The Role of Industrialization and Renewable Energy on Environmental Quality in Oil Exporting Sub-Saharan African Countries

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Abstract

As countries grow, the call for achieving industrial sustainability becomes crucial for their development. As a result, this paper investigates the role of industrialization and renewable energy on environmental quality (proxied as load capacity factor) across seven (7) oil-exporting SSA countries between 1990 and 2023. Using cross-sectional dependence induced techniques such as panel-corrected standard error (PCSE) and feasible generalized least squares (FGLS), this study finds that while a unit increase in industrialization exacerbates environmental quality by 0.47 units, a unit increase in renewable energy plays an important role in improving environmental quality by 0.06 units. However, the amount of renewable energy consumption does not have the full potential to reduce the adverse environmental effects of industrialization. Further, the result indicates that while population reduces ecological quality, economic growth improves it. The study recommends that policymakers in oil-exporting countries should tailor their policies towards environmental regulation and encourage the use of eco-friendly technologies in the manufacturing sectors, through tax incentive policies, green industrial zones, and benchmarking ecological performance across these countries.

Keyword: Load capacity factor; Panel corrected standard error; Industrialization; Environmental quality; Oil-exporting countries; Feasible generalized least square.

JEL Classification Codes: C21, C23, O14, Q56, Q53.

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1. Introduction

Sustainable industrialization (as enshrined in the sustainable development goal 9) has become a crucial aspect of sustainable development across the world. This is because industrialization represents a socioeconomic process that relate to the ways value is discovered and created more efficiently (Simandan, 2020), which will manifest in increased productivity, technological advancement, and economic transformation. As the most important panacea for economic growth, several industrial policies (such as automotive industrial policies, green industrial policies, and government-supported research and development policies) have been used by policymakers to expand their economies (Tai & Ku, 2013; Opuku & Yan, 2018; Andreoni & Tregenna, 2020; Mentel *et al.*, 2022a). However, most of these policies came with environmental consequences that adversely affect human health (Haider *et al*., 2024; Mentel *et al*., 2022a; Siddique & Alvi, 2025).

The environmental consequences of industrialization are mostly driven by industries' use of natural resources. For instance, several industries utilize non-renewable energy (due to its cheapness and accessibility) for economic activities. For this reason, energy accounts for more than three-quarters of total Greenhouse Gas (GHG) emissions (with worldwide consumption from electricity and heat (29.7%), transportation (13.7%), manufacturing and construction (12.7%), and buildings (6.6%)), which invariably increase the adverse impact on the environment (Aquilas *et al*., 2024; IEA, 2024; World Resource Institute, 2024). Simultaneously, few papers have argued that the adverse effect of industrialization can be mitigated through the use of renewable energy resources (Mentel *et al*., 2022a;b; Aquilas *et al*., 2024). This is because the utilization of renewable energy consumption serves as a substitute for reducing carbon-emitting production, which in turn promotes green growth and leads to the creation of footprint-reducing jobs in the industries (Mentel et al., 2022a; Nathaniel, 2025b).

Moreover, the industrialization-environment debate has entered another dimension in recent years, with scholars having mixed arguments on whether or not industrialization degrades the environment. For instance, with the use of different environmental indicators (majorly CO2 emissions (CO2), ecological footprint (EF), and load capacity factor (LF)), several studies establish that industrialization increases environmental harm (Aquilas et al., 2024; Popescu et al., 2024; Siddique & Alvi, 2025), while others indicate sustainable industrial impact (Ali *et al*., 2023; Haider *et al*., 2024).[1] Recently, unlike other environmental indicators, recent studies accentuate that the LF has become a better indicator (Samour et al., 2023; Jin &Huang, 2023; Aquilas *et al*., 2024). This is because the LF focuses on the integration of both the demand and supply side of the ecosystem. Thus, the LF is an environmental quality indicator that compares biocapacity and EF while tracking ecological thresholds (Siche *et al*., 2010; Pata & Isik, 2021).

Despite the recent call for environmental quality through various sustainable means, Sub-Saharan Africa (SSA) remains a vulnerable region, with unstable level of industrialization. This is because weak environmental regulation and economic activities from industrialization outweigh the ecological threshold, leading to a reduction in environmental quality (Akinsola *et al*., 2022; Mentel *et al*., 2022b; Aquilas *et al*., 2024). Moreover, several studies posit that unsustainable industrialization in the region is a result of high dependence on natural resource extraction, as many of these economies, particularly the resource-intensive countries (RICs) whose group holds

[1] The CO2, EF, and LF are majorly used by studies as environment proxies.

about 74% of the region's gross domestic product (GDP), have been seen to increase environmental atrophy (Aladejare & Nyiputen, 2022; Oteng-Abayie *et al*., 2022; IMF, 2024; World Bank, 2025).

Furthermore, given the importance of resource-dependence accumulation among the RICs in SSA, this study focuses on the oil-exporting countries, whose economies while representing 33% of the total RICs in SSA (IMF, 2024), contribute about 42% of its total manufacturing output between 1990 and 2023 (World Bank, 2025). This high performance relative to their group size (about 9% more than the expected size) indicates an increment of industrial contribution above weight, which is likely to come with greater environmental harm. The fact that oil-exporting countries are known to engage in high industrial activities, with their major responsibility in increasing global ecological problems, further intensifies this concern (Azam *et al*., 2022; Idowu *et al*., 2023). Also, while the oil-exporting countries increase their industrial output relative to GDP, the use of clean natural resources (such as renewable energy), followed by LF, resulted in a decline in the past three decades (See Figure 1). As such, this study raised questions like what are the environmental impacts of industrialization and renewable energy across the oil-exporting SSA countries. Does the renewable energy moderate industrialization-environmental impact across the oil-exporting SSA countries?

