macroeconomic factors affect environmental pollution. Studies consistently find that the shadow economy tends to worsen environmental outcomes, although its effects can be moderated by strong financial systems and institutional quality. Empirical evidence demonstrates varied interactions between shadow economies and environmental outcomes. Dada et al. (2023) establish that financial sector development can mitigate the adverse environmental effects of informal economic activities, while their earlier work (Dada et al., 2022) identifies institutional quality (particularly anti-corruption measures) as another key moderating factor. However, findings remain context-dependent, as shown by Nguyen and Nguyen (2023), whose analysis reveals divergent short-term and long-term impacts of 6unregulated economic activities on natural resource depletion, particularly in forest ecosystems. Additionally, Jeetoo and Chinyanga (2023) support the EKC hypothesis in the context of resource depletion but not CO_2 emissions, and Eren et al. (2022) confirm the EKC in Turkey while exploring the interaction between informality and other economic variables.

Similarly, Onifade (2022) investigates the validity of EKC in oil-rich African countries, finding that fossil energy use, income levels, and manufacturing share significantly drive CO_2 emissions. While the analysis provides partial validation of the EKC hypothesis, its statistical significance is confined to lower and middle quantiles. This limited scope of verification indicates inconclusive evidence for the inverted U-shaped relationship in the studied context, pointing to the need for further empirical investigation. Eren et al. (2022) analyze Turkey's environmental performance and show that the informal economy, alongside energy use and financial sector development, negatively affects environmental quality. Their results support the EKC hypothesis while emphasizing the harmful role of informality in environmental degradation. Chu and Hoang (2022) found an inverted U-shaped relationship between the shadow economy and ecological footprint in OECD nations, where environmental impact first worsens then improves with informal sector growth. Unidirectional causality flows from shadow economy to ecological damage, varying by ecosystem conditions. This suggests informal sector expansion can eventually reduce environmental harm after reaching a threshold.

Similarly, Tachega et al. (2021) empirically supported the EKC framework across African development stages, though observed prematurely low turning points and cautioned against overreliance on CO_2 metrics. Parallel Nigeria-focused research by Dada & Ajide (2021) revealed countervailing effects - informal sector pollution versus institutional mitigation - yet found their net long-term interaction statistically negligible.

Adu and Denkyirah (2019) analyzed West African countries (1970-2013) and found economic growth increased CO_2 emissions short-term without subsequent long-term reductions, contradicting the EKC hypothesis. They noted potential multicollinearity issues between GDP terms. Separately, Medina and Schneider's (2019) MIMIC model analysis of 157 countries showed Sub-Saharan Africa's shadow economy averages 39% of GDP, initially harming but eventually benefiting the formal economy. Meanwhile, Churchill et al. (2018) discovered only 9 of 20 OECD countries followed the EKC pattern, demonstrating its inconsistent applicability even in developed nations.

Similarly, Atasoy (2017) analyzed U.S. state-level data and found stronger support for the EKC using the AMG estimator compared to the CCEMG method, highlighting the importance of estimator choice and the heterogeneity of results.

A significant limitation in current empirical research is the insufficient consideration of the shadow economy's moderating influence. Although numerous studies analyze the growth-pollution relationship (typically through the EKC framework) they frequently overlook informal sector dynamics. This research addresses this critical gap by examining how unregulated economic activities mediate the development-environment linkage in West Africa.

3. Methodology

3.1 Variables Description and Sources of Data

This study employs panel data from 1996 to 2022 for sixteen West African countries (Benin, Burkina Faso, Cape Verde, The Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo) to examine the effect of economic growth on environmental pollution in West Africa, which is represented by CO_2 emissions measured in metric tons per capita as the dependent variable. The independent variables include economic growth, captured by GDP per capita (measured in constant 2015 US$), shadow economy (SHE), which is expressed as a percentage of official GDP, renewable energy consumption (REC) as a percentage of total final energy consumption, and urbanization (URB), indicated by the urban population as a percentage of the total population. Table 1 provides variable codes, descriptions, expected signs of coefficients, and sources of data for clarity and references.

