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# Does Resource Dependency Undermine Environmental Sustainability? Evidence from Resource-Intensive and Non-Resource-Intensive West African Economies

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## Abstract

The current study examined the environmental effect of natural resource extraction in 15 West African countries for the period 1980-2024. Despite the growing literature on resource-environment dynamics, only a few studies have explored the comparative effects between resource-intensive countries (RIC) and non-resource-intensive countries (NRIC). For this reason, this paper focuses on the comparative analysis of West Africa's RIC and NRIC. Unlike most resource-environment studies, this study utilized the load capacity factor as a comprehensive environmental quality indicator. With the use of the panel-corrected standard error technique and load capacity curve (LCC) hypothesis, the study found the RIC to validate the U-shaped LCC hypothesis, while the NRIC invalidates the LCC hypothesis (inverted U-shaped). Also, the results showed that natural-resource rents improve environmental quality in West Africa regardless of its resource group. Further, while renewable energy increases environmental quality, industrialization induces environmental damage in West Africa regardless of its resource group. The study recommended that policymakers should design growth strategies that integrate environmental sustainability, especially in the whole sub-region and RIC, where early-stage growth stresses ecosystems. Also, governments in West Africa should efficiently manage the revenue generated from their resource rents, thereby allocating some portion for environmental protection projects and clean technological adoption.

**Keywords**: Load capacity factor, Load capacity curve (LCC), Environmental sustainability, Natural resources

## 1. Introduction

In recent times, West Africa has remained one of the leading sub-regions in Africa with high environmental pressure. This is largely due to the increase in demand for land, energy, and water resources, reflected in the rising ecological footprint (such as land build-up, carbon emissions, cropland, fishing grounds, grazing land, and forest products).[1] As proclaimed by Global Footprint Network (2025), West Africa's ecological footprint (ECF) in the 21st century has continued to expand above its biocapacity (BC) level, creating an ecological deficit (less BC compared to ECF) within the sub-region. For instance, compared to other African sub-regions, West Africa has the highest ECF (352.88 million global hectare (GHA)), which rises above the BC (276.5 million GHA) between 2000 and 2024 (see Figure 1), indicating that higher pressure for environmental resources rises above the resources its ecosystem can regenerate. This ecological imbalance is a result of the sub-region's dependence on resource exploitation for economic growth, as both population and industrialization continue to expand (Asiedu et al., 2021; Musibau et al., 2022; Radoine et al., 2022; Onyemelukwe, 2024; Prempeh, 2024). With this environmental trajectory, there exists a growing imbalance between economic expansion and environmental sustainability in West Africa, which in turn is the foundation for exploring the environmental effects of natural resources. It is important to note that Figure 1 represents an aggregate regional comparison of total ecological footprint and biocapacity over 2000–2024. It therefore characterizes the ecological balance of West Africa as a whole and should not be interpreted as equivalent to the average of country-level load capacity factors used in the subsequent empirical analysis.

[1] Ecological footprint is an indicator of the area of water and land that is biologically productive, which is needed by a human being or activity to produce all its resource consumption and waste-generation absorption, utilizing current technology and resource management methods (Wackernagel & Rees, 1996; Rees & Wackernagel, 2008; Silalertruksa & Gheewala, 2019; Lewis & Cohen, 2022).

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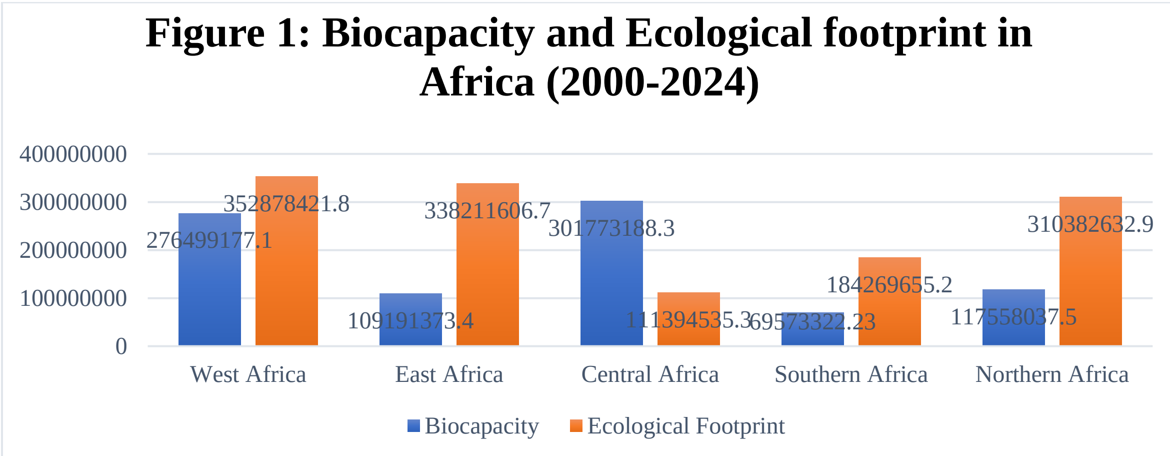



**Source: Global Footprint Network (2025)**

While the world (through the Sustainable Development Goals) remains steadfast in addressing global warming driven by ecological decline, natural resource dependence remains a key environmental issue for West Africa. This is because most of the countries in the sub-region heavily depend on extractive sectors that exploit natural resources, such as oil, gas, and solid minerals, for revenue generation and export earnings (AFRODAD, n.d.; Signé & Johnson, 2021; Ba & Jacquet, 2022). According to the Extractive Industries Transparency Initiative (2023–2025), the extractive sectors contribute 54.4% of government revenue and 75.5% of exports in Nigeria, 15% and 67% in Ghana, 17.10% and 92.32% in Guinea, 12% and 42% in Niger, 22.3% and 79% in Mali, 75.5% and 14.8% in Burkina Faso, 11% and 61% in Sierra Leone, 75.5% and 14.8% in Liberia, 1.05% and 17.50% in Togo, 9.4% and 13.83% in Senegal, and 5.53% and 15.87% in Côte d'Ivoire, respectively. However, these extractive activities have intensified pollution within these countries, as oil activities contribute to an average increase of emissions from 4.8 million tonnes in 2000 to 11.05 million tonnes in 2023 (GCB, 2024). This paradox highlights the resource-environment dilemma, where the benefits of economic expansion (through increased resource wealth) also lead to simultaneous ecological damage. Hence, this situation, coupled with weak governance, amplifies the negative ecological condition in West Africa. Therefore, policy design that balances growth and environmental sustainability requires an awareness of how West Africa's environment is impacted by natural resource dependency.

