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DETERMINANTS OF ENVIRONMENTAL QUALITY IN AFRICA

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Abstract

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Africa has diverse ecosystems and abundant natural resources crucial for its growth and development. Unsustainable use of natural resources can increase the ecological footprint and lead to environmental deterioration on the continent. Several factors influence ecological footprint – a proxy for environmental degradation. However, literature on the determinants of ecological footprint in Africa is mixed and without any evidence on the effect on different quantiles/groups. Therefore, this paper explored the impact of agricultural production, renewable energy, rule of law, natural resource dependence and foreign investments on ecological footprint in Africa controlling for economic growth. We used data from 44 countries in Africa spanning a period of 21 years (2000–2020) and applied fixed effects and method of moment quantile regression models for analysis. Our findings show that GDP per capita, livestock production and foreign direct investments had significant positive association with ecological footprint for most of the quantiles. In contrast, renewable energy consumption, crop production index, rule of law, urbanisation and natural resource rents all reduced ecological footprint in Africa for most of the quantiles. Continuous law enforcement in Africa combined with investment in renewable energy, sustainable crop production practices and sustainable management of natural resources would reduce the continent's ecological footprint and environmental degradation.

Key words: agriculture, rule of law, ecological footprint, renewable energy, natural resources dependence, foreign direct investments.

Introduction

Environmental sustainability has become a topical issue in recent years on the global development agenda. Africa is blessed with a wide diversity of ecosystems and biodiversity and an ample source of natural resources with the potential to sustain growth and development on the continent. As demands on capital stock rise, managing ecological footprints is essential to maintain the sustainability and quality of the environment. Achieving and maintaining a high level of ecological and environmental quality while using the diverse resources available to the region has been the interest of researchers and policymakers in recent times (Wu et al., 2023; Wu, Zhang, 2021). Africa has abundant natural resources, including non-renewable resources like minerals, coal, gas and oil and renewable resources like water, forestry and fisheries (Oteng-Abayie et al., 2022). It is also richly endowed with productive land. Natural resources are essential to most poor rural people's livelihoods and dominate many national economies. Large portions of Africa's population depend on these natural resources for their income and subsistence, and they also serve as a significant source of wealth for the continent's government (Zallé, 2019). The use of natural resources (including for agriculture) affects environmental quality (Adedoyin et al., 2020; Erdogan et al., 2021).

In several African countries, agriculture is an essential source of income and employment for rural dwellers and provides export revenue (Oluwatayo, Ojo, 2016). Agricultural production is crucial for food security and economic development (Pawlak, Kołodziejczak, 2020). However, the need to increase agricultural production for increased food security appears to undermine the urgency of reducing agriculture's negative environmental impacts. Agricultural production is linked to environmental and ecological quality (Dalin, Outhwaite, 2019). Higher yields have been achieved through fertilisers, herbicides, farming machinery and other farming practices which may be unsustainable. These agricultural practices believed to deplete the environmental quality include deforestation, soil degradation, air pollution and the use of chemical pesticides and fertilisers as they destroy the soil, harm animals and contaminate water systems (Chowdhury et al., 2022; Adeleye et al., 2021). Also, rising temperatures and changing precipitation patterns brought on by agricultural greenhouse gas (GHG) emissions can cause additional stress to various plant and animal species. Agricultural production also contributes to climate change through the use of fossil fuels.

In addition, urbanisation is a severe threat to global sustainable development in Africa because of population pressure, natural resource exploitation and the use of fossil fuels, all of which result in the emission of GHGs (Ofoezie et al., 2022). Rapid economic growth and urbanisation, fuelled by industrialisation and population growth, frequently result in increased pollution, habitat destruction and strain on natural resources (Radoine et al., 2022; Akinsola et al., 2022). Exploiting natural resources, such as oil, gas and minerals, has resulted in environmental degradation, including land degradation, water pollution and biodiversity loss (Ewim et al., 2023; Adeola et al., 2022). Urbanisation increases access to services and presents chances for economic growth (Bai et al., 2017). However, it strains the environment, and natural resources are depleted because of increased demand on the earth's biocapacity. With the increasing world's population, enormous strain will be placed on the planet's ecosystems and natural resources, as well as the demand for food, energy and other natural resources.

The energy sector is vital for urbanisation and economic growth. However, the reliance on fossil fuels contributes to GHG emissions and climate change. The use of renewable energy sources has drawn much attention from around the globe to slow down climate change and lessen environmental degradation. Renewable energy consumption offers a great chance to advance sustainable development in Africa. Africa can simultaneously increase its energy independence and enhance ecological and environmental quality by lowering its dependency on fossil fuels and GHG emissions.

On the other hand, foreign direct investment (FDI) is an invaluable vehicle for economies to drive sustainable economic growth by increasing productivity, accumulations of capital, the diffusion of technology and resolving many macroeconomic problems (Charfeddine, Mrabet, 2017). It can also lead to environmental degradation if it needs to be adequately regulated (Hongbo, Hanho, 2022). Several studies can attest to the negative impact of FDI on environmental sustainability (Chowdhury et al., 2021; Ashraf et al., 2020; Hakimi, Hamdi, 2016). This supports the pollution-haven hypothesis. This calls for strong enforcement of regulations and laws to discourage transferring of pollution to Africa. The effectiveness of environmental regulations and the enforcement of environmental laws and policies are critical for ensuring sustainable development and protecting ecological quality (Tietenberg, Lewis, 2019).

The benefits of Africa's abundant natural resources may be eroded because of weak laws and institutions that regulate the extraction of these resources. Unsustainable extraction and management of natural resources have adverse environmental effects without appropriate regulations and measures (Oteng-Abayie et al., 2022). This may result in biodiversity loss, pollution and climate change. An analysis of the correlation between ecological and environmental quality and natural resource rents in Africa can offer valuable insights for the sustainable use and preservation of these resources. Achieving sustainable development and safeguarding the environment require robust institutions, sound governance systems and efficient enforcement of environmental laws. Gaining insight into how the rule of law affects ecological and environmental quality will be beneficial for developing policy interventions.