Table 1. Variables Description and Sources of Data

Codes	Description	Signs	Sources
CO2	CO2 emissions (metric tons per capita)		World Bank (2023a)
GDP	Economic growth (GDP per capita constant 2015 US$)	+/-	World Bank (2023a)
SHE	Shadow Economy (% of official GDP)	+	World Bank (2023b)
REC	Renewable energy consumption (% of total final energy consumption)	-	World Bank (2023a)
URB	Urban population (% of total population)	+/-	World Bank (2023a)

Note: World Bank (2023a) is World Development Indicators and World Bank (2023b) is World Bank Informal Economy Database: Source: Researcher's compilations (2024)

This study adopts the Environmental Kuznets Curve (EKC) hypothesis as its theoretical foundation, which posits an inverted U-shaped relationship between economic growth and environmental pollution. Specifically, we anticipate that GDP per capita will initially show a positive association with CO_2 emissions, reflecting the environmental costs of early-stage economic development, but will eventually demonstrate a negative relationship after reaching a certain income threshold, as indicated by the squared GDP term. The shadow economy (SHE) is expected to positively influence pollution levels, given that informal sector activities typically operate outside environmental regulations. Conversely, renewable energy consumption (REC) is projected to have a negative effect on emissions due to its sustainable nature. The impact of urbanization (URB) remains theoretically ambiguous, as it could either increase pollution through greater energy demand or decrease it through more efficient infrastructure and technology adoption, depending on contextual factors.

3.2 Model Specification

This section specified the model formulated to achieve the objectives of the study. The model is anchored on the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between economic growth and environmental pollution. Specifically, it suggests that at the initial stages of economic development, environmental degradation increases with income growth, but after surpassing a certain threshold of income, further growth leads to environmental improvement. To empirically examine this relationship, the baseline model is specified as:

$$\mathrm{CO_2} = \mathrm{f(GDP, GDP^2)} \tag{1}$$

In model (1), CO_2 represents carbon dioxide emissions, serving as a proxy for environmental pollution; GDP denotes real gross domestic product per capita; and GDP^2 is the square of GDP per capita, included to capture the non-linear (inverted U-shaped) relationship as suggested by the Environmental Kuznets Curve (EKC) hypothesis.

Following the work of Dada et al. (2023), the baseline model is extended to account for additional determinants of environmental pollution relevant to the West African context. These include renewable energy consumption (REC), urbanization (URB), and the shadow economy (SHE). The augmented model is therefore specified as:

$$\mathrm{CO2} = \mathrm{f(GDP,\ GDP^2\ \ REC, URB, SHE\ )} \tag{2}$$

In its econometric form, the model can be expressed as:

$$\mathrm{CO2_{it}} = \alpha_0 + \beta_1\mathrm{GDP_{it}} + \beta_2\mathrm{GDP^2}_{\mathrm{it}} + \ \beta_3\mathrm{REC_{it}} + \beta_4\mathrm{URB_{it}} + \beta_5\mathrm{SHE_{it}} + \ \beta_6(\mathrm{GDP_{it}} * \mathrm{SHE_{it}}) + \varepsilon_{\mathrm{it}}$$
(3)

The model in equation (3) analyzes CO_2 emissions as the dependent variable influenced by GDP per capita, renewable energy use, urbanization, and the shadow economy. It incorporates the Environmental Kuznets Curve (EKC) by including both linear and squared GDP terms, suggesting that emissions initially rise with economic growth but decline after reaching a certain income level. Renewable energy is expected to reduce emissions, while the shadow economy is likely to increase them. The model also examines how urbanization and the interaction between GDP and the shadow economy affect emissions. CO_2 and GDP are log-transformed to address heteroskedasticity, and the model aims to explore the EKC hypothesis and environmental impacts of the shadow economy in West Africa.

3.3 Model Estimation Techniques

The study first examines summary statistics, then conducts cross-sectional dependence tests to determine the suitable estimation approach. Given West African nations' geographic closeness and shared traits, their panel data likely exhibits cross-sectional dependence - a condition that can distort results if unaddressed (Pesaran, 2004). We employ Pesaran's (2004) CD test, which reliably detects dependence across sample sizes, testing the null hypothesis of no cross-sectional correlation at standard significance levels (1%/5%/10%). The test specification follows:

$$\mathrm{CD} = \sqrt{2T/N(N-N)}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\rho}_{i,k}\right) \tag{4}$$

The study next implements Pesaran's (2007) CIPS and CADF unit root tests that accommodate cross-sectional dependence, followed by Westerlund's (2007) cointegration test to identify long-run relationships. All tests evaluate their respective null hypotheses at conventional significance levels (1%/5%/10%).