Notwithstanding, the detrimental environmental effect of natural resources appears widespread in economic literature, as several studies have argued that unsustainable natural resources exert both direct and indirect impact on the ecological system (Amer et al., 2024; Caglar et al., 2024b; Gong & Aslam, 2024;

Liu et al., 2024; Yingjun et al., 2024; Sun & Qamruzzaman, 2025). On the flip side, the environmental effect of natural resources leads to water pollution, soil degradation, and biodiversity loss. Thus, unsustainable mining, processing, and extraction activities aggravate environmental pollution, which in turn worsens climatic conditions. In contrast, the exploitation of natural resources indirectly intensifies ecological stresses through nonrenewable energy consumption, waste generation, and the utilization of dirty technology. However, studies by Du et al. (2024), Liu et al. (2024), and Ge and Mehmood (2024) made a contrasting opinion by asserting that a well-managed natural resource extraction can increase environmental sustainability. Thus, these opposing views increase the resource-environment debate, especially in West Africa, as evidenced by rising unsustainable environmental pressure.

Theoretically, the debate of how economic activities resulting from resource utilization affect environmental quality entered into another dimension at the beginning of this decade, with Dogan and Pata's (2022) proposed load capacity curve (LCC) hypothesis. The LCC hypothesis, which posits a U-shaped relationship between economic expansion and environmental quality (unlike the Environmental Kuznets curve), came as a result of Pata's (2021) empirical use of load capacity (LCF). The LCF (an all-inclusive environmental indicator compared to the ecological footprint), as proposed by Siche et al. (2010), evaluates sustainability through the balance between ecological footprint (demand for natural resources) and biocapacity (supply of natural resources). While this framework increases its relevance across several regions (Du et al., 2024; Sun et al., 2024; Sun & Qamruzzaman, 2025), limited attention has been paid to West Africa (SSA's sub-region with not just the highest natural resource endowment but the highest resource consumption in the 21st century). Thus, these relationships will ascertain whether West Africa's endowment of natural resources amplifies or mitigates ecological vulnerability.

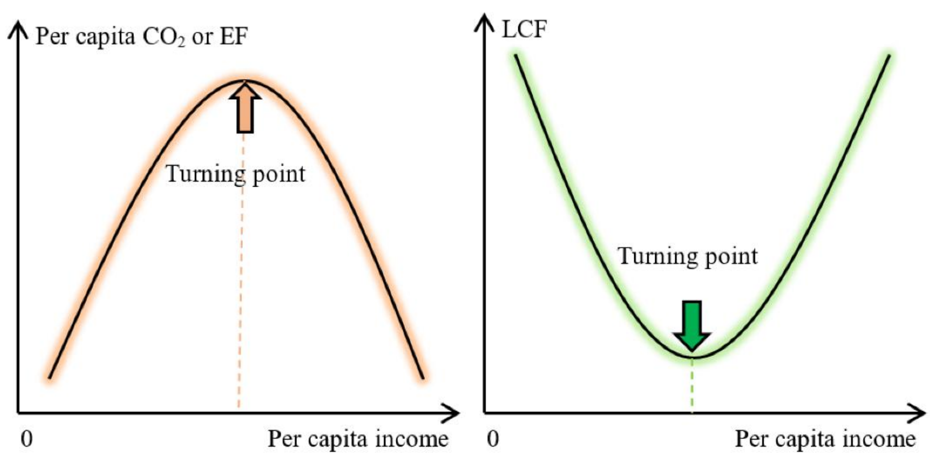
Despite the growing literature on resource-LCF dynamics, only a few studies have explored the comparative effects between resource-intensive and non-resource-intensive countries (Ni et al., 2022; Sibanda et al., 2023). This becomes relevant to West Africa, whose sub-region hosts about 53% of resource-intensive countries and 47% non-resource-intensive countries (IMF, 2025; World Bank, 2025). Following the IMF (2025) classification of sub-Saharan African economies, resource-intensive countries comprise oil exporters, for which net oil exports account for at least 30% of total exports, and other resource-intensive economies, where nonrenewable natural resources account for at least 25% of total exports. Countries that satisfy neither criterion are classified as non-resource-intensive. Accordingly, the RIC group comprises Nigeria, Burkina Faso, Ghana, Guinea, Liberia, Mali, Niger, and Sierra Leone, while the NRIC group comprises Cabo Verde, Benin, Senegal, Côte d'Ivoire, Guinea-Bissau, The Gambia, and Togo. For instance, between 2000 and 2021, resource-intensive countries in West Africa recorded resource rents of 11.9% of GDP, which is about 1.38 times 8.6% observed by the less non-resource-intensive countries. The unequal divergence in resource endowment across these countries provides a unique impetus for examining whether natural resource rents improve or worsen environmental quality, pertaining to their different levels of resource extraction. Notwithstanding, the absence of such a comparison constrains understanding of how sustainability is being influenced by resource management within the sub-region.

Against this backdrop, the current study examines the environmental effect of natural resources in West Africa within the LCC framework, while accounting for the distinction between resource-intensive countries (RIC) and non-resource-intensive countries (NRIC). Besides, analyzing the effect of West Africa's natural resources within the ecological realities allows the study to contribute to development policymaking and inform policymakers how to conserve the ecosystem's carrying capacity while pursuing economic expansion. In achieving the study's objectives, panel-corrected standard error (PCSE) and feasible generalized least squares (FGLS) techniques will be employed. The follow-up sections include related literature (both theories and empirics), data and methodology, results discussion, and conclusion.

**Literature Review**

In this section, this paper reviews different literature in two aspects. First is the theoretical aspect, which includes Dogan and Pata's (2022) LCC hypothesis, Pigou's (1924) externality theory, and the extension of Auty (1993) and Sachs and Warner's (1995) original Resource Curse Hypothesis called the Environmental Resource Curse (ERC). According to the LCC hypothesis, the environmental quality of a developing country will decrease with increased affluence (income), but at a turning point, when the developing country begins to utilize the acquired increase in affluence for ecological wisdom technologies, environmental quality will begin to rise. Moreover, this hypothesis is an extension of the environmental Kuznets curve (EKC) hypothesis proposed by Grossman and Krueger (1991). While the EKC emphasized the inverted U-shaped relationship between affluence and environmental degradation, the LCC hypothesis ascertained a U-shaped relationship between affluence and environmental quality (see Figure 2). Besides, the LCC hypothesis was proposed as a result of the growing LCF debate as a comprehensive environmental indicator that accounts not just for the natural resource demand by population but also the supply of resources by the ecosystem. Pigou's (1924) externality theory is an additional hypothesis. Externality theory upholds the notion that natural resources and environmental quality are inversely correlated, despite its origins in welfare economics. It is reasonable to believe that over-exploration of natural resources could lead to a deterioration of environmental quality, given the possibility of market failures (Inuwa et al., 2025). Furthermore, reliance on natural resources exacerbates environmental degradation, according to the Environmental Resource Curse (ERC), an expansion of the original Resource Curse Hypothesis (RCH) (Auty, 1993; Sachs and Warner, 1995). This RCH's extension indicates that pollution-intensive growth, weak institutions, and overexploitation are the causes of the rise in environmental degradation (Papyrakis & Gerlagh, 2007; Brunnschweiler & Bulte, 2008; Shao & Yang, 2014). Furthermore, resource-rich nations' reliance on these natural resources is apparent, since resource rents are viewed as a source of income, which lowers the incentives for green innovation and environmental preservation.

