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RESEARCH ARTICLE

Informal economy and ecological footprint: the case of Africa

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Abstract

Motivated by the growing levelof informal economy in emerging economies, this study examines the role of the informal economy in the ecological footprint for the case of Africa. The relationship between official economy, trade openness, governance indicator, financial development, and urbanization on ecological footprint is also investigated. Applying data from 1991 to 2017, this empiric utilizes panel estimation procedures to account for cross-sectional dependence and slope heterogeneity in panel data. The results establish the presence of cross-sectional dependence and slope heterogeneity across countries in Africa. Furthermore, long-run cointegration is confirmed using Westerlund panel cointegration. Driscoll-Kraay's (DK) estimation technique shows that informal economy, official economy, governance, financial development, and urbanization have significant positive impacts on ecological footprint, implying that they contribute to environmental degradation. However, trade openness has a negative and significant effect on ecological footprint, improving environmental quality. Similarly, the Dumitrescu-Hurlin (DH) Granger causality test reveals a two-way relationship between the informal economy and ecological footprint and formal economy and ecological footprint. However, the study finds a one-way connection from urbanization and financial development to ecological footprint and from ecological footprint to governance indicators and trade openness. The implications of the findings for a sustainable environment are discussed.

Keywords Ecological footprint (EFP) · Informal economy · Formal economy · Driscoll-Kraay (DK) · Westerlund · Dumitrescu-Hurlin (DH)

JEL codes O13 · O44 · P28 · Q57

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Nomenclature

EFP	Ecological footprint
DK	Driscoll-Kraay
DH	Dumitrescu-Hurlin
CD	Cross-sectional dependence
EKC	Environmental Kuznets curve
ARDL	Autoregressive distributed lag

Introduction

This study examines the impact of the informal economy on Africa's ecological footprint and is motivated by some factors. The continuous increase in environmental degradation and greenhouse gases (GHG), especially in developing countries, has become worrisome to policymakers, researchers, development agencies, and international organizations alike. This has resulted in the loss of infrastructural facilities, natural resources, organisms, and human lives (Dada et al. 2021a, 2021b). Specifically, the Sustainable Development

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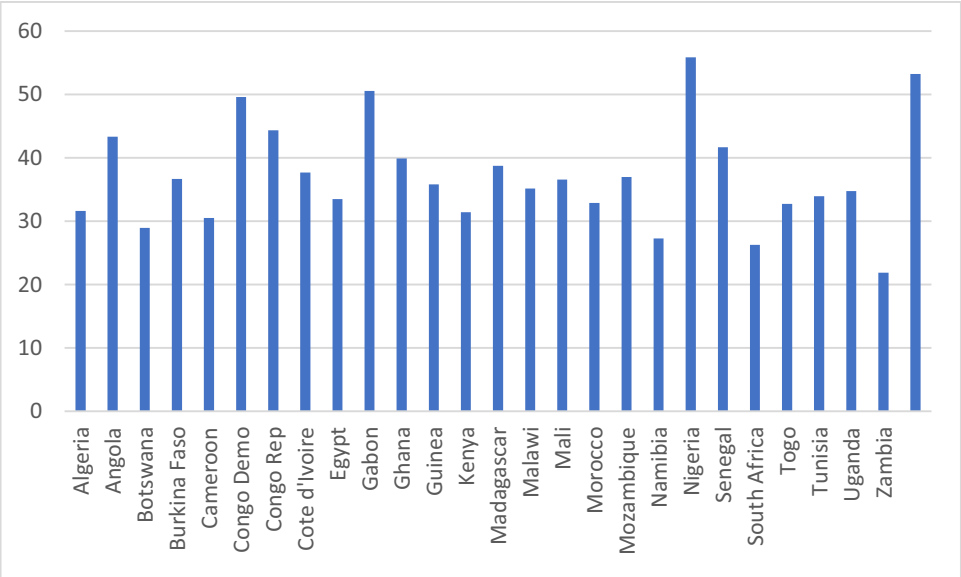

Fig. 1: Average value of informal economy in Africa (1995–2017). Source: authors' calculation based on Melinda and Schneider's (2019) dataset

Goals (SGDs) numbers 6, 7, 11, 12, 13, 14, and 15 clearly state the need for countries to work together to reduce the menace of environmental degradation that poses a significant threat to organisms' survival (Asongu and Odhiambo 2018; Dhrifi et al. 2019; Dada and Fanowopo 2020). The Rio Conventions on climate change further stress the need for proper, effective, and efficient utilization of environmental resources and related ecosystems (Akinlo and Dada 2021). Similarly, the Copenhagen Accord signed by country members requires countries to reduce their GHG emissions willingly.