This study employs the panel ARDL (autoregressive distributed lag) approach for parameter estimation, which offers several advantages: (1) it effectively handles cross-sectional dependence, (2) allows variable-specific lag structures, (3) simultaneously estimates short-run dynamics and long-run equilibrium relationships, and (4) delivers reliable results even with limited samples (Pesaran et al., 2001). The panel ARDL specification is expressed as:

$$\begin{aligned}\Delta \mathrm{lnCO2}_{it} = {} & \alpha_0 + \alpha_1 \mathrm{lnCO2}_{it} + \alpha_2 \mathrm{lnGDP}_{it} + \alpha_3 \mathrm{lnGDP}_{it}^2 + \alpha_4 \mathrm{REC}_{it} + \alpha_5 \mathrm{URB}_{it} + \alpha_6 \mathrm{SHE}_{it} \\ & + \alpha_7(\mathrm{lnGDP}_{it} * \mathrm{SHE}_{it}) + \sum_{i=1}^{p} \Delta\beta_1 \,\mathrm{lnCO2}_{t-i} + \sum_{j=0}^{q} \Delta\beta_2 \,\mathrm{lnGDP}_{t-i} + \sum_{j=0}^{q} \Delta\beta_3 \,\mathrm{lnGDP}_{it}^2 \\ & + \sum_{j=0}^{r} \Delta\beta_4 \,\mathrm{REC}_{t-i} + \sum_{j=0}^{s} \Delta\beta_5 \,\mathrm{URB}_{t-i} + \sum_{j=0}^{t} \Delta\beta_6 \,\mathrm{SHE}_{t-i} + \sum_{j=0}^{u} \Delta\beta_7 \,(\mathrm{lnGDP}_{it} * \mathrm{SHE}_{it})_{t-i} \\ & + \mu_t \qquad (5)\end{aligned}$$

In this model, i and j indicate the lag orders (where i ranges from 1 to p, and j spans 0 to u), while t denotes the time period. The dependent variable is CO_2 emissions, and the independent variables include GDP, REC, URB, and SHE. The intercept is represented by α_0, while α_1 to α_7 correspond to the long-term coefficients of the predictors. The short-term dynamics are captured by β_1 (the coefficient of the lagged dependent variable) and β_2 to β_7 (the coefficients of the lagged independent variables). Finally, μ_t signifies the error term. The error correction representation of Equation (5) is given below:

$$\Delta \ln CO2_{it} = \alpha_0 + \sum_{i=1}^{p} \Delta\beta_1 \ln CO2_{t-i} + \sum_{j=0}^{q} \Delta\beta_2 \ln GDP_{t-i} + \sum_{j=0}^{q} \Delta\beta_3 \ln GDP_{it}^2 + \sum_{j=0}^{r} \Delta\beta_4 REC_{t-i} + \sum_{j=0}^{s} \Delta\beta_5 URB_{t-i} + \sum_{j=0}^{t} \Delta\beta_6 SHE_{t-i} + \sum_{j=0}^{u} \Delta\beta_7 (\ln GDP_{it} * SHE_{it})_{t-i} + ECT_{t-1} + \mu_t \quad (6)$$

ECT_{t-1} denotes the one-period lagged error correction term derived from the cointegration equation. It reflects the long-run equilibrium relationship among the variables. The ECT coefficient measures the adjustment rate at which any short-term disequilibrium converges back to the long-term equilibrium in each time period.

4. Results and Discussions

4.1. Results of Preliminary Tests

The result of descriptive statistics is presented in Table 2. The summary statistics in Table 2 offer key insights into the dataset's central tendencies, variability, and distribution across variables. Carbon dioxide (CO_2) emissions average 0.337 metric tons per capita, with a moderate spread and right-skewed, leptokurtic distribution, suggesting that a few countries contribute heavily to pollution. Economic growth (GDP) averages $1081.18, displaying substantial disparity and variability, with a strongly right-skewed and leptokurtic distribution indicating outliers with high income.

Table 2: Results of Descriptive Statistics

Variables	Observations	Mean	Std. Dev.	Min	Max	Skew.	Kurt.
CO2	432	0.337	0.243	0.044	1.074	1.131	3.61
GDP	432	1081.183	688.33	354.089	3667.057	1.521	4.857
REC	432	67.718	20.629	20.78	94.96	-0.739	2.325
URB	432	41.193	11.403	15.407	67.545	-0.357	3.113
SHE	432	41.771	5.976	31.028	58.312	0.846	3.454

Source: Researcher’s computations (2024), Using Stata-17.

Renewable energy consumption (REC) averages 67.72%, showing high reliance on renewables, a wide range of values, and a mildly left-skewed, near-normal distribution. Urbanization (URB) averages 41.19%, with moderate variability and a nearly symmetric, normal distribution. The shadow economy (SHE) averages 41.77% of GDP, indicating a strong informal sector presence, with some variation and a moderately right-skewed, slightly leptokurtic distribution.