**Figure 2:** EKC and LCC Hypotheses




***Source*: Dogan and Pata (2022)**

On the empirical side, there has been a growing environmental literature using LCF as an environmental indicator. On the one hand, several studies have analyzed the relationship between natural resources and environmental quality in individual economies. For instance, Fang et al. (2024) for Thailand, Caglar et al. (2024b) for Türkiye, Caglar et al. (2024a) for Russia, Yingjun et al. (2024) for Türkiye and Egypt, Usman et al. (2025) for China, Inuwa et al. (2025) for India, Bergougui and Meziane (2025) for Algeria. On the other hand, several studies have analyzed the relationship between natural resources and environmental quality across different regions. For instance, Ni et al. (2022) for resource-consuming economies, Li et al. (2023) for Next-11 economies, Zhao et al. (2023) for Brazil, Russia, India, China, and South Africa plus Turkey (BRICS+T), Du et al. (2024) for 6 Association of Southeast Asian Nations (ASEAN) countries, Ge and Mehmood (2024) for Organization for Economic Co-operation and Development (OECD) countries, Liu et al. (2024) for group of twenty (G-20), Sun et al. (2024) for 17 Asian-Pacific Economic Cooperation countries (APEC), Sun and Qamruzzaman (2025) for BRICS+T, and Yang et al. (2024) for BRICS. Together, these studies highlight the growing shift towards LCF-related literature, and their findings can be summarized in Table 1.

In North African economies, Okere et al. (2025) used natural resources, financial technology (FinTech), and globalization as key factors influencing LCF for the period 1991-2022. Using the Augmented Mean Group (AMG) estimator, the result showed that while the LCC hypothesis is not validated, FinTech benefits the economy by increasing LCF. However, environmental aggravation was determined by natural resource rents and globalization. In sub-Saharan Africa, Nwani et al. (2025) investigated the impacts of tech-driven industrial diversification (TID) and natural wealth (NR) on LCF for the period 1991 to 2020 using quantile regression. The finding revealed that while renewable resources increase environmental quality, mineral resources decrease environmental quality. Also, while NR decreases environmental quality, TID increases environmental quality. Also, in the same region, Erdogan (2024) utilized augmented mean group (AMG) linked natural resources and LCF for the period 1992-2020. The result indicated that environmental quality in SSA is dampened by natural resources. Within West African countries, Akadiri et al. (2025) examined the LCF effect of the determinants such as urbanization, foreign direct investment (FDI), economic growth, and resource dependency in Nigeria. For the period 1970-2022 and with the use of wavelet quantile regression (WQR), the study found that economic growth, FDI, urbanization, and resource dependency all aggravate environmental quality. Further, Uche and Ngepah (2024) explain how energy transition, green technology, and resource rents explain LCF in South Africa. For the period 1978-2018 and the use of quantile regression, the study found that green technology significantly improved LCF. Also, the result showed that resource rents increase LCF at some point, but are ineffective at the lower quantile of the distributions.

After reviewing these papers, the study articulates that the study on the resource-LCF relationship is growing, and gaps still exist. Because the relationship is missing in Sub-Saharan Africa’s most environmentally damaged and resource-dependent sub-region. Unlike the growing body of literature, this study adds to the body of knowledge not just by investigating the environmental effect of natural resources but by disaggregating the countries into resource-intensive and non-resource-intensive West African countries.

| Table 1: Literature summary on the LCF effects of natural resources | | | | | |
|---|---|---|---|---|---|
| n/s | Authors | Period | Region/countries | Methods | Findings |
| 1 | Bergougui and Meziane (2025) | 1980 to 2023 | Algeria | ARDL and DARDL | Environmental quality is reduced as a result of natural resources, technological innovation, and urbanization. However, environmental quality increases with an increase in economic growth. |
| 2 | Inuwa et al. (2025) | 1970 to 2017 | India | DARDL | Natural resources and economic growth insignificantly decrease and insignificantly improve environmental quality, respectively, while clean energy deteriorates environmental quality. |
| 3 | Sun and Qamruzzaman (2025). | 1990 to 2022 | BRICS+T | DSUR | While validating the LCC hypothesis, indicators such as clean energy, technological innovation, and trade openness expand environmental quality. However, natural resources impede environmental quality. |
| 4 | Usman et al. (2025) | 1970 to 2018 | China | ARDL | While invalidating the LCC hypothesis, clean energy induces quality to the environment. However, natural resources exacerbate the environment. |
| 5 | Caglar et al. (2024a) | 1992 to 2021 | Russia | N-ARDL | A positive shock to natural resources increases its deleterious effect on environmental quality, while environmental resilience increases with an increase in negative shocks to natural resources. Further, renewable energy and human capital increase environmental resilience. |
| 6 | Caglar et al. (2024b) | 2000 to 2022 | Turkiye | ARDL | While validating the LCC hypothesis, environmental quality deteriorates with an increase in natural resources. However, human capital articulates environmental abatement. |

| | | | | | |
|---|---|---|---|---|---|
| 7 | Du et al. (2024) | 1990 to 2020 | 6 ASEAN nations | MMQR, FE, and FMOLS | While economic growth breeds a reduction in environmental quality, determinants such as biomass energy, social globalization, and natural resources improve it. |
| 8 | Fang et al. (2024) | 1984 to 2018 | Thailand | ARDL | Environmental quality reduces with an increase in urbanization, political risk, and natural resources. Also, a resulting LCC hypothesis exists. |
| 9 | Ge and Mehmood (2024). | 1990 to 2022 | OECD | MMQR | Environmental quality improves with an increase in both natural resources and renewable energy, but it deteriorates with an increase in energy production. |
| 10 | Liu et al. (2024). | 1990 to 2020 | G-20 countries. | MMQR | Coupled with the existence of the LCC hypothesis, determinants like environmental technology and globalization finance aggravate environmental quality. However, natural resource improves environmental quality. |
| 11 | Sun et al. (2024) | 1990 to 2019 | 17 APEC countries | | While environmental quality is improved with an increase in natural resources, renewable energy, urbanization, and technological development, it is reduced by economic growth. |
| 12 | Yang et al. (2024) | 1990to2018 | BRICS nations | AMG | An invalidation of the LCC hypothesis, while natural resources, financial development, and economic progress aggravate environmental quality. However, environmental quality increases with an increase in the use of clean energy. |
| 13 | Yingjun et al. (2024) | 1990 to 2022 | Turkey and Egypt | ARDL | The LCC hypothesis is validated for both countries, but environmental quality reduces with an increase in trade openness and natural resources. |