In addition, there has been a growing recognition of the importance of environmental laws and regulations as the rule of law for environmental sustainability in Africa. Several factors have contributed to this recognition, including the increasing frequency and severity of environmental crises and the realisation that environmental degradation is often exacerbated by weak governance and institutional legal framework. As a result, the rule of law has been increasingly seen as a necessary foundation for effective environmental management in Africa. The relationship between the rule of law and ecological sustainability in Africa is complex and multifaceted. A strong rule of law is essential to promoting environmental protection and sustainable development. However, in Africa, the rule of law is often weak, and the enforcement of environmental laws needs to be improved. Despite this, some African countries have successfully used the rule of law to promote sustainable development and protect the environment.

Previous studies have examined the individual impacts of various agricultural productions, economic growth, urbanisation, renewable energy consumption, FDI, natural resource rents and the rule of law on ecological quality in Africa and their interference with each other. For instance, previous authors have summarised their findings on the effect of the rule of law on agricultural production, economic growth and energy consumption. Lin et al. (2022) found that environmentally solid institutions are necessary for sustainable and inclusive economic growth. The study of Gelgo et al. (2023) looks at how institutional quality affects agricultural value added in East Africa and concludes that higher per capita GDP, lower rates of the rural population, more effective governments and higher spending on education all have a substantial impact on this growth. More so, Dźwigoł et al. (2023) found that an economy with a high rule of law is positively associated with renewable energy consumption. However, none of the studies assessed the effects of the rule of law, agricultural production, economic growth, urbanisation, renewable energy consumption, FDI, and natural resource rents on African ecological footprint.

The issue of environmental quality has generated attention among scientists in developing regions such as Africa. Several studies have been carried out to understand the factors affecting environmental quality in different parts of the world, but there is no consensus yet in literature in terms of the sign of the effects. For example, a strand of literature on the effect of economic growth on ecological footprint – a robust indicator for measuring environmental quality – find that GDP (whether in an aggregate or relative form) is significantly and positively associated with ecological footprint in different parts of the World (see Ponce et al., 2023; Destek et al., 2023; Ragmoun, 2023; Chekouri et al., 2023; Javeed et al., 2023; Nan et al., 2023; Xu et al., 2022; Wan et al., 2022; Salman et al., 2022; Abid et al., 2021; Ahmed et al., 2021; Chen et al., 2021; Ahmed et al., 2022; Danish et al., 2020; Dogan et al., 2019). However, Abid et al. (2021) and Chen and Chang (2016) find an insignificant relationship between economic growth (GDP) and ecological footprint in many countries in the world.

Also, the evidence on the effects of urbanisation, renewable energy consumption, natural resource rents and FDI on ecological footprint are similar to that of economic growth. For example, Ullah et al. (2023b), Chekouri et al. (2023), Xu et al. (2022), Zuo et al. (2022), Oteng-Abayie et al. (2022), Abid et al. (2021), Alvarado et al. (2021) and Erdogan et al. (2021) find that natural resource rents have a significant and positive link with ecological footprint, while Ragmoun (2023), Kibria (2023), Alvarado et al. (2021) and Danish et al. (2020) observed that natural resource rents is negatively and significantly associated with ecological footprint. However, Abid et al. (2021) and Alvarado et al. (2021) find no relationship between natural resource rents and ecological footprint. Also, the evidence on urbanisation-ecological footprint nexus produced by scientists is mixed. For example, Ponce et al. (2023), Ragmoun (2023), Chekouri et al. (2023), Salman et al. (2022), Oteng-Abayie et al. (2022), Abid et al. (2021), Erdogan et al. (2021) and Dogan et al. (2019) find that urbanisation has a positive link with ecological footprint, while Ullah et al. (2023b), Ponce et al. (2023), Khan et al. (2023), Ansari et al. (2022), Okelele et al. (2022), Abid et al. (2021), Danish et al. (2020) and Dogan et al. (2019) observed that urbanisation is negatively and significantly associated with ecological footprint. Other studies, such as Wang et al. (2022) and Abid et al. (2021), documented no link between urbanisation and ecological footprint. Divergent outcomes have been documented in literature on the impact of renewable energy consumption on ecological footprints in different parts of the world. For instance, Javeed et al. (2023), Nan et al. (2023), Ragmoun (2023), Ahmed et al. (2022), Okelele et al. (2022), Ansari et al. (2022), Wan et al. (2022), Xu et al. (2022), Danish et al. (2020) and Dogan et al. (2019) find a significant negative link between renewable energy consumption and ecological footprint. Conversely, other studies including Albayrak et al. (2022) and Dogan et al. (2019) find a significant positive link between renewable energy consumption and ecological footprint in Turkiye and Indonesia. In addition, few of related works such as Salman et al. (2022) established no significant relationship between renewable energy consumption and ecological footprint. Another factor influencing ecological footprint is FDI, but contrasting literature studies have presented positive influence, no relationship and negative linkage of FDI with ecological footprint. For instance, Khan et al. (2023), Salman et al. (2022), Zuo et al. (2022), Okelele et al. (2022), Abid et al. (2021), Chowdhury et al. (2021) and Udemba (2020) find a positive and significant link between FDI and ecological footprint, while Kumar and Datta (2023), Destek et al. (2023), Oteng-Abayie et al. (2022), and Dogan et al. (2019) document a negative and significant link between FDI and ecological footprint. However, Oteng-Abayie et al. (2022), Abid et al. (2021), and Dogan et al. (2019) find no relationship between FDI and ecological footprint.

The literature is replete on the determinants of ecological footprints. Despite the increasing number of studies on the drivers of environmental degradation, the unique role of agricultural production and rule of law in ecological footprint are grossly understudied. Few studies (see Ullah et al., 2023a; Udemba, 2020) have documented the impact of agricultural production on ecological footprint. Albeit limited, the evidence produced by the few existing studies are mixed and largely neglected Africa, where majority of the populace depend on agriculture for their livelihood and where law enforcement is weak. The main economic activity in Africa is agriculture, and agriculture contributes to environmental degradation on the continent. Also, enforcement of legislations and laws are weak on the continent and could hamper any progress made in protecting the environment. This means that any study considering the determinants of ecological footprint on the continent without attention to agriculture and rule of law is incomplete. Against this milieu, our paper aims to close the gaps identified using panel data obtained from credible databases from 2000 to 2020 of 44 African countries.