As a result of the undesirable effect of environmental degradation on organisms' survival (Nathaniel and Khan 2020), empirical researchers have examined various factors responsible for greenhouse emissions and environmental degradation, which could be broadly classified as mixed. Factors such as economic growth/per capita income, human capital development, urbanization, existing levels of financial development, trade, natural resources, and institutions (see Ahmed et al. 2020a, 2020b; Solarin and Al-mulali 2018; Shahbaz et al. 2013; Dada et al. 2021a, 2021b) have been extensively identified in the literature. However, the role of informal economy has not been adequately captured in the empirical studies. Since informal economy and formal economy share most features in terms of their determinants, there is a likelihood for the informal economy to influence environmental quality.

The informal economy,[1] also known as the shadow economy or parallel economy, refers to all economic activities outside the official economy. In most cases, activities in the informal economy are masked from the government officials, especially tax authorities. Thus, it is commonly referred to as illegal business enterprises. The informal economy has become part of both developed and developing countries. The informal economy exists alongside the formal economy. As noted by Medina and Schneider (2019), the magnitude of the informal economy is significant in developing nations, especially sub-Saharan African countries. Figure 1 presents the average values of the informal economy in Africa between 1995 and 2017, which range between one-third and two-thirds of gross domestic product. The informal economy employs more than 70% of the population in Africa (International Labour Organization, ILO, 2012, Ajide and Dada 2022). In light of those mentioned above, this study intends to bridge the gap in the literature by exploring the nexus between the informal economy, formal economy, and the ecological footprint in Africa.

Against this backdrop, this current study contributes to the environmental economic literature in diverse areas. This study is the first attempt to examine the role of the informal economy on environmental degradation in Africa, although studies in Africa have extensively dwelled on the role of the official economy (proxied by GDP growth) on environmental degradation (see Nathaniel et al. 2020a, 2020b; Nathaniel and Iheonu 2019; Hanif 2018). However, the neglect of the impact of the informal sector on environmental issues necessitates this study. The formal economy alone cannot adequately represent the effect of economic activities on the environment. Informal economy activities like metal works, transportation with ineffective and obsolete vehicles, automotive repair, and crude mining substantially affect the ecosystem (Dada et al. 2021a, 2021b; Cervero 2000). The consistent increase in the trend of informal economy in Africa could hinder achieving environmental sustainability,

[1] For detailed explanation on informal economy, see Dada and Ajide (2021) and Dada et al. (2021a, 2021b).

necessitating the need to account for the role informal economy plays in achieving it.

Second, this study uses ecological footprint (henceforth EFP) to capture environmental degradation. Previous studies in Africa have used CO_2 emission, methane emission, and PM4 (Nkengfack et al. 2020; Akinlo and Dada 2021; Dada and Ajide 2021; Hanif 2018) as a proxy for environmental pollution. Although these proxies are widely used in the extant literature, they do not capture the wholeness of natural habitat (Alola et al. 2019); while the increase in technological advancement and regulatory framework might reduce CO_2 emission, other pollutants which CO_2 and its variants do not capture might increase it. Thus, the use of EFP provides an extensive measure of environmental degradation and sustainability (Solarin et al. 2019). As Ulucak and Bilgili (2018) expressed, EFP captures biologically productive land and water an individual and the entire population consume, and the anthropogenic pressure on the environment. The EFP measures the built-up land, carbon emissions, cropland, fishing grounds, forestry products, and grazing land (Ecological Footprint Network, EFN, 2019), thereby providing a comprehensive environmental degradation measure and a more reliable and robust result than other conventional proxies.

Furthermore, the direction of causation between the informal economy and EFP is investigated in this study. Extant studies that have examined the direction of causality between economic growth and environmental degradation/pollution using the official economy could be generally classified as inconclusive, thereby necessitating the need to use the informal economy. For instance, a one-way causal relationship from economic growth to environmental pollution was established by Lee and Yoo (2016) for Mexico; Chang (2010) for China; and Saboori et al. (2012) for Malaysia, among others. On the other hand, Baloch et al. (2019), Menyah and Wolde-Rufael (2010), and Acheampong (2018) established a unidirectional causality from environmental pollution to economic growth, while studies by Kasman and Duman (2015) and Wang et al. (2016) among others found a neutral effect between environmental degradation and economic growth. It is essential to contribute to the extant studies in this area by examining the direction of causality between environmental degradation and informal economy and other important factors such as urbanization, trade, financial development, and governance indicators. This is important because there is a tendency for an upsurge in informal activities to lead to a rise in the extraction and consumption of natural resources, which worsens ecological footprint and environmental sustainability (Danish and SU-Din 2019). Since environmental sustainability deals majorly with the ability of a country to effectively use its natural resources to meet current demand without negatively affecting future demands calls for empirical investigation.