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|---|---|---|---|---|---|
| 14 | Li et al. (2023) | 1990 to 2018 | Next-11 countries | | While natural resources, globalization, and economic growth constitute a decrease in environmental quality, governance and digitization increase environmental quality. |
| 15 | Zhao et al. (2023) | 1990 to 2018 | BRICS-T | CS-ARDL | Natural resources and stock market development hinder an increase in environmental quality, while renewable energy improves it. |
| 16 | Ni et al. (2022) | 1996 to 2019 | Resource-consuming economies | CS-ARDL | The deterioration of a quality environment increases with an increase in natural resources and economic growth, while digitization and governance intensify environmental quality. |

*Note: MMQR: method of momentum quantile regression, AMG: augmented mean group; DSUR: Dynamic Seemingly Unrelated Regression, VECM: Vector Error Correction Model; GMM: Generalized Method of Moments; N-ARDL: Nonlinear-autoregressive distributed lag; FE: fixed effects, FMOLS: fully modified ordinary least squares, DARDL: dynamic ARDL; PCSE: panel corrected standard error.*

***Sources:*** Authors

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## Data and Methods

This paper utilizes an unbalanced dataset from the World Bank (2025) and the Global Footprint Network (2025), spanning 1980–2024 for 15 West African countries. The unbalanced structure reflects differences in data availability across countries and variables over the study period. While GDP and LCF have nearly complete coverage, missing observations are more pronounced for natural resource rents, renewable energy, and industrialization. Consequently, the number of observations used in the empirical estimations varies according to the joint availability of the variables. Following the International Monetary Fund (IMF, 2025) classification of sub-Saharan African economies, resource-intensive countries comprise oil exporters, for which net oil exports account for at least 30% of total exports, and other resource-intensive economies, where nonrenewable natural resources account for at least 25% of total exports. Countries that satisfy neither criterion are classified as non-resource-intensive. Accordingly, the resource-intensive country (RIC) group comprises Nigeria, Burkina Faso, Ghana, Guinea, Liberia, Mali, Niger, and Sierra Leone, while the non-resource-intensive country (NRIC) group comprises Cabo Verde, Benin, Senegal, Côte d'Ivoire, Guinea-Bissau, The Gambia, and Togo. The study period is determined by data availability and consistency across the variables. The variables, their justification, and descriptions are shown in Table 2.

**Table 2:** Variables Description and Literature Justification

| Definition | Measurement | Literature | Symbol | Source |
|---|---|---|---|---|
| Load capacity factor | Biocapacity/Ecological footprint | Sun and Qamruzzaman (2025) | *LCF* | Global Footprint Network (2025) |
| GDP per capita | Constant US Dollars | Bergougui and Meziane (2025) | *GDP* | World Bank (2025) |
| Natural resources | Total natural resources rents (% of GDP) | Yingjun et al. (2024) | *NRR* | World Bank (2025) |
| Renewable energy | Percentage of total final energy consumption | Usman et al. (2025) | *REN* | World Bank (2025) |
| Industrialization | Manufacturing, value added (% of GDP) | Prempeh (2024) | *IND* | World Bank (2025) |

Source: Authors

Following prior LCC studies, this study specifies environmental quality as a function of economic growth and natural-resource rents. The baseline relationship is:

$$LCF\_it = \alpha_0 + \alpha_1 GDP\_it + \alpha_2 GDPSQ\_it + \alpha_3 NRR\_it + \varepsilon\_it \quad (1)$$

where LCF_it is the load capacity factor for country i in year t; GDP_it is GDP per capita; GDPSQ_it is the squared standardized GDP term used to capture nonlinearity; NRR_it is total natural-resource rents as a percentage of GDP; $\alpha_0$ is the intercept; $\alpha_1$–$\alpha_3$ are slope coefficients; and $\varepsilon\_it$ is the disturbance term. Adding renewable energy and industrialization as controls gives:

$$LCF\_it = \beta_0 + \beta_1 GDP\_it + \beta_2 GDPSQ\_it + \beta_3 NRR\_it + \beta_4 REN\_it + \beta_5 IND\_it + \varepsilon\_it \quad (2)$$

REN_it denotes renewable energy consumption as a percentage of total final energy consumption, and IND_it denotes manufacturing value added as a percentage of GDP. For estimation, each continuous variable is standardized using the full-sample mean and standard deviation: $Z\_it = (X\_it - \bar{X})/s\_X$. The nonlinear income term is then constructed as $GDPSQ\_it = (Z\_GDP,it)^2$; that is, GDP is standardized first and the standardized GDP variable is subsequently squared. This ordering is important for interpreting the turning point. The same full-sample transformation is retained when estimating the RIC and NRIC subsamples, so the standardized turning points can be converted back to dollars using the full-sample GDP mean and standard deviation. The expected LCC pattern is $\beta_1 < 0$ and $\beta_2 > 0$; NRR is expected to reduce LCF under the environmental resource-curse argument, REN is expected to increase LCF, and IND is expected to reduce LCF. Disaggregating equation (2) gives:

$$LCF\_it\hat{}RIC = \gamma_0 + \gamma_1 GDP\_it + \gamma_2 GDPSQ\_it + \gamma_3 NRR\_it + \gamma_4 REN\_it + \gamma_5 IND\_it + \varepsilon\_it\hat{}RIC \quad (3)$$

$$LCF\_it\hat{}NRIC = \delta_0 + \delta_1 GDP\_it + \delta_2 GDPSQ\_it + \delta_3 NRR\_it + \delta_4 REN\_it + \delta_5 IND\_it + \varepsilon\_it\hat{}NRIC \quad (4)$$

Equation (3) is estimated for resource-intensive countries (RIC), while equation (4) is estimated for non-resource-intensive countries (NRIC). The $\gamma$ coefficients and $\varepsilon\_it\hat{}RIC$ refer to the RIC specification, whereas the $\delta$ coefficients and $\varepsilon\_it\hat{}NRIC$ refer to the NRIC specification. In all equations, i indexes countries and t indexes years.