First, our study made valuable contributions to the existing scholarly debate on determinants of environmental quality and the policymaking process on many fronts. Our research addressed a lacuna in the existing literature by offering new insights from rigorous econometric analysis on factors affecting ecological footprints. Second, we utilised robust datasets spanning over 20 years (2000–2020) from credible databases—the World Development Indicators and Global Footprint Network. Third, the scope of our study is broad and covers 44 African countries, which is the first to cover this number of African countries. Fourth, an essential contribution of this study is that it highlights the importance of renewable energy, the collection of natural resource rents and the rule of law in promoting environmental quality by reducing ecological footprints. Our findings would be helpful to policymakers in Africa and other regions with similar contexts that are trying to invest in promoting ecological quality and achieving carbon neutrality. This study has laid a solid foundation for contemporary and future researchers who want to explore environmental degradation determinants on other continents. Our study encourages exploring the agriculture–economy–energy–urbanisation–environment nexus on other continents to establish a balance between these factors and environmental quality. The findings would also be helpful for environmental quality policy formulation, implementation of the Nationally Determined Contributions of African countries and the resolutions of the Africa Climate Summit to prepare Africa for a 1.5 °C world.

Methodology

Data source

This paper focused on the African continent. We used data from 44 countries in Africa (see Table 1 for details).

Table 2 shows the sources of the data used in this paper. Ecological footprint data were obtained from the Global Footprint Network. In contrast, GDP per capita, renewable energy consumption, the rule of law, urban population, total natural resource rents, crop production index, livestock production index and FDI, net inflows data were obtained from the World Development Indicators database of the World Bank.

Analytical technique

We used the fixed effects (FEs) and method of moment quantile regression (MM-QR) approaches to model the impacts of agricultural production, economic growth, urbanisation, renewable energy consumption, FDI, rule of law and natural resource rents on ecological/environmental quality in Africa. The implicit model of our FEs and MM-QR model is stated as follows:

$$Y=f(GDP,RENEW,LAW,URB,NATR,CROP,LIV,FDI), \quad (1)$$

where EFP is ecological footprint (global hectares per capita), GDP is GDP per capita (constant 2015 US$), RENEW is renewable energy consumption (% of total final energy consumption),

Table 1. List of countries studied.

Algeria	Comoro Island	Malawi	South Africa
Angola	Democratic Republic of Congo	Mali	Swaziland/Eswatini
Benin	Egypt	Mauritania	Tanzania
Botswana	Ethiopia	Mauritius	Togo
Burkina Faso	Gabon	Morocco	Tunisia
Burundi	Gambia	Mozambique	Uganda
Cape Verde	Ghana	Namibia	Zambia
Cameroon	Guinea	Niger	Zimbabwe
Central African Republic	Guinea Bissau	Nigeria	
Chad	Kenya	Rwanda	
Côte d'Ivoire Congo Republic	Lesotho Madagascar	Senegal Sierra Leone	

Table 2. Description of the variables.

Variables	Data Source
Ecological footprint (global hectares per capita)	Global Footprint Network (Global Footprint Network, 2023)
GDP per capita (constant 2015 US$)	World Development Indicators Database (World Bank Group, 2023a)
Renewable energy consumption (% of total final energy consumption)	World Development Indicators Database (World Bank Group, 2023a)
Rule of law (number of sources)	World Development Indicators Database (World Bank Group, 2023a)
Urban population (% of total population)	World Development Indicators Database (World Bank Group, 2023a)
Total natural resource rents (% of GDP)	World Development Indicators Database (World Bank Group, 2023a)
Crop production index (2014–2016 = 100)	World Development Indicators Database (World Bank Group, 2023a)
Livestock production index (2014–2016 = 100)	World Development Indicators Database (World Bank Group, 2023a)
FDI, net inflows (% of GDP)	World Development Indicators Database (World Bank Group, 2023a)

LAW is rule of law (number of sources), URB is urban population (% of total population), NATR is total natural resource rents (% of GDP), CROP is crop production index (2014–2016 = 100), LIV is livestock production index (2014–2016 = 100) and FDI is foreign direct investment, net inflows (% of GDP).

To control for possible heteroskedasticity in our dataset, we converted the real values of the variables to their natural logarithmic values. The FEs and MM-QR models with the logarithms are presented thus:

$$lnY_{it}=\beta_0+\beta_1+lnGDP_{it}+\beta_2+lnRENEW_{it}+\beta_3+lnLAW_{it}+\beta_4+lnURB_{it}+\beta_5+lnNATR_{it}+\beta_6+lnCROPt+\beta_7+lnLIV_{it}+\beta_8\,lnFDI_{it}+\varepsilon_{it,} \qquad (2)$$

where i is 1, 2, 3, …, 44 countries; t is 2000, 2001, 2002, …, 2020 year; ln denotes natural logarithm and ε is the error term. Furthermore, β_1, β_2 and β_3 define the estimated percentage change in ecological footprint caused by a one percent change in GDP, rule of law, renewable energy consumption, urban population, total natural resources rents, crop production index, livestock production index and FDI, while all other factors are constant.