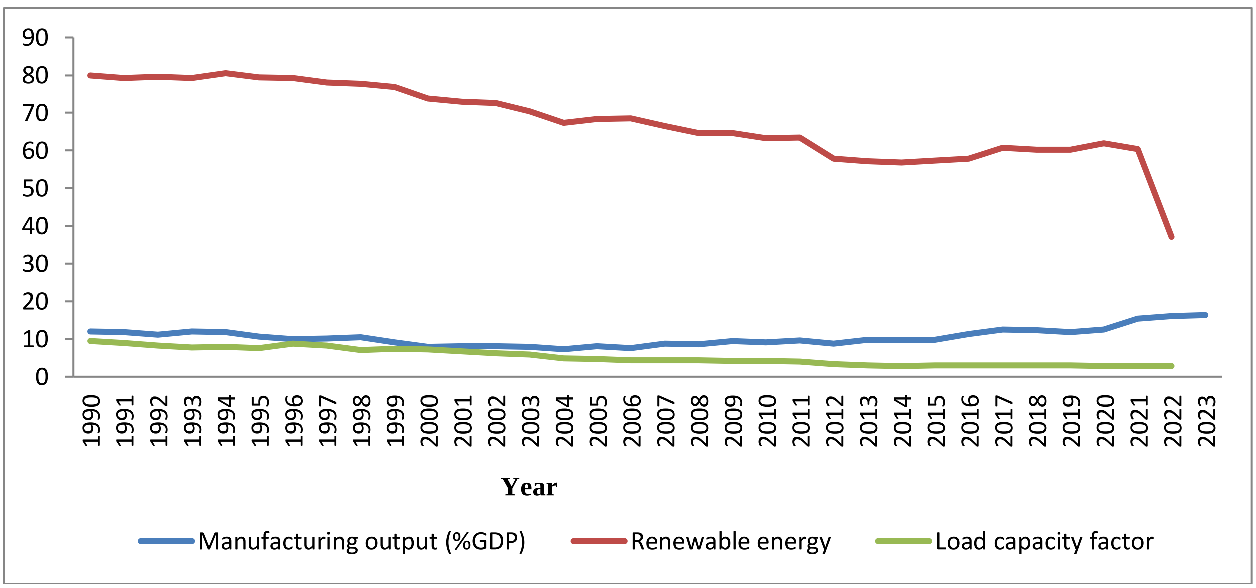

Figure 1: Manufacturing output, Renewable energy, and Load capacity factor (1990-2023)

Source: Global Footprint Network (2025) and World Bank (2025).

To this end, this study investigates the role of industrialization and renewable energy on environmental quality in the oil-exporting SSA countries. Importantly, this study explores the relationship using the panel-correlated standard error (PCSE) and feasible generalized least squares (FGLS) techniques. These techniques are second-generation estimation techniques designed for addressing panels assumed to exhibit cross-sectional dependence (CD). Compared to other CD allowance techniques, these techniques produce coefficients with heteroskedasticity and autocorrelation-consistent (HAC) standard errors (SE). Following this section, section two briefly explains the review of recent literature, while sections three, four, and five indicate the methodology, result discussion, and concluding remarks, respectively.

The remainder of this study is organized as follows. Section 2 reviews the literature. While section 3 describes the methodology, section 4 presents and discusses the estimated results. Section 5 concludes.

2. Literature Review

Theoretically, several authors emphasize how anthropogenic activities and natural resource use affect the environment. First, is the load capacity hypothesis (LCC), which is an extension of Grossman and Krueger's (1991) environmental Kuznets curve (EKC). This extension which was put forward by Dogan and Pata (2022) as a result of the relevance given to LF (a broad environmental indicator) empirically by Pata (2021), indicate that as countries begin to pursue development through industrialization, environmental pressure (ecological footprint) will set in above the carrying capacity by nature (biocapacity), which will in turn decline the LF due to high environmental pollution. However, when these countries attain development, they begin to aim at structural change through the use of environmental abating technologies, which in turn increase environmental quality (increase in LF).[2] However, unlike EKC's inverted U-shaped hypothesis, LCC hypothesis posit a U-shaped relationship between growth and environment (Byaro *et al.*, 2024). Second, is the pollution haven hypothesis (PHH), which states that industries with environmental-aggravating productions are relocated from developed economies (due to strict environmental regulations) to emerging economies with weaker environmental regulations (Copeland & Taylor, 1994; Copeland, 2005; Huay *et al.*, 2022). This is done through international trade, whereby pollution-enhancing industries are migrated into underdeveloped nations. Thus, these underdeveloped nations become a haven for dirty goods pollution (Gill *et al.*, 2018; Opoku & Aluko, 2021).

On empirical ground, several studies relating to the environmental impact of industrialization and renewable energy have increased in recent years. On one hand, several recent studies have analyzed the industrialization-environment relationship using majorly three environmental indicators such as CO2 emissions (Mentel *et al.*, 2022a;b; Sikder *et al.*, 2022; Voumik & Sultana, 2022; Ali *et al.*, 2023; Patel & Mehta., 2023; Haider *et al.*, 2024; Siddique & Alvi, 2025), ecological footprint (Akinsola *et al.*, 2022; Aladejare & Nyiputen, 2022; Usman & Balsalobre-Lorente, 2022; Usman *et al.*, 2022; Wang *et al.*, 2022; Li & Li, 2023; Liao *et al.*, 2023; Popescu *et al.*, 2024), and load capacity factor (Jin & Huang, 2023; Samour *et al.*, 2023; Aquilas *et al.*, 2024). A summary of these studies is shown in Table 1 below.