The next step in this study involved conducting a cross-sectional dependence (CD) test. This test assesses whether the variables exhibit interdependence or correlation across the different panel groups, in this case, the West African countries. Cross-sectional dependence can arise from shared regional characteristics or common external shocks affecting all countries. Identifying such dependence is crucial, as ignoring it could lead to biased results in panel data models. The results of the CD test are presented in Table 3.

Table 3: Result of Cross-sectional Dependence Test

Variables	CD-test Statistics	P-values
CO2	24.654	0.000
GDP	27.592	0.000
REC	23.344	0.000
URB	55.316	0.000
SHE	29.444	0.000

The null hypothesis of no cross-sectional dependence is strongly rejected, with all test statistics being statistically significant at p-values of 0.000. This confirms that CO_2 emissions, GDP, renewable energy consumption (REC), urbanization (URB), and the shadow economy (SHE) are interconnected across West African countries. Economic, environmental, and geographic ties mean that shocks in one nation can transmit to others. Notably, GDP and urbanization exhibit particularly strong spillover effects. Consequently, second-generation econometric methods that address cross-sectional dependence must be employed for reliable estimation.

To properly assess variable stationarity and cointegration relationships, the study utilizes the Pesaran (2003) CADF and Pesaran (2007) CIPS unit root tests, along with the Westerlund cointegration test – all of which account for cross-sectional dependence. The findings from these tests are reported in Tables 4 and 5 respectively. These approaches ensure robust analysis by correcting for the observed interdependencies among the West African economies.

Table 4: Results of Panel Unit Root Tests

	CADF Test		CIPS Test		
Variables	Level	1st Diff	Level	1st Diff	Status
$lnCO_2$	-2.807**	N/A	-2.893**	N/A	I(0)
lnGDP	-2.457	-3.543**	-2.010	-4.551**	I(1)
REC	-1.953	-3.477**	-2.082	-4.887**	I(1)
URB	-1.068	-3.150**	-0.591	-3.080**	I(1)
SHE	-2.692**	N/A	-2.637*	N/A	I(0)

Note: **$p < 0.05$, ln: natural logarithm; N/A: not applicable; panel unit root and cointegration tests performed using Stata17.

The results of the panel unit root tests (CADF and CIPS) presented in Table 4 evaluate the stationarity properties of the variables. The tests reveal that CO_2 emissions ($lnCO_2$) are stationary at level [I(0)], with both test statistics showing significance, indicating that differencing is unnecessary. However, economic growth (lnGDP), renewable energy consumption (REC), and urbanization (URB) exhibit non-stationarity at level but achieve stationarity after first differencing, suggesting they are integrated of order one [I(1)]. The shadow economy (SHE) presents mixed stationarity results: while the CADF test confirms stationarity at level at the 5% significance level, the CIPS test only marginally supports this conclusion at the 10% level. After first differencing, however, it becomes clearly stationary. Therefore, SHE can cautiously be treated as I(0), though differencing may still be applied for robustness.

Table 5: Results of Cointegration Tests

Model: $lnCO_2$ = f(lnGDP, $lnGDP^2$, REC, URB, SHE, lnGDP_SHE)		
	Statistic	P-value
Variance ratio:	-1.970**	0.0385

Note: ***p < 0.01, **p < 0.05, *p < 0.10, ln: natural logarithm; N/A: not applicable; panel unit root and cointegration tests performed using Stata17.

Source: Researcher's computations (2024).

The Westerlund cointegration test results confirm a statistically significant long-run equilibrium relationship between CO_2 emissions and the explanatory variables. The variance ratio statistic of -1.970 is significant at the 5% level (p-value = 0.0385), providing strong evidence of cointegration. This finding indicates that while some variables exhibit non-stationarity in their level forms, they maintain a stable long-run association. Consequently, the model satisfies the necessary conditions for meaningful long-run analysis, as the variables demonstrate a consistent co-movement pattern over time despite short-term fluctuations.

4.2. Results of Long-run and Short-run Estimations

The long-run coefficient estimates presented in the upper section of Table 6 demonstrate statistically significant relationships between all explanatory variables and environmental pollution (measured by CO_2 emissions). Most notably, economic growth (GDP) shows a strong positive association with emissions, evidenced by its highly significant coefficient of 10.985. This robust relationship suggests that economic expansion in West African countries comes with substantial environmental costs through increased carbon emissions.

Table 6. Results of Estimated Long-run Coefficients (Dep. var is $lnCO_2$)

		Long-run Estimates		
Variables	Coefficient	Std. Error	t-Statistic	P-Value
lnGDP	10.985	1.303	8.430	0.000
$lnGDP^2$	-0.564	0.065	-8.670	0.000
REC	-0.026	0.002	-10.460	0.000
URB	0.192	0.035	5.500	0.000
SHE	0.443	0.077	5.730	0.000
lnGDP*SHE	0.055	0.010	5.480	0.000

Source: Researcher's computations (2024), using Stata-17.