The empirical strategy recognizes the strong cross-sectional dependence documented below and the time-series cross-section structure of the data. The study therefore uses Beck and Katz's (1995) panel-corrected standard errors (PCSE) as the principal estimator and Parks' (1967) feasible generalized least squares (FGLS) as a sensitivity check. PCSE is useful for inference when panel disturbances exhibit heteroskedasticity, serial correlation, and contemporaneous correlation, while FGLS explicitly models the disturbance covariance structure. Because T exceeds N in this application, both procedures are feasible for the panel structure. Nevertheless, neither estimator by itself removes coefficient bias caused by unobserved common factors, slope heterogeneity, or endogeneity. The preceding unit-root and cointegration tests establish that the variables are I(1) and share a long-run relationship; accordingly, the level regressions are used to summarize conditional long-run associations within that cointegrating relationship. They are not interpreted as structural or causal estimates. Given this limitation, FGLS is used only to assess whether the main coefficient patterns are stable to an alternative treatment of the error covariance structure, and the absence of a common-factor heterogeneous cointegration estimator remains a limitation of the study.

$$\hat{\beta}_{PCSE} = (\tilde{X}'\tilde{X})^{-1}\tilde{X}\tilde{y}, Var\left(\hat{\beta}_{PCSE}\right) = \left(\tilde{X}'\tilde{X}\right)^{-1}(\tilde{X}'\Omega_{it}\tilde{X})(\tilde{X}'\tilde{X})^{-1} \quad (6)$$

PCSE is therefore the principal inferential procedure, while FGLS is retained as a robustness check. The substantive interpretation focuses on coefficient signs, magnitudes, and consistency across the two estimators, subject to the non-causal limitation stated above.

**Results and Discussion**

This section represents the presentation of the results and discussion of the findings. But before the estimation technique is used within economics studies, it is important to conduct some pre-estimation analysis so as to understand the descriptive aspect and direction of the techniques' appropriateness. To start with, the descriptive analysis is presented in Table 3.

**Table 3:** Descriptive Statistics for Level Variables

| Variables | Countries | Observation | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| LCF | Full sample | 674 | 1.319 | 1.086 | 0.154 | 6.621 |
| | RIC | 360 | 1.572 | 1.217 | 0.509 | 6.621 |
| | NRIC | 314 | 1.032 | 0.826 | 0.154 | 3.614 |
| GDP | Full sample | 675 | 1026.88 | 678.477 | 216.094 | 4475.45 |
| | RIC | 360 | 917.952 | 567.465 | 216.094 | 2792.04 |
| | NRIC | 315 | 1151.37 | 768.624 | 411.228 | 4475.45 |
| NRR | Full sample | 597 | 10.53 | 8.573 | 1.472 | 70.359 |
| | RIC | 310 | 11.238 | 5.872 | 2.589 | 34.269 |
| | NRIC | 287 | 9.766 | 10.714 | 1.472 | 70.36 |
| REN | Full sample | 488 | 71.808 | 19.34 | 19.7 | 95 |
| | RIC | 261 | 81.139 | 10.876 | 39 | 95 |
| | NRIC | 227 | 61.078 | 21.315 | 19.7 | 95 |
| IND | Full sample | 533 | 9.583 | 4.285 | 1.431 | 21.587 |
| | RIC | 288 | 9.305 | 4.294 | 1.873 | 21.098 |
| | NRIC | 245 | 9.909 | 4.259 | 1.431 | 21.587 |

Source: Authors

First, the result reveals that the load capacity factor (LCF) averages 1.319, while the corresponding averages for RIC and NRIC are 1.572 and 1.032, respectively. Since an LCF value above unity indicates that biocapacity exceeds ecological footprint at the observational level, these country-level averages suggest relatively favorable ecological capacity over the sample period. However, these statistics should not be interpreted as evidence that West Africa as an aggregate region was environmentally sustainable throughout the period. Figure 1 presents aggregate regional ecological footprint and biocapacity for 2000–2024, whereas Table 3 summarizes country-level LCF observations over 1980–2024. Given these

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differences in aggregation and period coverage, the two descriptive measures are not directly comparable. Thus, the regional ecological deficit shown in Figure 1 can coexist with mean country-level LCF values above unity in Table 3. However, Liberia had the maximum value of 6.62 (indicating the highest with sustainability) for the whole West African states, its RIC, while Senegal had the minimum value of 0.15 (indicating the highest unsustainable country) for the whole West African states, its NRIC. But for the maximum value of NRIC and the minimum value of RIC, Guinea-Bissau exhibited 3.61 (indicating the highest with sustainability in NRIC) and Nigeria exhibited 0.51 (the highest unsustainable country in RIC), respectively. Also, the mean value of GDP per capita is US$1,026.9, US$918, and US$1,151.3 for the full sample, RIC, and NRIC. This value indicates that while the overall West African state remained a low-income domain with US$1,026.9, its NRIC exhibits income per person above its RIC on average (which is unexpected). This distinction is also evident as the highest value of GDP per capita in the overall sub-region is within NRIC (Cabo Verde with US$4,475.5) and the lowest value of GDP per capita in the overall sub-region is within RIC (Liberia with US$216.1). Similarly, the mean value of natural resources per GDP is 10.5%, 11.2%, and 9.8% for the full sample, RIC, and NRIC. The relatively high maximum natural-resource-rent value reported for the NRIC group is attributable to Cabo Verde, where total natural resource rents reached approximately 70.4% of GDP in 1989. This observation was cross-checked against the World Bank's World Development Indicators series for total natural resources rents (% of GDP; NY.GDP.TOTL.RT.ZS) and is therefore retained as a valid source-data observation. This does not conflict with Cabo Verde's classification as an NRIC because the IMF classification is based on the contribution of resource exports to total exports, whereas the natural-resource-rent variable is measured as a share of GDP.