On the other hand, several studies have investigated the environmental impact of renewable energy using different indicators. For instance, Hussain et al. (2024), established a strong negative

[2] The LCC hypothesis is in line with the EKC hypothesis in the aspect of the non-linear growth-environment relationship. Besides, the EKC posits that a nation's increased income will aggravate its environment, but on getting to a certain threshold (turning point), mitigation of these environmental challenges will set in. This is an indication that as the nation becomes richer, environmental abatement sets in (Opoku & Aluko, 2021). This can be done through three effects, that is, (i) early growth through unsustainable utilization of natural resources, leading to reduction in environmental quality (scale effect), (ii) environmental abatement through structural change as a result of increased growth of a nation (composition effect), (iii) as economies become richer, sustainability will rise through technological advancement and improved efficiency (technical effect).

relationship between renewable energy and CO_2 emission between 1971 and 2021 period while using different techniques (such as the mixed effect model, fixed effect model, and quantile model) across Group Twenty (G20) countries. Also, while using CO_2 as an environment indicator and wavelet coherence (WC) approach, Adebayo *et al*. (2023) discovered an aggravating impact of renewable energy regardless of the different sources (hydro and geothermal) across BRICS countries for the period between 1990q1 and 2019q4. Similarly, Chen *et al*. (2022) studied the CO_2 impact of renewable energy across 97 countries and found that renewable energy is significant in reducing environmental degradation only if these countries surpass their renewable energy threshold for the period between 1995 and 2015. In the same year, Magazzino *et al* (2022) while using FMOLS found renewable energy to be a guaranteed instrument for reducing CO_2 emissions in five Scandinavian countries for the period between 1990 and 2018. Using the same environmental indicator but a different technique (AMG), Akam *et al*. (2021) found renewable energy to be an abating tool for environmental harm in thirty-three heavily indebted poor countries for the period between 1990 and 2018. Furthermore, Maji *et al*. (2022) using GMM, evaluated the impact of clean energy and institutions on environmental quality in 45 SSA countries. With the period spanning between 2008 and 2020, the authors revealed a mitigating impact of renewable energy on CO_2 emissions, thereby reducing environmental harm in the region. However, the study also found that complementing clean energy with institutions increases environmental aggravation in the region.

With regards to EF, Nathaniel *et al* (2025a) across 25 ecological deficit sub-Saharan countries, found renewable energy in these countries not to be efficient enough to reduce environmental degradation between 1990 and 2022. In the same year, in contrast, Azimi and Rahman (2024) across 74 emerging economies explored renewable energy interplay with ecological footprint and found renewable energy to be efficient in mitigating environmental harm while using GMM and POLS for the period between 2000 and 2022. Further, using both EF and CO_2 as environmental indicators for 130 countries between the period 1992 and 2019, Li and Wang (2023) found renewable energy to be a significant factor in alleviating environmental pressure.

In term of LF as environmental indicator, Nwani et al. (2025) examined the ecological impact of renewable energy in SSA from 1991 to 2020. Using quantile regression and LF as an environmental indicator, the paper discovered that while renewable energy increases and decreases LF in the lower and upper quantiles respectively, growth enhancement in the region can lead to sustainability through renewable energy. Also, Annor *et al*. (2024) investigated the environmental impact of green energy (proxied with renewable energy) in 47 SSA countries for the period 1990-2021. With the use of a two-stage system, generalized methods of moment (GMM) and different environmental proxies (such as CO_2 and LF), the authors found a detrimental effect of green energy in SSA countries regardless of the ecological proxy. Further, between 2000 and 2018, Byaro *et al*. (2024) analyzed the environmental impact of clean energy in SSA. With the use of generalized quantile regression, the authors discovered that clean energy (such as renewable energy and clean cooking fuel) increases LF, thereby leading to the upsurge of environmental quality.

In all, while there are mixed findings on the environmental impact of industrialization and renewable energy using different environmental indicators, this study, like Mentel *et al*. (2022a:b), Nulambeh *et al*. (2024), and Aquilas *et al*. (2024) investigates the renewable role in mitigating or aggravating the industrialization-environment relationship in selected African countries. Unlike these two studies, this paper extends the gap by comparing the results of the LF indicator (a novel research) to that of the EF. Also, none of the previous industrialization-environment relationship studies has been on oil-exporting SSA countries. In light of the argument above, this study tends to add an empirical gap to the body of knowledge**.**

Table 1: Summary of Previous Studies on industrialization-environment nexus

Authors	Environmental indicator	Region/countries	Time period	Methodology	Findings
Edeme *et al.* (2025)	EF	38 African countries	1990-2019	ARDL	GDP↑REW↓FDI↑IND↑→EF↑
Siddique and Alvi (2025)	CO2	South Asia	1990-2018	AMG, FE, RE, and CCEMG	TOP↑URB↑REW↓IND↑→CO2↑
Wang and Xu (2025).	LF	European (E7) countries	2000-2022	MMQR	GLO↓GDP↑ENT↑IND↓→LF↑
Amoah *et al.* (2024)	CO2	28 SSA countries	2003-2021	GMM	IND↑IND*TO↑→CO2↑
Appiah *et al.* (2024)	CO2	SSA countries	1996-2019	Panel FMOLS	GDP↑GDP2↓CC↓RQ↓RL↓IND↑→CO2↑
Aquilas *et al.* (2024)	LF	46 African countries	2000-2022	FE and GLS	POP↓IND*REW↑REW↑IND↓→LF↑
Haider *et al.* (2024)	CO2	Pakistan	1974-2022	ARDL	POP↑GDP↑FDI↑IND↓→CO2↑
Nulambeh and Jaiyeoba (2024)	EF	36 SSA countries	2006-2020	GMM	GDP↑REW↓POP↓IQ↑IND↑→EF↑
Popescu et al. (2024)	EF	6 Balkan economies	1990-2022	FE, POLS, and dynamic-GMM	GDP↑GDP^2↓REW↑POP↓EC↑IND↑→EF↑
Ali *et al.* (2023)	CO2	Saudi Arabia	1991-2020	QR and QQ	URB↑EC↑FDI↓INN↓IND↓→CO2↑
Amoah *et al.* (2023)	CO2	30 SSA countries	2000-2022	CCEMG	FDII↑FDIO↓URB↑POP↓IND↑→CO2↑