In addition, the study adopts panel estimation methods that address the problem of cross-sectional dependence (CD) and spatial heterogeneity among the cross-sectional units. The presence of technology and globalization of the world economies in the past few decades has made countries experience ever-increasing economic, social, political, and linked financial markets, which is responsible for solid interdependence among a cross-section of units. These could promote the transfer of non-environmentally friendly equipment, which worsens environmental degradation (Akinlo and Dada 2021). Also, due to increasing competition in the global market, the environmental standard could be lowered, thus affecting environmental quality (Zhang and Zhou 2016; Dada et al. 2021a, 2021b).

Lastly, African countries are used in this study for the following reasons. Africa is an emerging region with a large volume of informal economic activities. Its economic growth rests on polluting sectors such as mining (oil and gas, gold, mercury) and agricultural activities (farming, lumbering, fishing). Also, in recent times, Africa has been seen as the top spot for dumping electronic waste and used equipment such as a car (usually called second-hand cars), which impacts the region's environmental sustainability. Emission from these gadgets affects the health outcomes of the citizen (Boogaard et al. 2017; Asongu and Odhiambo 2018; Akinlo and Dada 2021).

The rest of this study is arranged thus: literature review and stylized facts on the informal economy and EFP are discussed in the "Literature review" section. Materials and methodology are presented in the "Materials and methodology" section, the result and discussion are in the "Results and discussion" section, while concluding remarks are presented in the "Concluding remarks and policy implications" section.

Literature review

EFP: meaning and current trends in Africa

Ecological footprint (EFP) could be regarded as a tool for measuring the human population's demand on nature. A country's EFP is the summation of the productive terrestrial and aquatic ecosystem necessary to produce food, timber, food, and other resources needed by a defined population which is consumed, absorbed its wastes, and used to build up the required infrastructures at a curtained standard of living (Wackernagel and Rees 1996; Rees 1992; Global Footprint Network 2019). This implies that EFP is the environmental degradation indicator, holistically, through economic activities' direct and indirect processes (Mrabet and Alsamara 2017; Ulucak and Bilgili 2018). The EFP is currently being used as a measure of environmental damage in most recent

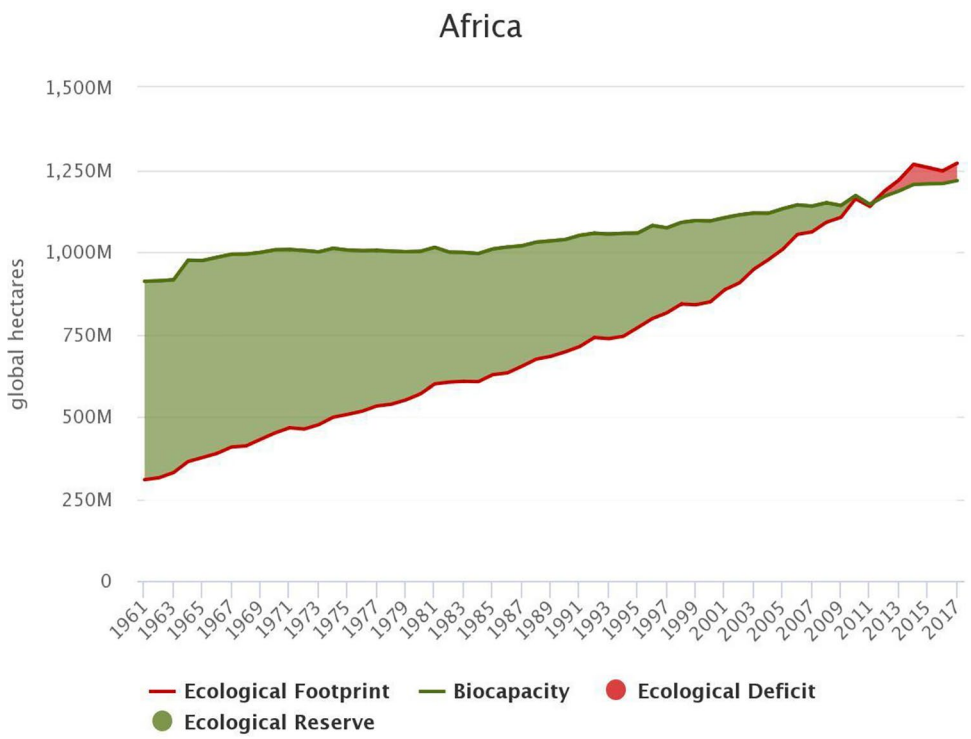

Fig. 2: African ecological footprint. Source: Global Footprint Network (2021)