This study combines the Driscoll–Kraay (D-K) (1998) FEs and MM-QR approaches to provide baseline estimates that are resilient to cross-sectional and temporal dependency and to evaluate additional aspects of the conditional distribution of ecological footprint. The D-K regression method simulates the conditional mean of the dependent variable only while the MM-QR evaluates additional aspects of the conditional distribution of the dependent variable (Machado, Santos Silva, 2019). Using the MM-QR estimator, the impacts of agricultural production, economic growth, urbanisation, renewable energy consumption, FDI, rule of law and natural resource rents on ecological/environmental quality in Africa on the lower, median and higher distributions of Africa's ecological footprint are investigated. The MM-QR estimator produces accurate and valid results in the absence of strong distributional assumptions (Canay, 2011). The MM-QR generates regression quantiles based on the conditional location-scale shift model. This enables individual effects to have an effect on the distribution as a whole (Emenekwe, Emodi, 2022). Consequently, MM-QR is more trustworthy and has emerged as the primary quantile regression method in contemporary research (Emenekwe, Emodi, 2022). The following is a broad description of the location-scale variant model's conditional quantile, $Q_Y\ (\tau|X_{it}\ )$, estimation:

$$Q_Y\ (\tau|X_{it}\ )=(\alpha_i+\delta_i\ qi)+X'_{it}\beta+Z'_{it}\gamma q(\tau) \qquad (3)$$

where X_{it} is a vector of explanatory variables (i.e., GDP, rule of law, renewable energy consumption, urban population, total natural resources rents, crop production index, livestock production index and FDI). $Q_Y\ (\tau|X_{it}\ )$ is the quantile distribution of the dependent variable (ecological footprint) conditional on the location of the exogenous variable $X_{it}.\alpha_{it}=\alpha_i+\delta_i q(\tau)$ is the scalar

Table 3. Descriptive statistics of the variables.

	N	Minimum	Maximum	Mean	Std. deviation	Skewness	Kurtosis
Ecological footprint (global hectares per capita)	924	0.57	4.02	1.48	0.68	1.363	1.310
GDP per capita (constant 2015 US$)	924	255.10	10956.90	1859.79	1873.60	1.856	3.390
Renewable energy consumption (% of total final energy consumption)	924	0.06	98.34	63.30	28.39	-0.834	-0.637
Rule of law (number of sources)	924	3.00	18.00	11.82	3.52	-0.398	-0.581
Urban population (% of total population)	924	8.25	90.09	40.18	16.90	0.403	-0.293
Total natural resource rents (% of GDP)	924	0.00	59.68	10.98	10.18	1.778	3.406
Crop production index (2014–2016 = 100)	924	26.27	200.65	88.93	23.59	-0.001	0.545
Livestock production index (2014–2016 = 100)	924	25.58	162.36	89.10	19.35	-0.588	0.718
FDI, net inflows (% of GDP)	924	-18.92	46.28	3.42	5.09	3.404	19.316

coefficient of the quantile $-\tau$ FE for individual i or the distributional effect at $\tau.q(\tau)$ is the τ-th quantile resulting from the following optimisation function:

$$\min_{q} \sum_{i} \sum_{t} \rho_{\tau} \left(\widehat{R}_{it} - \left(\widehat{R}_{it} + Z'_{it}\widehat{\gamma} \right) q \right), \tag{4}$$

where the following expression specifies the check-function: $\rho_{\tau}(A)=(\tau-1)AI\{A \leq 0\}+\tau AI\{A > 0\}$. From the MM-QR model in Equation (4), we specify the following quantile-based approach for this study:

$$Q_{lnYi,t}[\tau|\alpha_i, v_{it}, X_{i,t}]=\alpha_{i\tau}+\beta_1 lnGDP_{it}+\beta_2 lnRENEW_{it}+\beta_3 lnLAW_{it}+\beta_4 lnURB_{it}+\beta_5\, lnNATR_{it}+\beta_6 lnCROP_{it}+\beta_7\, lnLIVi_t+\beta_8\, lnFDI_{it}+v_{i,t}\,. \tag{5}$$

Results

The descriptive statistics result in Table 3 shows that the average ecological footprint is 1.48 gha per capita, which is lower than the global average of 2.58 gha per person reported by Global Footprint Network (2023), and the maximum value reaches 4.02 gha per capita. Likewise, the average urbanisation level is 40.18 percent against the global average of 57 percent reported by the World Bank Group (2023b), and the maximum value reaches 90.09 percent. The average GDP per capita 1859.79 constant 2015 US $ indicates the low development level of African countries because this value is far lower than the global average of 11,287.1 constant 2015 US $ reported by the World Bank Group (2023c). The average renewable energy consumption is 63.30%, which is higher than the global current rate of 19.77% reported by IEA, IRENA, UNSD, World Bank and WHO (2023), and the maximum reaches 98.34%. The average total natural resource rent is 10.98%, which is higher than the global current rate of 3% reported by World Bank Group (2023d), and the maximum value reaches 59.68%. This shows greater dependence of African countries on natural resources than most parts of the world. The average rule of law index is approximately 12 sources. The average FDI is 3.42% of GDP, while the maximum is 46.28%. The average FDI, net inflows (% of GDP) of the African countries studied are less than the global average 1.7% of GDP reported by the World Bank Group (2023e). The average crop production index and livestock production index are 88.93 and 89.10, respectively.

Table 4. Multicollinearity test result using the VIF.

Variable	Tolerance	VIF
lnGDP	0.368	2.714
lnRENEW	0.639	1.564
lnLAW	0.810	1.235
lnURB	0.472	2.119
lnNATR	0.775	1.290
lnCROP	0.637	1.570
lnLIV	0.596	1.677
lnFDI	0.904	1.107

Table 5. Cross-section dependence test.

Variable	CD test	p-value
lnGDP	71.50	0.000
lnRENEW	55.47	0.000
lnLAW	132.04	0.000
lnURB	99.95	0.000
lnNATR	34.46	0.000
lnCROP	75.88	0.000
lnLIV	92.40	0.000
lnFDI	6.66	0.000
lnEFP	11.82	0.000

Multicollinearity

We used the variance inflation factor (VIF) to test for the existence of multicollinearity among our independent variables. A VIF of less than or equal to 5 has been used by previous studies to indicate the absence of multicollinearity (Chidiebere-Mark et al., 2022; Emenekwe et al., 2022; Onyeneke et al., 2023a,b,c, 2024a). The result of the VIFs presented in Table 4 indicates the absence of multicollinearity among the independent variables.

Cross-section dependence test

Table 3 shows that there is cross-section dependence in our dataset. The null hypothesis of cross-section independence was re-

Table 6. Unit-root test.