Idowu *et al.* (2023)	CO2	8 OPEC countries	1985-2020	ARDL and CCEMG	FDI↑GDP↓IND*EC↑→CO2↑
Jin and Huang (2023)	LF	South Africa	1990-2019	Non-lineal ARDL	REW↑HC↑GDP↓IND↓→LF↑
Li and Li (2023)	EF	Asia	1990-2022	CS-ARDL	FD↓INN↓GDP↑IND*FD↓IND↑→EF↑
Liao *et al.* (2023)	EF	OECD economies	1990-2022	MMQR	GDP↑GIN↓REW↑IND*GIN↓FDI↑IND↑→EF↑
Patel and Mehta (2023)	CO2	India	1971-2019	Non-lineal ARDL	FD^{+}↓ FD^{-}↓GDP↑EC^{+}↑IND↑→CO2↑
Samour *et al.* (2023)	LF	BRICS-T	1990-2018	ARDL (linear and non-linear)	GDP↓EC↓REW↑HC↑IND↓→LF↑
Akinsola *et al.* (2022)	EF	9 African nations	1990-2019	Panel ARDL	GDP↑URB↑REER↓IND↑→EF↑
Aladejare and Nyiputen (2022)	EF	32 African economies	1991-2019	DCCE, D-K, GLS-MEM, and PCSE	TNR↑GDP↑URB↓HC↑GI↑→EF↑
Mentel *et al.* (2022a)	CO2	Europe and Central Asia	2000-2018	2-step GMM	REW↓IND*REW↑POP↓IND↑→CO2↑
Mentel *et al.* (2022b)	CO2	SSA countries	2000-2015	GMM	GDP↑GDP^{2}↑REW↓IND*REW↓URB↑TOP↓→CO2↑
Sikder *et al.*, 2022	CO2	Developing economies	1995-2018	Panel ARDL	URB↑GDP↑EC↑IND↑→CO2↑

Usman & Balsalobre-Lorente (2022)	EF	Newly industrialized nations	1990-2019	AMG	TR↑FD↑REW↓TNR↓IND↑→EF↑
Usman *et al*. (2022)	EF	G7 nations	1991-2018	Panel DOLS, FGLS, D-K, panel DOLS	EC↑FDI↑NEP↑IND↑→EF↑
Voumik and Sultana (2022)	CO2	BRICS	1972-2021	AMG and CS-ARDL	REW↓URB↑IND↑→CO2↑
Wang *et al* (2022)	EF	G7 nations	1990-2020	CS-ARDL	GDP↑INN↓TOP↑REW↓IND↑→EF↑
Appiah *et al*. (2021)	CO2	25 SSA countries	1990-2016	AMG, DCCE, and CCEMG	URB↑EC↑IND↑→CO2↑

Note: Fully modified ordinary least square (FMOLS), Dynamic ordinary least square (DOLS), Feasible generalized least squares (FGLS), Mixed effect model (MEM), dynamic common correlated effect (DCCE), Driscoll and Kraay (D-K), Panel corrected standard error (PCSE), Method of moment quantile regression (MMQR), Cross-sectional autoregressive distributed lag (CS-ARDL), Organization of Petroleum Exporting countries (OPEC), Quantile regression (QR), Quantile-on-quantile (QQ), Pooled ordinary least squares (POLS), Generalized least square (GMM), Autoregressive distributed lag (ARDL), Generalized least squares, Augmented mean group (AMG), Fixed effects (FE), Random effects (RE), and Common correlated effects mean group (CCEMG). Industrialization (IND), Urbanization (URB), trade openness (TOP), renewable energy (REW), population (POP), economic growth (GDP), foreign direct investment (FDI), nonrenewable energy (EC), technology innovation (INN), financial development (FD), green innovation, human capital (HC), globalization (GI), total resource rent (TNR), regulatory quality (RQ), control of corruption (CC), rule of law (RL), foreign direct investment inflow (FDII), foreign direct investment inflow (FDIO), trade oppenness (TO), institutional quality (IQ), environmental technology (ENT), globalization (GLO), and total reserve (TR). Also ↑→↓ represents increase, lead to, and decrease, respectively.

Source: Authors.

3. Data and Methods

3.1 Data

This study collates data with an unbalanced panel of seven oil-exporting sub-Saharan African (SSA) countries between 1990 and 2023 from both the Global Footprint Network (2025) and World Bank (2025). According to the International Monetary Fund (2024; 2025), these countries differ from the rest of the region's countries because nonrenewable energy accounts for more than 30% of their entire exports. They include: Angola, Cameroon, Chad, the Congo Republic of, Equatorial Guinea, Gabon, and Nigeria.[3] The justification for choosing 1990-2023 is due to availability of consistency and comprehensiveness of the data across key variables for each included countries, which in turn will allow for robust analysis. The study excluded South Sudan due to the limitation of quality data. The variable description is shown in Table 2.

Table 2: Variable Description

Definition	Symbol	Measurement	Prior Literature	Data Source
Load Capacity factor	LF	Biocapacity/Ecological footprint	Jin & Huang, (2023), Aquilas *et al.* (2024)	Global footprint network (2025)
Ecological footprint	EF	Gha per person	Haider et al., (2024), Siddique & Alvi (2025)	Global footprint network (2025)
Industrialization	IND	Manufacturing, value added (% of GDP)	Patel and Mehta, (2023), Aquilas *et al*. (2024)	World Bank (2025)
Gross Domestic Product (GDP) per capita	GDPPC	Constant US Dollars	Patel and Mehta, (2023), Popescu *et al*. (2024).	World Bank (2025)
Renewable energy	REW	Percentage of total final energy consumption	Hussain et al. (2024), Nathaniel *et al.* (2025a)	World Bank (2025)
Population growth	POP	Annual (%)	Voumik and Sultana (2022), Haider *et al.* (2024)	World Bank (2025)

Source: Authors

3.2 Model

Following the discussions of prior studies (Akinsola *et al*., 2022; Usman & Balsalobre-Lorente, 2022; Mentel *et al*., 2022a; b; Usman *et al*., 2022; Voumik & Sultana, 2022; Idowu *et al*., 2023;

[3] The study excluded South Sudan due to the limitation of quality data such as load capacity factor, Gross domestic Product (GDP) per capita, manufacturing value add (%GDP), and renewable energy.