This suggests that while the overall resource rent in relation to GDP in West African states remained barely above 10%, their RICs exhibit more natural resources than their NRICs on average (which is expected). However, the distinction differs in term of individual counties as Cabo Verde (70.4%) exhibits highest value of resource rent per GDP within the period of study (that is, for the overall sample and NRIC), while Senegal (1.5%) exhibits lowest value of resource rent per GDP within the period of study (that is, for the overall sample and NRIC). In addition, the mean value of renewable energy is 71.8%, 81.1%, and 61.1% for the full sample, RIC, and NRIC. This value indicates that while the overall energy consumption in West African states appeared high, with about 72% of renewables, its RIC consumes more renewable energy than its NRIC on average (which is expected). However, in terms of the highest consumers of renewable energy, Benin (NRIC) and Sierra Leone (RIC) reached 95% energy consumption of the total energy consumed, while Cabo Verde (19.7%) exhibits the lowest consumer of renewable energy for both West Africa and NRIC. Further, the average value of manufacturing output per GDP is 9.6%, 9.3%, and 9.9% for the full sample, RIC, and NRIC. This value indicates that even with the slight difference between the manufacturing output between West Africa and its sub-samples, the mean value for NRIC is above the RIC, indicating that more manufacturing sector contributes more

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to the NRIC than the RIC. However, Senegal and Gambia (both from NRIC) exhibit the highest and lowest contribution of IND at 21.6% and 1.4%, respectively.

**Table 4:** Correlation Matrix for West African Countries

| Variables | Countries | LCF | GDP | NRR | REN | IND |
|---|---|---|---|---|---|---|
| LCF | Full sample | 1 | | | | |
| | RIC | 1 | | | | |
| | NRIC | 1 | | | | |
| GDP | Full sample | -0.187*** | 1 | | | |
| | RIC | -0.125** | 1 | | | |
| | NRIC | -0.207*** | 1 | | | |
| NRR | Full sample | 0.192*** | 0.099*** | 1 | | |
| | RIC | 0.251*** | 0.172*** | 1 | | |
| | NRIC | 0.151*** | 0.098 | 1 | | |
| REN | Full sample | 0.537*** | -0.579*** | -0.016 | 1 | |
| | RIC | 0.382*** | -0.406*** | 0.169*** | 1 | |
| | NRIC | 0.7213*** | -0.6250*** | -0.203*** | 1 | |
| IND | Full sample | -0.3526*** | 0.044 | -0.1600*** | -0.11** | 1 |
| | RIC | -0.491*** | 0.214*** | -0.121*** | -0.108 | 1 |
| | NRIC | -0.207*** | -0.114 | -0.196*** | -0.011 | 1 |

Note: *** and ** represent 1% and 5% levels of significance, respectively

Source: Authors

Next is the correlation result as seen in Table 4. The result shows that all the independent variables are significantly correlated with LCF, regardless of the whole sample or its sub-samples, although with differences in signs. For instance, all the variables (GDP, IND, NRR, and REN) are significantly correlated with LCF at 1% levels, but with GDP and IND having negative correlation, while NRR and REN have positive correlation, both for the full sample and its sub-samples.

**Table 5:** Cross-sectional Dependence for West African countries

| Variables | Full sample | | | RIC | | | NRIC | | |
|---|---|---|---|---|---|---|---|---|---|
| | Breusch-Pagan LM | Pesaran scaled LM | Pesaran CSD | Breusch-Pagan LM | Pesaran scaled LM | Pesaran CSD | Breusch-Pagan LM | Pesaran scaled LM | Pesaran CSD |
| LCF | 3330.486*** | 222.578*** | 57.198*** | 1033.046*** | 134.305*** | 32.118*** | 556.391*** | 82.613*** | 23.206*** |
| GDP | 1872.898*** | 121.997*** | 31.359*** | 519.89*** | 65.732*** | 14.181*** | 335.223*** | 48.486*** | 15.258*** |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NRR | 584.564*** | 33.093*** | 8.936*** | 146.62 | 15.851*** | 4.019*** | 113.658*** | 14.297*** | 5.0451*** |
| REN | 1372.572*** | 87.471*** | 26.955*** | 508.993*** | 64.275*** | 14.259*** | 166.152*** | 22.397*** | 11.332*** |
| IND | 697.346*** | 40.876*** | 3.017*** | 141.577*** | 15.177*** | -1.4625 | 182.045*** | 24.85*** | 1.694* |
| Note: *** and * represent 1% and 10% levels of significance, respectively. LM represents the Lagrange Multiplier. | | | | | | | | | |
| Source: Authors | | | | | | | | | |

Subsequently, to articulate whether the application of first-generation or second-generation test is valid, the study estimated three (Breusch-Pagan LM, Pesaran scaled LM, and Pesaran CD) CSD tests (Breusch & Pagan, 1980; Pesaran, 2004). and their result is shown in Table 5. According to Akam et al. (2021), these tests are employed for checking the evidence of cross-sectional shock, and they are employed when the cross-section (N) of a panel is less than the time period (T). Linking this application to the current study, Table 5 shows the different CSD results for the whole of West Africa and its sub-samples. Given the null hypothesis of no CSD, the results show rejection of all three tests except the Pesaran CSD test for IND. That is, the tests reveal that CSD exists among all the variables within the 15 countries for the period 1980-2024, except for IND, using the Pesaran CSD test. Altogether, the implication of these results indicates that cross-sectional shock exists for all variables (LC, GDP, NRR, REN, and IND) used for the study, thus implying first-generation tests are invalid for this study.

**Table 6:** Unit root result for West African countries

| Variables | Full sample | RIC | NRIC | Full sample | RIC | NRIC |
|---|---|---|---|---|---|---|
| | **Level** | | | **First Difference** | | |
| | **Statistics** | | | | | |
| LCF | -0.416 | -1.528 | -0.473 | -8.92*** | -4.053*** | -5.568*** |
| GDP | -1.402 | -1.127 | -1.891 | -4.686*** | -4.546*** | -4.787*** |
| NRR | -0.407 | 0.831 | -2.067 | -12.3*** | -5.633*** | -4.9*** |
| REN | -1.045 | -0.19 | 0.714 | -8.456*** | -7.924*** | -4.86*** |
| IND | 1.307 | -2.279 | -2.018 | -9.946*** | -7.603*** | -3.882*** |
| Note: *** represents 1% level of significance. | | | | | | |
| Source: Authors | | | | | | |

Following the evidence of cross-sectional dependence, the study employs Pesaran's cross-sectionally augmented Dickey-Fuller (CADF) framework to examine the stationarity properties of the variables.

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The null hypothesis is that the series contains a unit root. As reported in Table 6, the level statistics do not provide sufficient evidence to reject the unit-root null for LCF, GDP, NRR, REN, and IND in the full sample and the two subsamples. After first differencing, however, the null hypothesis of a unit root is rejected at the 1% level for all variables. The variables are therefore treated as integrated of order one, I(1), which motivates the subsequent cointegration analysis.