H_0 = All panels contain unit roots. ***H_0*** = series have a unit root. Pesaran's CADF test.				
	At level I(0)	**At first difference I(1)**		
Variable	**t-statistic**	**t-statistic**	**Decision: H_0**	**Result**
lnEFP	−2.152***	−3.435***	Reject	I(0) at 1%
lnGDP	−1.748	−2.724***	Reject	I(1) at 1%
lnRENEW	−2.123***	−2.914***	Reject	I(0) at 1%
lnLAW	−2.243***	−3.583***	Reject	I(0) at 1%
lnURB	−2.114***	−3.243***	Reject	I(0) at 1%
lnNATR	−2.388***	−3.100***	Reject	I(0) at 1%
lnCROP	−2.166***	−3.563***	Reject	I(0) at 1%
lnLIV	−2.442***	−3.737***	Reject	I(0) at 1%
lnFDI	−2.368***	−3.689***	Reject	I(0) at 1%
Im–Pesaran–Shin unit-root test				
	At level I(0)	**At first difference I(1)**		
Variable	***t*-statistic**	***t*-statistic**	**Decision: H_0**	**Result**
lnEFP	−0.882	−12.495***	Reject	I(1) at 1%
lnGDP	6.532	−4.154***	Reject	I(1) at 1%
lnRENEW	2.576	−8.328***	Reject	I(1) at 1%
lnLAW	6.335	−8.088***	Reject	I(1) at 1%
lnURB	0.275	−17.454***	Reject	I(1) at 1%
lnNATR	−2.153**	−11.329***	Reject	I(0) at 5%
lnCROP	−0.562	−13.362***	Reject	I(1) at 1%
lnLIV	−1.033	−11.331***	Reject	I(1) at 1%
lnFDI	−0.946	−13.661***	Reject	I(1) at 1%

Note: ** and *** indicate significance at 5% and 1% levels respectively.

Table 7. Cointegration test.

H0: No cointegration. Ha: All panels are cointegrated.		
Kao test for cointegration.		
Test	**Statistic**	**p-value**
Modified Dickey–Fuller t	−8.9797***	0.000
Dickey–Fuller t	−8.5568***	0.000
Augmented Dickey–Fuller t	−3.7413***	0.000
Unadjusted modified Dickey–Fuller t	−12.0652***	0.000
Unadjusted Dickey–Fuller t	−9.4617***	0.000

Note: *** indicates significance at 1% level.

jected by applying the Pesaran (2015) cross-section dependence tests for the panel data (Table 5). The cross-section dependence tests suggest that the countries chosen for this research have similar traits and shocks (Pesaran, 2015).

Unit-root test

To avoid a spurious and misleading regression, a unit-root test is important (see Onyeneke et al., 2024b, 2023a,b,c,d; Anyaegbu et al., 2023). This ensures that the panels and series are stationary and produces a regression equation based on unit-root approaches (Onyeneke et al., 2024c; Emenekwe et al., 2022a,b; Chidiebere-Mark et al., 2022; Raihan et al., 2023a,b). Adopting the stationary tests assists in identifying the integration technique before proceeding to cointegration. Many studies have adopted double to multiple unit-root tests to ascertain the series and panel sequence of integration (Emenekwe et al., 2022a,b; Chidiebere-Mark et al., 2022; Onyeneke et al., 2024c; Anyaegbu et al., 2023; Onyeneke et al., 2023b,c,d). We applied the Pesaran's Cross-section Augmented Dickey–Fuller (CADF) and Im–Pesaran–Shin unit-root tests to check the unit-root properties and order of integration of the model variables.

Table 6 presents the results of the unit-root tests. The results indicate that under Pesaran's CADF test, all the variables except GDP per capita were stationary at both level and first difference. GDP per capita was only at stationary at first difference. Under Im–Pesaran–Shin unit-root test, all the variables were stationary at first difference, while natural resource rents were the only variable stationary at level. This indicates that the dataset should be further tested for cointegration.

Cointegration test

We utilised the Kao testing method developed by Kao (1999) to identify cointegration among the variables. This method has been used by previous studies (see Chidiebere-Mark et al., 2022; Onyeneke et al., 2023a,b, 2024a) because of its advantage of checking for cointegration in panel data and spurious regression and residual-based tests (Kao, 1999). This method has advantage over several other panel cointegration techniques because of its ability to test the cointegration properties of more than seven independent variables.

Based on the stationarity tests, our study found that the panels under investigation are (I)1 panel. Therefore, we used the Kao test to evaluate the cointegration properties of the eight independent variables and dependent variable considered in this study. The result is presented in Table 7. The result shows that all the test statistics under the Kao approach are statistically significant at a 1% level. We, therefore, conclude that the variables are cointegrated.

Empirical results from panel regression techniques

Table 8 reports the FE D-K and MM-QR regressions results of the impacts of agricultural production, economic growth, urbanisation, renewable energy consumption, FDI, rule of law and natural resources rents on ecological footprints. The estimates of the FE D-K are found in column 1, whereas the estimates of the MM-QR are found in columns 2–8. The estimates of the FE D-K are the mean effect, whereas the estimates of the MM-QR are estimates for distributional heterogeneity. The estimated quantiles are 10, 25, 50, 75 and, 90th. The coefficients are presented as estimates with z-values in parentheses.

The result column (1) shows the conditional mean estimates obtained using the FE D-K estimation technique. The results show that GDP per capita, livestock production and FDIs have significant direct relationship with ecological footprint, while renewable energy consumption, rule of law, urbanisation and natural resources rents have significant inverse relationship with ecological footprint in Africa. The coefficients of GDP per capita, livestock production and FDIs are 0.31, 0.12 and 0.03, respectively. These imply that a 1% increase in GDP per capita, livestock production index and FDIs would increase the conditional mean of ecological footprint in Africa by 0.31, 0.12 and 0.03%, respectively. Conversely, the coefficients of renewable energy consumption, rule of law, urbanisation and natural resources rents are -0.06, -0.16, -0.12 and -0.02 respectively. These imply that that a 1% increase in renewable energy consumption, number of sources of rule of law, urbanisation and natural resource rents would decrease the conditional mean of ecological footprint in Africa by 0.06, 0.16, 0.12 and 0.02%, respectively.