Aquilas *et al*., 2024; Nulambeh *et al*., 2024), this paper utilizes Dietz and Rosa's (1997) Stochastic Impacts Regression on Population, Affluence and Technology (STIRPAT) framework. This framework is a stochastic extension of the Impact Population Affluence Technology (IPAT) proposed by Ehrlich and Holdren (1971).[4] The STIRPAT is given as:

$$I_{it} = \alpha {P_{it}}^{\beta_1} {A_{it}}^{\beta_2} {T_{it}}^{\beta_3} e_{it} \qquad (1)$$

where I is environmental impact, P is population, A is Affluence (economic growth), and T is technology.[5] Also, while α is the constant term, $\beta_1 - \beta_3$ represents the parameters, *it* indicates the panel (cross-section and time period), and e represents the residual term. $\alpha > 0,\ \beta_1 > 0, \beta_2 > 0$, and β_3 </> 0. To analyze the objective of the study, equation (1) can be written as:

$$LF_{it} = \delta_0 + \delta_1 IND_{it} + \delta_2 REW_{it} + \delta_3 GDP_{it} + \delta_4 POP_{it} + \varepsilon_{it} \qquad (2)$$

Where LF indicates load capacity factor, IND indicates industrialization, REW represents renewable energy, GDP represents economic growth, and POP this represents the population. $\delta_0 - \delta_5$ represents the variables' parameters, *t* (1990-2023), *i* (seven countries) and ε is the estimation residual. Theoretically, δ_1 <0 reveals the adverse environmental impact of industrialization, noting that industrialization reduces environmental quality. Contrarily, δ >0 shows the mitigating impact of renewable energy on the environment. However, $\delta_3 - \delta_4$ <0 shows the adverse environmental impacts of economic growth and population (Jin & Huang, 2023; Samour *et al*., 2023; Aquilas *et al*., 2024). To establish the efficiency of industrialization, while following the argument of enabling the environmental impact of renewable energy moderation (Mentel *et al*., 2022a; b; Aquilas *et al*., 2024)., this study emphasizes that LF can be determined by IND*REW. This is written as:

$$LF_{it} = \emptyset_1 + \emptyset_1 IND_{it} + \emptyset_2 REW_{it} + \emptyset_3 (IND_{it} * REW_{it}) + \emptyset_4\ GDP_{it} + \emptyset_5 POP_{it} + u_{it} \ (3)$$

where $\emptyset_0 - \emptyset_6$ indicates the parameters; u_{it} is the residual. IND-LF entire influence in Equation (3) can be determined using the first differential, given as:

$$\frac{\partial LF_{it}}{\partial IND_{it}} = \emptyset_1 + \emptyset_3 REW_{it} \qquad (4)$$

From equation (4), different scenarios are put forward by the paper concerning $\emptyset_1$ and $\emptyset_3$. Starting with $\emptyset_3$>0, this indicates that renewable energy reduces the adverse environmental impact of industrialization. So if $\emptyset_1$>0, environmental quality of industrialization is improved by δ_3>0. But if $\emptyset_1$<0, then environmental aggravating industrialization is reduced by δ_3>0. Moreover, if$\emptyset_1 + \emptyset_3 \overline{REW}_{it} > 0$, the total effect of IND and REW on LF becomes positive. [6] In addition, δ_3<0 indicates that REW increases the adverse environmental impact of industrialization. Thus, if $\emptyset_1$>0,

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[4] York et al (2003b) acknowledges the limitations of IPAT framework.

[5] The T in the STIRPAT model can represent anything relating to production per unit such as industrialization, human capital, nuclear power, technological innovation, and financial development (York et al., 2003a;b; Voumik & Sultana, 2022).

[6] $\overline{REW}$ represents mean value of REW. See Ofori and Asongu (2021) for further clarification on the total effect.

environmental quality of industrialization is reduced by δ_3<0. But if $\emptyset_1$<0, then the environmental aggravating industrialization is increase by δ_3<0. Moreover, if $\emptyset_1 + \emptyset_3 \overline{REW}_{it} < 0$, total effect of IND and REW on LF becomes negative. (Where ($\overline{REW}$) is mean of REW)

Unlike previous studies especially that of Mentel *et al*. (2022a:b) and Aquilas *et al*. (2024) who estimated the interaction relationship between IND and REW, this paper checks for the robustness of the LF indicator (used in equation (2)) by using EF as another indicator for the environment.[7] This can be written as:

$$EF_{it} = \omega_0 + \omega_1 IND_{it} + \omega_2 REW_{it} + \omega_3 GDP_{it} + \omega_4 POP_{it} + \mu_{it} \qquad (5)$$

Where EF indicates ecological footprint, IND, REW, GDP, and POP remain the same as given in equation (2). $\omega_0 - \omega_5$ represents the variables' parameters, *t* and *i* remain the same as given in equation (2), and μ is the estimation residual. Theoretically, $\omega_1, \omega_3, \omega_4$ >0 reveals that industrialization, economic growth, and population growth increase EF, thereby causing damage to the environment. . Contrarily, ω_2 <0 shows an ecological decline impact of renewable energy (see Nulambeh & Jaiyeoba, 2024; Popescu *et al*., 2024). Further, the IND*REW on EF can be written as:

$$EF_{it} = \cap_1 + \cap_1 IND_{it} + \cap_2 REW_{it} + \cap_3 (IND_{it} * REW_{it}) + \cap_4 GDP_{it} + \cap_5 POP_{it} + \in_{it} \quad (6)$$

where $\cap_0 - \cap_6$ indicates the parameters; $\in_{it}$ is the residual. IND-LF entire influence in equation (6) can be determined using the first differential, given as:

$$\frac{\partial EF_{it}}{\partial IND_{it}} = \cap_1 + \cap_3 REW_{it} \qquad (7)$$

Like equation (4), equation (7) indicates different scenarios concerning $\cap_1$ and $\cap_3$.

Starting with $\cap_3$>0, this indicates that renewable energy increases the adverse environmental impact of industrialization. So, if $\cap_1$>0, environmental aggravation of industrialization is increased by δ_3>0. But if $\cap_1$<0, then ecological quality of industrialization is reduced by δ_3>0. Moreover, if$\cap_1 + \cap_3 \overline{REW}_{it} > 0$, there exists a total adverse effect of IND and REW on EF. In addition, $\cap_3$<0 indicates that REW reduces the adverse environmental impact of industrialization. Thus, if $\cap_1$>0, environmental aggravation of industrialization is reduced by $\cap_3$<0. But if $\cap_1$<0, then the environmental mitigating industrialization is increased by δ_3<0. In addition, if $\cap_1 + \cap_3 \overline{REW}_{it} < 0$, there exists a total mitigating effect of IND and REW on EF. More importantly, while LF is a proxy for environmental quality, EF is a proxy for environmental harm.