These findings corroborate existing research in developing economies where industrialization-driven growth typically exacerbates environmental degradation. The significant negative coefficient for GDP^2 (-0.564) substantiates the Environmental Kuznets Curve (EKC) hypothesis, revealing an inverted U-shaped relationship between economic development and emissions. This suggests that while West

African nations currently experience rising pollution with economic growth, the region may eventually reach an inflection point where further development leads to environmental improvement - consistent with findings by Tachega et al. (2021) and other EKC studies in developing contexts.

The analysis demonstrates renewable energy's mitigating effect, with REC's negative coefficient (-0.026) confirming its long-term role in emissions reduction. This supports global evidence (e.g., Al-Mulali et al., 2015) that clean energy transitions are crucial for sustainable development in emerging economies. Conversely, urbanization (coefficient = 0.192) emerges as a pollution driver, echoing studies like Wang et al. (2016) that attribute this to increased energy demand and industrial activity in expanding cities.

Notably, the shadow economy's positive coefficient (0.028) highlights its environmental costs. Unregulated activities - from illegal resource extraction to inefficient energy use - significantly contribute to emissions, underscoring how informal sectors can undermine environmental regulations.

Furthermore, the interplay between GDP and the shadow economy (lnGDP*SHE) yields a positive and statistically significant coefficient of 0.055, suggesting that the informal sector intensifies the link between economic expansion and CO_2 emissions. In regions with a sizable informal economy, efforts to curb pollution and adopt green technologies may prove less effective, as a significant portion of emissions-generating activities operate outside regulatory frameworks. This result adds a critical layer to the Environmental Kuznets Curve (EKC) hypothesis: although the EKC posits that pollution should decline after a certain threshold of economic growth, a large shadow economy can hinder or even negate this expected reduction.

For the EKC to hold true in West Africa, mitigating the environmental consequences of informal economic activity is essential. Formalizing these unregulated sectors is key to unlocking the environmental improvements typically linked to advanced economic development. Without such interventions, West African nations may experience persistently high CO_2 emissions, even as their economies reach stages where pollution would normally begin to decrease.

Table 7. Results of Estimated Short-run Coefficients (Dep. var is lnCO_2)

Variables	Coefficient	Std. Error	t-Statistic	P-Value
Constant	-16.911	3.892	-4.340	0.000
lnGDP(-1)	6.534	21.859	0.300	0.765
lnGDP2 (-1)	-0.529	1.423	-0.370	0.710
REC (-1)	-0.025	0.005	-5.380	0.000
URB (-1)	0.008	0.002	5.220	0.000
SHE (-1)	0.028	0.005	5.750	0.000
lnGDP*SHE (-)	0.001	0.075	0.020	0.987
ECT	-0.329	0.076	-4.350	0.000

Source: Researcher's computations (2024), using Stata-17.

Examining the short-term estimates, the findings show notable distinctions from the long-term results. While economic growth (GDP) and its squared term (GDP^2) do not significantly influence CO_2 emissions in the short run, their environmental effects become apparent over an extended period. In contrast, renewable energy consumption (REC), urbanization (URB), and the shadow economy (SHE) all exhibit immediate impacts on emissions. The negative coefficient for REC (-0.025) confirms that increasing renewable energy use directly lowers emissions, whereas the positive coefficients for URB (0.008) and SHE (0.028) indicate that urban expansion and informal economic activities drive emissions up in the short term.

Additionally, the significant and negative error correction term (ECT) (-0.329) validates a stable long-run connection among the variables. This term suggests that short-run deviations from equilibrium are corrected at a speed of 32.9% per period, reflecting a relatively swift adjustment toward the long-term relationship.

5. Conclusion and Recommendations

The results of this study confirm that economic growth in West Africa initially worsens environmental degradation but eventually reduces it after attaining a specific income threshold, thereby validating the long-run existence of the Environmental Kuznets Curve (EKC) in the region. The analysis further indicates that the shadow economy amplifies the environmental damage caused by economic expansion, whereas renewable energy consumption significantly reduces carbon emissions. Urbanization, however, was found to contribute positively to environmental pollution.

Based on these findings, West African policymakers should prioritize sustainable growth by enforcing stricter environmental regulations, particularly in the informal sector. Formalizing shadow economic activities through improved governance and policy frameworks could help mitigate their negative ecological effects. Additionally, governments should adopt urban development strategies that harmonize industrialization with environmental sustainability, ensuring that economic progress does not come at the expense of long-term ecological health.

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