studies, which shows its relationship with growth, energy consumption, and natural resources, among others (Asici & Aşıcı and Acar 2016; Solarin and Bello 2018; Zafar et al. 2019; Ozcan et al. 2019).

Figure 2 shows that Africa is well endowed with ecological reserves. As can be seen, it is well demonstrated that in 1961, the biocapacity reserve was around 3.5 global hectares per person to EFP of about 1.2 global hectares. However, starting from 2002, the ecological reserve shrinks to about 0.2 global hectares per person. In 2017, it is evident that Africa is now recording an ecological deficit. This is based on the fact that most African countries are exporters of non-renewable resources such as crude oil, ore, and diamonds, from which they generate revenue. From the graph, we can conclude that environmental degradation is getting higher in Africa because the health of the natural system is reducing. The biodiversity is decreasing by nearly 40%, meaning that the African ecosystem is being damaged every day while the EFP increases. This implies that demand for nature is getting higher when compared to its supply. This is a result of the overuse of natural resources and waste accumulation. Based on this context, this paper examines how the informal sector of the African economy contributes to environmental degradation.

Theoretical preposition

Most empirical studies have used environmental Kuznets curve (EKC) hypothesis proposed by Kuznets (1995) as a theoretical basis for studying the relationship between economic variables and environmental indicators (Ulucak and Bilgili 2018; Solarin and Bello 2018; Dada and Ajide 2021). The EKC shows that at an initial level of development, the quality of the environment diminishes. Subsequently, the environmental quality improves as the economy develops. The empirical outcomes of studies show various extensions to EKC shapes, including monotonous decreasing or increasing, *N*-shaped, inverted *U*-shaped, and inverted *N*-shaped (Abid 2015; Köksal et al. 2020). Environmental problems become cumbersome in developing economies such as Africa, where environmental regulations and standards are weak due to the massive presence of informal economic activities. In developing countries, companies explore the advantages of the weak standards and regulations by using input materials with a higher level of pollution to produce the final products.

In this case, underground economic activities influence environmental degradation. This is consistent with theoretical links provided by Biswas et al. (2012), explaining that an informal economy may increase environmental pollution, especially in an economy with a higher level of corruption. Since EFP can be classified as a form of environmental degradation, the informal economy may have a significant impact on EFP. Furthermore, Becker (1968) provides that economic agents may operate in an informal economy after weighing the cost and benefit. In environmental economics, firms may decide to work in the underground economy to escape environmental regulations and laws for causing

environmental damages in the official economy. In the same vein, Chaudhuri and Mukhopadhyay (2006) provide a theoretical link in a framework of three-sector general equilibrium, which accounts for the informal economy. The authors explain that the formal sector bears the tax burden for pollution of the informal economy whenever it is above the permissible level in the economic system. As a result, there is an increase in the use of the informal sector's output in the formal sector, generating environmental pollution. This increases the emission tax burden payable in the formal economy. Despite this, the authors conclude that the increase in the tax rate and the polluting informal economy still increase the deteriorating impact on the environment.

Empirical literature

Consistent with the theoretical underpinning, few studies have examined the impact of the informal economy on EFP. The study of Köksal et al. (2020) investigates the informal economy's role in EFP in Turkey from 1961 to 2014. The study documents a positive relationship between informal economic activities and the EFP level. This means that informal economic activities constitute a long-run driver of pollution. In Chaudhuri and Mukhopadhyay (2006) and Baksi and Bose (2010), it was documented that informal economic activities increase environmental degradation. Therefore, firms are being pressured to be friendly with the environment. In a related study conducted by Shujahur-Rahman et al. (2019) in 16 European countries, it was concluded that environmental degradation was affected by financial development and energy use, and renewable energy increases environmental quality due to a decline in EFP for the period 1991–2014.