3.2 Estimation Technique

Like previous studies (Aladejare & Nyiputen, 2022; Usman *et al*., 2022), this paper utilizes the second-generation technique such as Panel Correlated Standard Error (PCSE) by Beck and Katz

[7] This study utilizes only EF because previous have established that it is a better indicator for environmental pollution than CO2 emissions ((Akinsola et al., 2022Usman & Balsalobre-Lorente, 2022; Usman et al., 2022; Liao et al., 2023; Popescu et al., 2024).

(1995) and checks for robustness using feasible generalized least square (FGLS) by Parks (1967) but popularized by Kmenta (1986). The motivation behind these techniques is the efficiency they have in producing coefficients either balanced or unbalanced with heteroskedasticity and autocorrelation-consistent (HAC) standard errors (SE). While the PSCE (performs well in large T with small panels) corrects the small standard error biases of the FGLS with its large-*T* asymptotics–based SE (Hoechle, 2007; Bailey & Katz, 2011), Also, unlike PSCE, the FGLS analyzes optimistic variance-covariance coefficients that is unacceptable, (Beck and Katz, 1995). Moreover, it has been established that before using any of these second-generation techniques, shocks must exist among the included variables.[8] For this reason, this study employs Pesaran's (2015) cross-sectional dependence (CD) test. Thereafter, pre-regression tests like Pesaran's (2007) cross-sectional augmented Dickey-Fuller (CADF) are used to check the variable's stationarity levels and Westerlund's (2005) cointegration for checking the variable's co-movement in the long-run.

4. Results and Discussion

This section discusses the results of various estimators in section 3.2. But before that, the summary statistics of the variables are presented.

Table 3: Summary Statistics Results

Variables	LF	EF	IND	REW	GDPPC	POP
Mean	5.389	1.395	10.583	69.623	3157.77	3.171
Minimum	0.515	0.659	0.233	3.7	349.353	2.093
Maximum	24.246	2.768	25.751	91.3	13048.1	6.41
Median	2.2078	2.96	9.569	77.35	2093.94	2.96
Observations	231	231	211	226	238	238
LF	1					
EF	0.089	1				
IND	-0.26**	0.157*	1			
REW	0.0581	-0.044	-0.192**	1		
GDPPC	0.036**	0.464**	0.281**	-0.6**	1	
POP	-0.103	0.115	-0.195**	-0.511**	0.221*	1

*Note: ** and * represent P-value <1% and 5% significance level, respectively. LF, EF, IND, REW, GDPPC, and POP represent load capacity factor, ecological footprint, industrialization, renewable energy, GDP per capita, and population growth, respectively.*

Source: Authors' computation

At the outset, the summary in Table 3 indicates two parts (descriptive and correlation). According to the descriptive statistics, the mean value of LF across the oil-exporting SSA is 5.389, ranging between 0.515 (Nigeria) and 24.246 (Gabon). This is an indication that with a high sustainability level across the oil-exporting countries (above sustainability threshold, i.e, LF>1), Gabon's

[8] Solely assuming the disturbances of variables within this panel are cross-sectionally independent is incongruous.

environmental demand is met by its available resources, while Nigeria's environmental demand exceeds her carrying capacity.[9] Similarly, the average value of EF across the oil-exporting SSA is 1.395, with a range between 0.659 (Equatorial Guinea) and 2.768 (Nigeria). This is an indication that while Equatorial Guinea exerts the lowest demand for natural resources, Nigeria demands more natural resources across the included countries. In addition, the average value of IND within the oil-exporting is 10.583% of GDP, ranging between 0.233% (Chad) and 25.751% (Equatorial Guinea) implies that the value added by the manufacturing sector to GDP across the included countries is higher in Equatorial Guinea and lower in Chad. Also, the REW within these oil-exporting SSA countries is 69.623%, with Equatorial Guinea having the lowest value of 3.7% and Gabon having the highest value of 91.3%, implying that renewable energy is high in Gabon and low in Equatorial Guinea within the period of study, South Africa has the lowest form of clean energy. Further, the average value of GDPPC is US$3157.77, ranging between US$349.353 and US$13048.1 (Equatorial Guinea). This reveals that Equatorial Guinea exhibits both the lowest and highest GDP per person across the included countries. Moreover, the average value of POP is 3.171%, with Equatorial Guinea having the highest value of 6.41% and Nigeria having the lowest value of 2.093%. This outcome indicates that Nigeria has the lowest population growth while Equatorial Guinea has the highest population growth within the period of study. Finally, the correlation statistics in Table 3 reveal that among all the explanatory variables, only IND (negative) and GDPPC (positive) significantly correlate with both LF and EF.

Table 4: Cross-Sectional Dependence Result

Variable	Statistics
LF	25.245**
EF	25.497**
IND	-2.108**
REW	15.029**
GDPPC	25.37**
POP	26.313**

*Note: ** and * represent P values <1% and 5% significance level, respectively. H0 indicates that the residuals are weakly cross-sectional dependent. LF, EF, IND, REW, GDPPC, and POP represent load capacity factor, ecological footprint, industrialization, renewable energy, GDP per capita, and population growth, respectively.*

Source: Authors

Subsequently, based on the CD result as represented in Table 4, there exists a rejection of the H_0 across all the included variables given that the P-values of Pesaran's (2015) CD test are less than 1% significant level. This is an implication that cross-sectional shocks exist among the variables. Thus, the application of first-generation techniques hereafter becomes invalid. Hereafter, second-generation techniques are used for analysis.

[9] This high sustainability level is in line with the Median (2.2078) value in Table 3, indicating high supply of resources than demand of natural resources.