The FE D-K estimation results are similar to the location coefficients from the MM-QR estimation (result column (2)). The location coefficients represent the median value of the dependent variable, aquaculture production, for each independent variable. Thus, the location results suggest that the median value of ecological footprint is directly related to GDP per capita, livestock production index and FDIs, while the median value of ecological footprint is inversely associated with renewable energy consumption, rule of law, urbanisation and natural resource rents. Furthermore, the scale coefficients (result column (3)) represent each independent variable's dispersion or spread of the ecological footprint. The results suggest that the dispersion of ecological footprint is directly associated with GDP per capita, renewable energy consumption, natural resources rents and crop production index, while the dispersion of ecological footprint is inversely associated with rule of law, urbanisation and livestock production index.

The result columns (4)–(8) show the MM-QR coefficients of the independent variables (GDP per capita, livestock production index, rule of law, urbanisation, natural resources rents, renewable energy consumption, crop production index and FDIs), indicating the percentage change in ecological footprint per capita for a 1% change in the independent variable while holding other variables constant. The coefficient of GDP per capita was 0.19 at the 10th quantile, 0.24 at the 25th quantile, 0.31 at the 50th quantile, 0.38 at the 75th quantile and 0.45 at the 90th quantile. This suggests that a 1% increase in GDP per capita was associated with a 0.19% increase in ecological footprint per capita at the 10th quantile, a 0.24% increase at 25th quantile, a 0.31% increase at the 50th quantile, a 0.38% increase at the 75th quantile and a 0.45% increase at the 90th quantile. All quantile coefficients were statistically significant. These results suggest that the relationship between economic growth (proxied by GDP per capita) and ecological footprint is direct and linear, implying that the pursuit of economic growth in Africa would increase the ecological footprint of the continent and, by extension, contribute to environmental degradation on the continent.

The coefficient of renewable energy consumption was -0.09 at the 10th quantile, -0.08 at the 25th quantile, -0.06 at the 50th quantile, -0.04 at the 75th quantile and -0.02 at the 90th quantile. This suggests that a 1% increase in renewable energy consumption was associated with a 0.09% reduction in ecological footprint at 10th quantile, a 0.08% decrease in ecological footprint at 25th quantile, a 0.06% decrease in ecological footprint at 50th quantile, a 0.04% reduction in ecological footprint at 75th quantile and a 0.02% reduction in ecological footprint at 90th quantile. All quantile coefficients, except the 90th quantile, were statistically significant. These results suggest that the relationship between renewable energy use and ecological footprint is inverse and linear, implying that continuous use of renewable energy in Africa would decrease the ecological footprint of the continent and, by extension, reduce environmental degradation.

The coefficient of the rule of law was -0.09 at the 10th quantile, -0.12 at the 25th quantile, -0.16 at the 50th quantile, -0.20 at the 75th quantile and -0.24 at the 90th quantile. This suggests that a 1% increase in the extent of enforcement of laws and regulations (including environmental laws) was associated with a 0.09% reduction in ecological footprint at the 10th quantile, a 0.12% reduction in ecological footprint at the 25th quantile, a 0.16% reduction in ecological footprint at the 50th quantile, a 0.20% reduction in ecological footprint at the 75th quantile and a 0.24% reduction in ecological footprint at the 90th quantile. All quantile coefficients were statistically significant. These results suggest that the relationship between the rule of law and ecological footprint is inverse and linear, implying that continuous enforcement of laws in Africa would decrease the ecological footprint of the continent and, by extension, reduce environmental degradation on the continent.

The coefficient of urbanisation was 0.03 at the 10th quantile, -0.03 at the 25th quantile, -0.11 at the 50th quantile, -0.20 at the 75th quantile and -0.27 at the 90th quantile. This suggests that a 1% increase in the rate of urbanisation was associated with a 0.03% increase in ecological footprint at the 10th quantile, a 0.03% decrease in ecological footprint at the 25th quantile, a 0.11% decrease in ecological footprint at the 50th quantile, a 0.20% reduction in ecological footprint at the 75th quantile and a 0.27% reduction in ecological footprint at the 90th quantile. All quantile coefficients, except the 10th and 25th quantiles, were statistically significant.

Table 8. Impacts of agricultural production, economic growth, urbanisation, renewable energy consumption, FDI, rule of law and natural resource rents on ecological footprint result from FE D-K and MM-QR regressions.

		MM-QR						
Variables	**FE D-K**	**Location**	**Scale**	**Q.10th**	**Q.25th**	**Q.50th**	**Q.75th**	**Q.90th**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
lnGDP	0.31***	0.31***	0.08***	0.19***	0.24***	0.31***	0.38***	0.45***
	(31.21)	(16.50)	(7.23)	(7.62)	(11.80)	(16.16)	(16.66)	(15.78)
lnRENEW	-0.06***	-0.06***	0.02***	-0.09***	-0.08***	-0.06***	-0.04***	-0.02
	(-10.40)	(-5.49)	(3.41)	(-6.76)	(-6.80)	(-5.58)	(-3.09)	(-1.46)
lnLAW	-0.16***	-0.16***	-0.05**	-0.09**	-0.12***	-0.16***	-0.20***	-0.24***
	(-5.43)	(-4.88)	(-2.43)	(-2.05)	(-3.35)	(-4.82)	(-5.17)	(-4.89)
lnURB	-0.12***	-0.12***	-0.09***	0.03	-0.03	-0.11***	-0.20***	-0.27***
	(-4.01)	(-3.72)	(-5.10)	(0.78)	(-0.96)	(-3.58)	(-5.33)	(-5.85)
lnNATR	-0.02***	-0.12***	0.03***	-0.07***	-0.05***	-0.02***	0.01	0.03***
	(-5.04)	(-2.92)	(7.14)	(-7.42)	(-6.23)	(-3.08)	(0.70)	(2.71)
lnCROP	-0.04	-0.04	0.05***	-0.11**	-0.08**	-0.04	0.0003	0.03
	(-0.87)	(-1.06)	(1.98)	(-2.26)	(-1.96)	(-1.11)	(-0.01)	(0.59)
lnLIV	0.12**	0.12**	-0.09***	0.25***	0.20***	0.12**	0.04	-0.02
	(2.64)	(2.31)	(-2.86)	(3.88)	(3.56)	(2.39)	(0.67)	(-0.33)
lnFDI	0.03***	0.03***	0.002	0.03***	0.03***	0.03***	0.03***	0.03***
	(3.22)	(3.79)	(0.46)	(2.63)	(3.30)	(3.78)	(3.40)	(2.86)
Constant	-1.22***	-1.22***	0.13	-1.42***	-1.33***	-1.23***	-1.10***	-1.01***
	(-5.07)	(-5.41)	(0.97)	(-4.93)	(-5.52)	(-5.45)	(-4.13)	(-3.02)
Observations	924	924	924	924	924	924	924	924
Groups	44	44	44	44	44	44	44	44

Note: t-values and z-values are in parentheses. ***0.01; **0.05.