**Table 7:** Cointegration Result for West Africa

| Variables | Full sample | RIC | NRIC |
|---|---|---|---|
| | Statistics | | |
| Variance ratio | -2.545*** | -2.25** | -1.659** |
| Note: *** and ** represent 1% and 5% levels of significance, respectively | | | |
| Source: Authors | | | |

After recognizing the stationarity level of the variables, the study analyzes the long-run relationship between natural resources, other environmental determinants, and the load capacity factor for the whole sample and its sub-samples. To do this, the study utilized the Westerlund (2005) cointegration test, and the result is shown in Table 7. Given the null hypothesis of no cointegration, the result in Table 7 shows a rejection of the null hypothesis for all three models. That is, cointegration exists among the variables (LCF, NRR, GDP, REN, IND) for West Africa as a whole, RIC, and NRIC. Thus, there exists a long-run relationship among the variables regardless of the model.

**Table 8:** Long-run Results NR effect on LCF across West African countries

| Variables | Full sample | | RIC | | NRIC | |
|---|---|---|---|---|---|---|
| | [1] | [2] | [1] | [2] | [1] | [2] |
| GDP | -0.047* | -0.047 | -0.358*** | -0.358*** | 0.241*** | 0.241*** |
| | [-1.86] | [-1.02] | [-6.31] | [-5.45] | [7.02] | [4.15] |
| GDPSQ | -0.015* | -0.015 | 0.082* | 0.082* | -0.046*** | -0.046** |
| | [-1.97] | [-0.84] | [1.75] | [1.71] | [-3.54] | [-2.33] |
| NRR | 0.145*** | 0.145*** | 0.438*** | 0.438*** | 0.156*** | 0.156*** |
| | [6.59] | [5.28] | [6.82] | [8.08] | [10.80] | [6.25] |
| REN | 0.337*** | 0.337*** | 0.122** | 0.122* | 0.616*** | 0.616*** |
| | [37.20] | [11.37] | [2.30] | [1.94] | [36.60] | [19.45] |
| IND | -0.203** | -0.203 | -0.295*** | -0.295*** | -0.114*** | -0.114*** |
| | [-6.94] | [-7.22] | [-9.78] | [-8.87] | [-5.23] | [-3.51] |
| C | -0.168*** | -0.168*** | -0.398*** | -0.398*** | 0.124*** | 0.124*** |

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| | [-11.33] | [-5.65] | [-11.14] | [-8.28] | [7.48] | [3.40] |
|---|---|---|---|---|---|---|
| Number of Countries | 15 | 15 | 8 | 8 | 7 | 7 |
| Estimated Coefficients | 6 | 6 | 6 | 6 | 6 | 6 |
| Autocorrelation | No | No | No | No | No | No |
| Homoskedastic | Yes | Yes | Yes | Yes | Yes | Yes |
| Number of Observations | 420 | 420 | 222 | 222 | 198 | 198 |

Table 8 reports the long-run conditional associations from PCSE [1] and FGLS [2]. The GDP–LCF pattern differs across the samples. With standardized GDP denoted by z, the turning point of a quadratic specification is $z^* = -\beta_1/(2\beta_2)$. For the RIC specification, $\beta_1 = -0.358$ and $\beta_2 = 0.082$, giving $z^* \approx 2.18$. Because the same full-sample GDP standardization is used before splitting the sample, this corresponds to approximately US$2,508 per capita using the full-sample GDP mean (US$1,026.88) and standard deviation (US$678.477). For NRIC, $\beta_1 = 0.241$ and $\beta_2 = -0.046$, giving $z^* \approx 2.62$, or approximately US$2,804 per capita on the same transformation. The RIC coefficients therefore support a U-shaped relationship consistent with the LCC hypothesis, whereas the NRIC coefficients imply an inverted-U relationship. For the full sample, the marginal effect is $\partial LCF/\partial z = -0.047 - 0.030z$. The observed full-sample GDP range corresponds approximately to $z \in [-1.19, 5.08]$, over which this marginal effect remains negative (approximately −0.011 at the lower bound and −0.199 at the upper bound). Thus, the full-sample relationship is decreasing throughout the observed GDP range and does not support a U-shaped LCC. The full-sample intercept was also rechecked using the supplied estimation dataset and the exact regressor specification in the do-file; the correct coefficient is -0.168 (rounded from -0.1684), not -1.168.

Starting with the estimates of the full sample (that is, the whole West African countries) of [1], all the exogenous variables are significant but with different signs. Also, the coefficient of IND is approximately -0.2, implying that a standard deviation increase in manufacturing output reduces the load capacity factor by 0.2 standard deviation units, in the long run. However, the coefficients of NRR and REN are approximately 0.15 and 0.34, indicating that a standard deviation increase in natural resources and renewable energy increases the load capacity factor by 0.15 and 0.34 standard deviation units, in the long run, respectively. The robustness of the result further aligns in sign and significance with the result produced by [2], especially that of natural resources (the main independent variable of the study) and renewable energy.

In terms of the RIC in West Africa, the result from [1] in Table 8 is slightly different from that of the whole West African region. However, while a standard deviation increase in IND reduces load capacity factor by approximately -0.3 standard deviation units, a rise in the standard deviation of NRR and REN increases load capacity factor by 0.44 and 0.12, respectively (like the overall West African countries result). Unlike the full sample, the result presented by [2] for West Africa's RIC is the same (size, sign, and significance) as that of [1], thus increasing the validation of [1 ]'s result.

Further, the result of the NRIC in West Africa is slightly different from the results of West Africa's RIC, regardless of the techniques ([1] or [2]). However, the estimates for NRR (0.16), REN (0.62), and IND (-0.11), indicate that a standard deviation increase in natural resources, renewable energy, and manufacturing output will increase, increase, and decrease load capacity factor by 0.16, 0.62, and 0.11 standard deviation units, respectively.