Table 5: Unit root Results

Variables	CADF	
	Level	First difference
LF	-1.868	-3.744**
EF	1.643	-2.616**
IND	-0.842	-4.548**
REW	0.373	-5.174**
GDPPC	2.174	-3.452**
POP	-0.491	-4.796**

*Note: ** and * indicate P value < 1% and 5%, respectively. Null hypothesis (H_0) of unit root. LF, EF, IND, REW, GDPPC, and POP represent load capacity factor, ecological footprint, industrialization, renewable energy, GDP per capita, and population growth, respectively.*
Source: Authors

Next, this paper analyzes the stationarity result of the variables as shown in Table 5. The result reveals that at level, the study does not reject the H_0, which is an indication that all the variables are nonstationary at I(0). However, after differencing them, the study rejects H_0, which is an indication that all the variables became stationary at their first difference.

Table 6: Westerlund's Cointegration Results

Variables	LF/IND,REW,GDPPC,POP	EF/IND,REW,GDPPC,POP
	Statistics	Statistics
Variance ratio	1.951**	-1.637*

Note: $^{**\text{ and }*}$ represent P value < 1% and 5% significance level, respectively. LF, EF, IND, REW, GDPPC, and POP represent load capacity factor, ecological footprint, industrialization, renewable energy, GDP per capita, and population growth, respectively.
Source: Authors

Consequently, Table 6 represents Westerlund's (2005) cointegration results for both environmental indicators. The result reveals that there exists a rejection of the H_0 regardless of the environment indicator. The implication of this is that a long-run relationship exists between the included variables regardless of the environment indicator used.

Table 7: Long-run estimation of environmental impact of industrialization and renewable energy across Oil-exporting Sub-Saharan African countries

Dependent variable:	LF				EF			
	PCSE	PCSE	FGLS	FGLS	PCSE	PCSE	FGLS	FGLS
Variables	[1]	[2]	[3]	[4]	[1]	[2]	[3]	[4]
IND	-0.467**	-0.663**	-0.467**	-0.663**	0.014**	0.093**	0.014**	0.093**
	[-8.22]	[-4.80]	[-8.82]	[-4.20]	[4.30]	[6.73]	[2.17]	[6.76]
REW	0.060**	0.008	0.060**	0.008	0.014**	0.035**	0.014**	0.035**
	[3.7]	[0.24]	[3.32]	[0.19]	[9.41]	[9.44]	[7.94]	[9.17]
*IND*REW*	-	0.003	-	0.001	-	-0.001**	-	-0.001**
	-	[1.48]	-	[12.05]	-	[-6.15]	-	[-6.13]
GDPPC	0.001**	0.001**	0.001**	-3.379**	0.000***	0.000**	0.000**	0.000**
	[16.24]	[16.33]	[12.00]	[-5.50]	[15.36]	[13.15]	[09.96]	[10.85]
POP	-3.328**	-3.379**	-3.328**	-3.379**	0.414***	0.436**	0.414**	0.436**
	[-5.88]	[-6.16]	[-5.41]	[-5.50]	[8.01]	[8.67]	[7.13]	[-6.13]
*Cons_*	11.274**	14.996**	11.274**	14.996**	-1.312**	-2.823**	-1.312**	-2.823**
	[3.74]	[4.22]	[3.67]	[3.60]	[-5.04]	[-8.02]	[-4.53]	[-7.78]
No of countries	7	7	7	7	7	7	7	7
Estimated coefficients	5	6	5	6	5	6	5	6
Autocorrelations	0	0	0	0	0	0	0	0
Homoskedastic	yes	yes	Yes	Yes	yes	yes	yes	yes
No. of Observation	202	202	202	202	202	202	202	202

Note: ** represents P-value < 1% significance level. LF, EF, IND, REW, GDPPC, and POP represents load capacity factor, ecological footprint, industrialization, renewable energy, GDP per capita, and population growth, respectively. Also, PCSE and FGLS represent Panel correlated standard error and Feasible generalized least squares, respectively.

Source: Authors

After recognizing the cointegration existence among the variables, this paper employs the panel correlated standard error (PCSE) and feasible generalized least squares (FGLS) for the long-run environmental impact of industrialization and renewable energy across the oil-exporting SSA countries. As shown in Table 7, the result representing equation (2) is significant for all the independent variables, with values showing consistency between PCSE and FGLS. For instance, the coefficient for IND is -0.467 using both PCSE [1] and FGLS [3]. This implies that a unit rise in industrialization will reduce the load capacity factor by 0.467 units in the long run. In addition, the coefficient for REW is 0.06 using both PCSE [1] and FGLS [3] implies that a unit rise in renewable energy will increase the load capacity factor by 0.06 units in the long run. Surprisingly, the coefficient of GDPPC is 0.001 (same for PCSE [1] and FGLS [3]), indicating a 0.001 increase in load capacity factor by one unit increase in economic growth. Further, the coefficient of POP is -3.328 (same for PCSE [1] and FGLS [3]), indicating a 3.328 decrease in load capacity factor by one unit increase in population.

To check if renewable energy mitigates or intensifies the environmental harm of industrialization, this study utilizes the interaction term as seen in equations (3-4). The results are shown in Table 7, columns [2] and [4]. They show that the value of IND*REW is 0.003 (for PCSE [2]) and 0.001 (for FGLS [4]) but not significant, implying the interaction between industrialization and renewable energy is not adequate to improve load capacity factor.

The implications of these results are given below. First, the result indicates that industrial activities adequately reduce environmental quality within the oil-exporting SSA countries. This is not surprising because these countries rely heavily on oil export as revenue (IMF, 2024), which leads to oil spills and gas flaring, and in turn damages the environment (deforestation, land, and water). For instance, the unsustainable industries (through oil spill and industrial wastes) discharged not just water waste into rivers but also increase its disposal practices (by contaminating the soil with toxic substances) and flaring operation (by burning excess gas like sulfur dioxide and nitrogen oxides), which increase biodiversity loss and posed health risks to people living within the oil-exporting countries (Rodríguez *et al*., 2014; Gadom *et al*., 2018; Kikasu, 2021; Mesmin, *et al*., 2022; Najoui *et al*., 2022; Adeyanju *et al*., 2025). Also, adverse environmental impact of industrialization may be due to lack of strict environmental regulation by many of these oil-exporting countries, which results in the adoption of obsolete technologies by several industries, thereby intensifying environmental damage (Azam *et al*., 2022; Idowu *et al*., 2023). Besides, the finding suggests the urgent need for oil-exporting SSA countries to revise their industrial policies. Governments should incentivize the adoption of clean production technologies, discourage outdated machinery, and enforce environmental compliance standards in industrial operations. In line with previous studies, the result resonates with the findings of Samour et al. (2023) for BRICS-T countries, Jin and Huang (2023) for South Africa, Byaro *et al.* (2024) for SSA, and Aquilas *et al.* (2024) for 46 African countries.