These results suggest that the relationship between rate of urbanisation and ecological footprint was negative. This implies that urbanisation in Africa decreased the continent's ecological footprint.

The coefficient of natural resources rents (a proxy for abundance/dependence on natural resources) was -0.07 at the 10th quantile, -0.05 at the 25th quantile, -0.02 at the 50th quantile, 0.01 at the 75th quantile and 0.03 at the 90th quantile. This suggests that a 1% increase in natural resource rents was associated with a 0.07% decrease in ecological footprint at the 10th quantile, 0.05% decrease in ecological footprint at the 25th quantile, 0.02% decrease in ecological footprint at the 50th quantile, 0.01% increase in ecological footprint at the 75th quantile and 0.03% increase in ecological footprint at the 90th quantile. All quantile coefficients, except the 75th quantile, were statistically significant. These results suggest that the relationship between natural resource rents and ecological footprint was largely negative, but non-linear. Although natural resource rents, which is a proxy for abundance/dependence on natural resources, decreased ecological footprint in Africa, continued overdependence on natural resources increased ecological footprint on the continent.

Similarly, the coefficient of crop production index was -0.11 at the 10th quantile, -0.08 at the 25th quantile, -0.04 at the 50th quantile, 0.0003 at the 75th quantile and 0.03 at the 90th quantile. This suggests that a 1% increase in crop production index was associated with a 0.11% decrease in ecological footprint at the 10th quantile, a 0.08% decrease in ecological footprint at the 25th quantile, a 0.04% decrease in ecological footprint at the 50th quantile, a 0.0003% increase in ecological footprint at the 75th quantile and a 0.03% increase in ecological footprint at the 90th quantile. Crop production index was statistically significant for all quantile coefficients, except at 75th and 90th quantiles. Overall, this result suggests that crop production is inversely related to ecological footprint on the continent.

The coefficient of livestock production was 0.25 at the 10th quantile, 0.20 at the 25th quantile, 0.12 at the 50th quantile, 0.04 at the 75th quantile and -0.02 at the 90th quantile. This suggests that a 1% increase in livestock production index was associated with a 0.25% increase in ecological footprint per capita at the 10th quantile, a 0.20% increase in ecological footprint per capita at the 25th quantile, a 0.12% increase in ecological footprint per capita at the 50th quantile, a 0.04% increase in ecological footprint per capita at the 75th quantile and a 0.02% decrease in ecological footprint per capita at the 90th quantile. All quantile coefficients, except the 75th and 90th quantiles, were statistically significant. These results suggest that the relationship between livestock production and ecological footprint is direct and linear, implying that increasing livestock production in Africa would increase the ecological footprint of the continent and, by extension, contribute to environmental degradation on the continent.

The coefficient of FDI was 0.03 at all the quantiles studied, and they were all statistically significant and positively signed. This suggests that a 1% increase in FDIs was associated with a 0.03% increase in ecological footprint per capita at the 10, 25, 50, 75 and 90th quantiles studied. These results suggest that the relationship between FDIs and ecological footprint was direct and linear. This statistically significant positive link at the 1% level between FDIs and ecological footprint (for all the quantiles) in Africa reveals that the continent's rising receipts of foreign investments is contributing to environmental degradation.

Discussion

The paper investigated the effect of agricultural production, economic growth, renewable energy use, natural resource rents, urbanisation and rule of law on ecological footprints in the context of Africa. The FE D-K estimation and the MM-QR estimation results revealed a strong positive relationship between GDP per capita and ecological footprint. This outcome implies that an increased level of economic growth on the continent led to an increased ecological footprint. The positive relationship between GDP per capita and ecological footprint in Africa is congruent with those of Danish et al. (2020), Ahmed et al. (2021), Salman et al. (2022), Xu et al. (2022) and Luo et al. (2023). This finding suggests that the economic growth receives higher priority in Africa than environmental protection.

Our study found a negative link between renewable energy use and ecological footprint in Africa, implying that increased renewable energy consumption reduces ecological footprint, thereby increasing environmental protection. This is particularly true regarding the continent's marginal contribution to global warming. In fact, Africa contributes only 3% of global energy-related CO_2 emissions and has the lowest per capita emissions compared to other regions (International Energy Agency, 2023). The average renewable energy consumption in Africa is about 63.30% (Table 3), indicating high dependence on renewables and low energy-related emissions. Also, the International Energy Agency (2023) projected that renewables will account for over 80% of power generation on the continent by 2030. Our finding substantiates other previous studies, including Olanipekun et al. (2019), Wang and Dong (2019), Danish et al. (2020), Emenekwe et al. (2022a) and Chidiebere-Mark et al., which (2022) found a negative link between renewable energy consumption and ecological footprint and carbon emissions. Renewable energy consumption will help countries save money, reduce emissions and combat climate change (Raihan et al., 2023b).

Rule of law significantly reduced ecological footprint in Africa. The outcome of this demonstrates that the role enforcing laws and regulations (including environmental laws and regulations) play in protecting the environment in Africa. If Africa must make progress in achieving environmental sustainability and achieve carbon neutrality in the future, greater attention must be paid to enforcing laws and other commitments on the continent. This finding demonstrates that laws and regulations will ensure sustainable extraction of natural resources, which would reduce waste and harmful environmental impact of the natural resources in Africa (Oteng-Abayie et al., 2022). Our finding supports the results of previous studies including Adams et al. (2020) and Duodu et al. (2021), all of which argue that quality of environmental institutions, policies and laws promote environmental quality.