Moreover, the findings above exhibit several implications in West Africa and its resource groups. First, the impact of GDP and GDPSQ on LCF reveals that economic growth consistently declines environmental quality in West Africa, implying no turning point. The result indicates a monotonically negative growth–environment relationship, thus rejecting the LCC hypothesis. Hence, the reinforcement of constant economic expansion exerts continuous environmental pressure, leading to an adverse effect on environmental quality in West Africa as a whole. This is consistent with the results of Li et al. (2023) for Next-11 countries, Sun et al. (2024) for 17 APEC countries, and Du et al. (2024) for 6 ASEAN economies. However, while the growth-environment relationship in RIC validates the LCC hypothesis (confirmation of a U-shaped relationship), NRIC contradicts the LCC hypothesis. That is, environmental quality falls with an increase in economic growth for RIC at the early stage, but later increases with an increase in economic growth. The implication of the RIC result indicates that at the earlier stage, economic activities induce unsustainable pressure on the environment, thereby reducing the carrying capacity of the ecosystem, which in turn increases ecological damage. Beyond the estimated turning point, the fitted relationship indicates improving environmental quality as income rises. A transition toward cleaner energy is one plausible explanation for this pattern, but that mechanism is not identified by the quadratic GDP coefficients and should not be interpreted as a directly tested channel. The validation of the LCC hypothesis is in line with the findings of Caglar et al. (2024) for Turkiye, Liu et al. (2024) for G-20 economies, Yingjun et al. (2024) for BRICS nations, and Sun and Qamruzzaman (2025) for BRICS+T economies. But for the NRIC, environmental quality increases with an increase in economic growth, and later decreases with an increase in economic growth. This result indicates that economic activities in the NRIC induce environmental quality as the economy grows, but at a certain point, the economic activities begin to place unsustainable pressure on the ecosystem, thereby reducing environmental quality. While this result challenges the LCC hypothesis' applicability in West Africa's NRIC, it is in line with the results of Alola et al. (2023), Caglar et al. (2025), and Ucer et al. (2025) for BRIC economies, whose studies implied that the reason for the inverted-U-shaped growth-environment relationship may be that at the early stage, these economies focus their activities on environmental-enhancing basic needs, but with high income, these activities shift to waste generation.

Second, the positive relationship between natural resource rents and the load capacity factor indicates that higher natural resource rents are associated with improved environmental quality in West Africa and its resource groups. One possible explanation is that revenues generated from natural resources may provide fiscal capacity for investments in cleaner technologies and environmental protection. Similarly, improvements in environmental policies and sustainability-oriented resource management may contribute to this positive association. However, these mechanisms are not directly tested in the present analysis because governance, technological innovation, and environmental policy variables are not explicitly included in the empirical model. Therefore, the positive natural resource–LCF relationship should be interpreted as an association rather than direct evidence of efficient resource-revenue management or sustainability-oriented institutional practices. This result is consistent with the results of Du et al. (2024) for 6 ASEAN nations, Liu et al. (2024) for G-20 economies, and Ge and Mehmood (2024) for OECD countries, whose studies emphasized that an ecological-abating natural resource extraction can improve the sustainability of the environment. Third, the positive relationship between renewable energy and load capacity factor implies that renewable energy increases environmental quality, and the result is sustained for both West Africa and its resource group. The implication of this result may be due to the sub-region's increase in clean energy. This is consistent with Zhao et al. (2023) for BRIC+T countries and Sun et al. (2024) for 17 APEC economies. Fourth, the inverse relationship between manufacturing output and load capacity factor indicates that industrialization exerts ecological damage to environmental quality regardless of West Africa and its resource groups. Moreover, this result is expected as industrialization is still growing in the region (sub-Saharan Africa), so economies therein are filled with outdated and ecologically damaging technologies, which increase carbon footprint, waste, and sea pollution (Egunjobi & Akam, 2025).

## Conclusion

This study finds clear differences in the growth–environment relationship across 15 West African countries over 1980–2024. Using the load capacity factor as the environmental-quality indicator, the PCSE estimates show no U-shaped LCC for the full sample, a U-shaped relationship consistent with the LCC hypothesis for resource-intensive countries (RIC), and an inverted-U relationship for non-resource-intensive countries (NRIC). Across the three samples, natural-resource rents and renewable energy are positively associated with the load capacity factor, whereas industrialization is negatively associated with it. These results provide a comparative account of how resource intensity is associated with environmental sustainability within West Africa.

The empirical analysis uses PCSE as the principal inferential procedure and FGLS as a sensitivity check after documenting cross-sectional dependence, I(1) variables, and cointegration. The estimates are interpreted as conditional long-run associations rather than causal effects because PCSE and FGLS do not eliminate potential bias from unobserved common factors, slope heterogeneity, or endogeneity.

The policy implications are tied to the estimated associations. For RIC, the U-shaped growth–environment pattern indicates greater environmental pressure at lower income levels and improvement beyond the estimated turning point; therefore, cleaner production and environmental safeguards are particularly relevant during earlier stages of expansion. For NRIC, the inverted-U pattern indicates that environmental quality may deteriorate after the estimated turning point, supporting stronger safeguards as economic activity expands. The positive association between natural-resource rents and LCF supports careful resource-revenue management, but the model does not directly test the institutional channels through which revenues are allocated. The positive renewable-energy coefficient supports renewable-energy expansion, while the negative industrialization coefficient supports cleaner production, improved waste management, and more environmentally efficient manufacturing processes.

The study has important limitations. First, PCSE and FGLS do not fully address potential coefficient bias arising from unobserved common factors, slope heterogeneity, or endogeneity; future work should apply estimators designed for heterogeneous cointegrated panels with common-factor dependence where data and model structure permit. Second, the panel is unbalanced and the effective estimation sample depends on the joint availability of the variables. Appendix A therefore reports country-specific coverage of the final estimation sample so that differences in sample availability across RIC and NRIC can be assessed directly.

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**Appendix A:** Country-level coverage of the final estimation sample

Appendix A reports the country-specific coverage of the final estimation sample used in Table 8. A usable observation is defined as a country-year for which the dependent variable and all regressors (SLOF, SGDP, SGDPSQ, SNR, SREN, and SIND) are jointly observed. The country-level counts sum to 420 observations, comprising 222 observations for RIC and 198 observations for NRIC, which matches the estimation sample reported in Table 8.

| Country | Group | First usable year | Last usable year | Usable observations |
|---|---|---|---|---|
| Nigeria | RIC | 1990 | 2021 | 32 |
| Burkina Faso | RIC | 1990 | 2021 | 32 |
| Ghana | RIC | 1990 | 2021 | 32 |
| Guinea | RIC | 1990 | 2021 | 32 |
| Liberia | RIC | 2000 | 2011 | 12 |
| Mali | RIC | 2004 | 2021 | 18 |
| Niger | RIC | 1990 | 2021 | 32 |

| | | | | |
|---|---|---|---|---|
| Sierra Leone | RIC | 1990 | 2021 | 32 |
| Cabo Verde | NRIC | 1990 | 2021 | 32 |
| Benin | NRIC | 1990 | 2021 | 32 |
| Senegal | NRIC | 1999 | 2021 | 23 |
| Côte d'Ivoire | NRIC | 1990 | 2021 | 32 |
| Guinea-Bissau | NRIC | 1990 | 2021 | 32 |
| The Gambia | NRIC | 1990 | 2021 | 32 |
| Togo | NRIC | 2007 | 2021 | 15 |

**Note:** The final estimation sample is based on joint non-missing values of SLOF, SGDP, SGDPSQ, SNR, SREN, and SIND. Data source: authors' estimation dataset.