Second, the environmental impact of renewable energy outcomes indicates that the use of clean energy by the oil-exporting SSA countries can adequately increase environmental quality. This is not surprising as literature within the region where these oil-exporting countries are situated, posited that clean energy sources (such as wind, solar, and geothermal) have high potential in mitigating the overall adverse environmental pollution (Mentel *et al*., 2022b; Aquilas *et al*., 2024;

Nulambeh & Jaiyeoba, 2024). Besides, similar findings have been established by studies such as Akam et al. (2021) for heavily indebted poor countries, Chen *et al*. (2022) for 97 countries, Magazzino *et al*. (2022) for SSA countries, Awosusi *et al*. (2024) for Japan, Byaro *et al*. (2024) for SSA countries, Hussain *et al*. (2024) for G20 countries, and Nwani *et al*. (2025) for SSA countries. Third, the moderation outcome of renewable energy impact on industrialization-environment implies that renewable energy fails to significantly mitigate the adverse impact of industrialization on environmental quality. In other words, industrial green development from the use of renewable energy is redundant to increase environmental sustainability in the oil-exporting SSA countries. The result is unsurprising, as the study has earlier highlighted the declining use of renewable energy in these countries. Since renewable energy marginally improves environmental quality but fails to offset industrial pollution, these countries should increase investment in large-scale, integrated renewable systems (solar, wind, hydro) and implement grid-level transitions rather than isolated, small-scale projects. However, this contradicts the findings of Mentel et al. (2022a,b) and Aquilas *et al*. (2024), who moderated the renewable energy impact on industrialization-environment nexus.

Fourth, the population–environment relationship suggests that population growth diminishes environmental quality, primarily due to increased demand for natural resources by the population that exceeds the ecological carrying capacity in oil-exporting countries. The negative effect of population growth on environmental quality calls for population management strategies such as urban planning reforms, waste management infrastructure, and public campaigns on sustainable resource use in densely populated oil-producing regions. This result resonates with prior studies such as Haider *et al*. (2024) for Pakistan and Aquilas *et al*. (2024) for 46 African countries.

Fifth, the positive growth-environment link implies that economic growth guided by green policies may support environmental sustainability. Thus, SSA oil-exporters should diversify away from oil into less polluting, green growth sectors such as ecotourism, agriculture technology, and services, which is in line with Haider *et al.* (2024) for Pakistan and Wang and Xu (2025) for E7 nations. Further, to better understand the driver of environmental pressure, this study compares the LF results with the EF by presenting the results of the impact of IND and REW on EF. This is to denote the importance of using a better environmental indicator for estimation. Moreover, the study shows consistency in terms of significance and the use of PCSE and FGLS in analyzing the industrialization-energy-environment nexus. For instance, an increase in industrialization (IND) intensifies environmental harm (see the PCSE [1] and FGLS [3] results for IND under EF). However, for the environmental impact of renewable energy, the result is inconsistent with LF results, as the result shows that renewable energy increases ecological footprint, thereby adversely increasing environmental degradation (see the PCSE [1] and FGLS [3] results for REW under EF). The inconsistency of the EF results in relation to the LF also appears while using IND*REW (see the PCSE [2] and FGLS [4] results for IND*REW under EF). For instance, unlike the IND*REW impact on LF, the IND*REW impact on EF indicates that renewable energy adequately mitigates the adverse impact of industrialization on environmental quality (due to the significant result). In all, the reason for the inconsistent results between the demand side environmental indicator (EF) and the comprehensive (integration of both demand and supply sides) environmental indicator (LF), especially in terms of renewable energy, could be because EF fails to balance the environment’s capacity to support human-induced waste. So, policies should be tailored towards overall environmental sustainability instead of focusing on the demand side of the environment.

5. Conclusion

This study investigates the environmental issue resulting from growth-driven industrial policies, primarily highlighting the role renewable energy plays across seven (7) oil-exporting SSA countries (a novel research) between 1990 and 2023. With the use of second-generation techniques such as PCSE and FGLS, the findings of this study indicate that industrialization exacerbates environmental harm. Also, while renewable energy plays an important role in mitigating environmental harm in these countries, its consumption does not have the full potential to reduce the adverse environmental effect of industrialization. Unlike other studies, this study compares the results of both LF (comprehensive measure) and EF, with a finding that the dependence on EF result will give a misleading decision, as renewable energy does not just increase environmental harm but also reduces the adverse effect of industrialization.

Given these findings, the governments within the oil-exporting countries should tailor their policies towards environmental regulation and encourage the use of eco-friendly technologies in their manufacturing sectors. This can be done through tax incentive policies, green industrial zones, and benchmarking ecological performance across these countries. Regarding the clean energy impact, these countries should make large-scale renewable energy projects (e.g., solar farms, wind parks) their priorities, thereby including them in their national energy strategies. This may require long-term plans, but the government can incentivize, through subsidizing those clean energy startups. In addition, renewable energy quotas for industries (e.g., requiring 30–50% of industrial energy from renewables) should be introduced to increase the use of clean energy within the industries. Further, strengthen urban planning and resource management policies that reflect rapid population growth, including investment in waste recycling systems, public transportation, and green infrastructure (e.g., parks, green belts) to maintain ecological balance. Lastly, encourage economic diversification into environmentally sustainable sectors (e.g., agriculture tech, services, ecotourism). This will align environmental goals with industrial policies.

Future studies can increase their investigation by including other oil-exporting countries within North Africa or extend the investigation by including other region's oil-exporting countries. Also, upcoming studies can investigate the environmental impact of industrialization by comparing the STIRPAT framework with the LCC framework.

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