The empirical results confirm that urbanisation reduces ecological footprint in Africa. Proper biologically productive land utilisation and control of over-exploitation of environmental resources could be responsible for the negative link between urbanisation and ecological footprint in Africa (Danish et al., 2020). Also, there are positive externalities associated with urbanisation, including proper waste management and provision of environment-friendly infrastructure and services, all of which make it possible to build and sustain urban environments (Danish, Wang, 2019). Furthermore, many urban inhabitants are well-educated and are knowledgeable of the benefits of keeping the environment clean; also, the purchasing power of urban inhabitants is high, and this makes it possible for the urban inhabitants to consume environment-friendly goods and utilise energy-efficient appliances in their homes (Danish et al., 2020). Other scholars have also suggested that urbanisation reduces environmental deterioration by creating opportunities and medium for innovation and resource-use efficiency and use of environmental-friendly technologies (Charfeddine, Ben Khediri, 2016; Charfeddine, Mrabet, 2017). Our finding agrees with those of Danish and Wang (2019) and Danish et al. (2020), all of which produced evidence that urbanisation reduces ecological footprint.

Similar to renewable energy consumption, we find that natural resource rents have a negative link with ecological footprint, implying that natural resource rents are enhancing environmental quality. This finding confirms that natural resource rents reduce ecological footprint in Africa. Abundance of natural resources decreases dependence on imports of fossil fuel because the abundance of natural resources should sufficiently satisfy the energy requirements, which may in turn reduce ecological footprint (Gupta et al., 2022). The resource curse hypothesis can be used to explain this finding. The resource curse hypothesis states that there are abundant natural resources in an area; it can fall into a resource curse trap as a result of the institutions' quality and the environment in the place. Also, the negative link between natural resources and ecological footprint may be related to sustainable management of natural resources combined with the consumption and production, which allows the regeneration of the resources (Danish et al., 2020). Our finding is in line with previous studies including Danish et al. (2020), Adedoyin et al. (2020) and Erdogan et al. (2021), all of whom find negative association between natural resource rents and ecological footprint.

The 10th and 25th quantiles of crop production index yielded a negative association with ecological footprint. This implies that crop production reduced ecological footprint in Africa. Crop production could be beneficial to the environment because crops (especially tree crops) serve as carbon dioxide sink (Ali et al., 2022). Sustainable crop production and climate-smart agriculture could help sustain the positive role (tree) crops play in reducing ecological footprint in Africa. These important crop production approaches offer multiple benefits – increasing yield and food security, increasing climate and ecological resilience and mitigating carbon. Previous researchers such as Adeleye et al. (2021) and Chopra et al. (2022) have equally documented a negative association between crop production and environmental degradation.

Unlike crop production, the empirical result shows that livestock production index yielded mainly a positive link with ecological footprint and environmental degradation. This outcome implies that livestock production increased ecological footprint in Africa. Livestock production generally affects the environment because grazing of farm animals depletes natural resources and by extension degrades the environment (Onyeneke et al., 2024a). Unsustainable livestock production practices such as overgrazing and extensive rearing of farm animals (especially ruminants) increase ecological footprint and environmental degradation (Grossi et al., 2018; Chidiebere-Mark et al., 2022; Onyeneke et al., 2024a) in Africa. Our finding is backed by previous studies such as Chidiebere-

Mark et al. (2022), which find positive association between livestock production and environmental degradation.

FDIs have a positive association with ecological footprint, implying that FDI is contributing to environmental degradation in Africa through increasing ecological footprint. This finding suggests that the FDIs on the Africa largely deteriorate the environment. This finding supports the pollution-haven hypothesis, which suggests that industries generating pollution in developed countries where laws and institutions are strong are often transferred to host (often developing countries) countries where laws and regulations are loose and weak. This implies that net FDI inflows in Africa might be toward pollution-intensive industries and technologies. The petroleum industries in Nigeria are good examples of the deleterious impact of huge FDIs on the environment. The Niger Delta region of the country has suffered monumental environmental degradation resulting from oil and gas exploration, gas flaring and oil spillage. Our result supports the findings of Avci (2023), Ponce et al. (2023), Khan et al. (2023), Salman et al. (2022), Zuo et al. (2022), Okelele et al. (2022), Abid et al. (2021), Chowdhury et al. (2021) and Udemba (2020), which found that FDIs have a positive and significant link with ecological footprint.

Conclusion

This study examined the impact of agricultural production, economic growth, urbanisation, renewable energy consumption, FDI, natural resource rents and the rule of law on Africa's ecological and environmental quality. We used data from 44 countries in Africa. We proxied agricultural production with crop and livestock production indexes. The findings reveal that economic growth (GDP per capita), livestock production and FDIs had a significant positive association with ecological footprints for most of the quantiles. We conclude that higher GDP per capita is at the cost of environmental quality, as an increase in GDP per capita depletes environmental quality as consumers demand more goods as their living standards improve. Livestock production has deteriorating environmental impacts as CO_2 is emitted in livestock rearing, including livestock feed, which requires considerable investments in feed formulation, transportation, grazing and meat processing. FDIs without solid policies to regulate the investments raise the ecological footprint.

In contrast, our findings conclude that renewable energy consumption, crop production index, rule of law, urbanisation and natural resource rents all reduced the ecological footprint in Africa for most of the quantiles. Strong laws and policies and solid law enforcement in Africa can promote sustainable investments in renewable energy, sustainable crop production practices, and sustainable consumption and management of natural resources. However, managing ecological footprints is essential to ensuring the sustainability and quality of the environment. The study further highlights the importance of legal frameworks in mitigating these adverse effects and fostering sustainable development. Policymakers and government agencies must establish adequate legal and regulatory frameworks to help mitigate the negative impacts of resource exploitation on the environment and promote sustainable development across the continent. Moreover, stakeholders must collaborate to develop innovative and sustainable solutions to address the challenges posed by economic growth, livestock production and FDIs. This will require increased investment in research, development, technology transfer and greater public awareness and education about the importance of environmental conservation and sustainable development.

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