In the study of Udemba (2020), it was found that there is a positive relationship between economic growth and EFP in Turkey. The author employs ARDL and Granger causality to analyze Turkey's data. Shao et al. (2021) examine the role of globalization, trade, and market size in the relationship between the underground economy and gas emissions in 134 countries from 1990 to 2018. The study uses World Bank and IMF data for the analysis. The authors discover that underground economic activities negatively impact environmental pollution in the long run. They also find a threshold effect in globalization, market size, and trade, while the relationship between the size of the market and emissions is significant. Mazhar and Elgin (2013) examine the role of environmental regulations on pollution in the presence of an informal economy. The study reveals the role of the informal economy using 100 countries. The study shows that environmental regulation increases pollution in an informal economy.

In Pakistan, Baloch et al. (2021) test whether a higher level of the informal economy may accompany higher environmental degradation by utilizing data from 1966 to 2008. Using ARDL bound test procedures, the study finds a cointegration among the variables and that the informal economy boosts environmental pollution. This result is robust to alternative estimation techniques like fully modified OLS and dynamic OLS. The policy involving the reduction of the informal economy should be implemented. Sohail et al. (2021) explore the effects of the shadow economy on clean energy and pollution from 1991 to 2019 in South Asian countries. The authors employ ARDL for the analysis showing that the underground economy increases cleaner energy consumption in Sri Lanka and Pakistan while it has a negative impact on India. Non-linear ARDL also demonstrates Pakistan's case that the underground economy improves cleaner energy. In related research conducted by Nkengfack et al. (2020), the authors conclude that the informal economy negatively impacts environmental quality. This implies that the shadow economy may serve as a factor for controlling environmental problems, most notably where there is an effective governance system. This conclusion contradicts the submission of the earlier scholars (see Maddah 2017). The Tunisian study by Abid (2015) and Blackman et al. (2006) in Mexico reveals that the informal economy increases CO_2 emissions. This means that it is necessary to limit informal economy size in the economic system.

Other studies look at how financial and other macroeconomic variables affect EFP in the economy. This is because a higher level of environmental issues may arise due to economic activities in which every economic system tends to protect the environment and the economy's development in line with EKC analysis. For instance, Godil et al. (2020) empirically examine the impact of tourism, financial development, and globalization on EFP in Turkey between 1986 and 2018. The study employs the Quantile ARDL approach. It was found that tourism, finance, and globalization positively impact EFP. The study also displays a *U*-shaped relationship for the case of Turkey. This suggests that financial development and globalization increase the level of EFPs. Kongbuamai et al. (2020) investigate the impacts of growth, energy, tourism, and natural resources on EFP in ASEAN economies by employing data from 1995 to 2016. Using second-generation panel data analysis, the results show a *U*-shaped relationship among the variables. There is a *U*-shaped EKC between tourism and natural resources with EFPs in ASEAN economies. This implies that natural resources and tourism improve the quality of the environment.

Huynh (2020) investigates the case of twenty-two Asian countries and the relationship between pollution and informal economy using the system GMM. He documents that the informal economy directly affects air pollution and expansionary fiscal policy reduces the detrimental impact throughout the study. Pang et al. (2020) also conclude that informal

economic activities directly impact environmental pollution in China. In Africa, the related studies include the informal economy and financial inclusion (Ajide 2021). In this study, the author shows that financial inclusion reduces the size of informality in Africa, meaning that finance can serve as a tool for lowering informal economic activities. In a related study, Ajide et al. (2022) document that in the long run, the informal economy reduces FDI inflow in Nigeria, while the opposite is the case in the short run. In addition, the study of Dada et al. (2021a) reveals that institutional quality moderates the relationship between the informal economy and CO_2 emission. This submission is consistent with the study of Dada and Ajide (2021) for the case of Nigeria. The authors conclude that the quality of institutions re-enforces the positive relationship between informalities and environmental pollution.

From the review, it is evident that little or no study examines the relationship between the informal economy and EFP in Africa despite the high level of underground economic activities. Our study fills these gaps by empirically examining the impact of the informal economy on EFP in selected African countries. To carefully position the objective of the study, we formulate this hypothesis: *Informal economy significantly affects ecological footprint in Africa*.

Materials and methodology

Data

This study uses a dataset of thirty-one African countries for the period 1991–2017 to examine the influence of the informal economy in addition to the official economy on ecological footprint. The list of the countries is presented in the Appendix. Ecological footprint per capita (EFP) is used to proxy environmental degradation. EFP measures anthropogenic activities in six primary areas. Data on EFP is obtained from Global Footprint Network (2021). The informal economy, also known as the shadow economy, connotes all illegal activities concealed from the tax authorities. Data on the informal economy is sourced from Medina and Schneider (2019) due to the robustness and flexibility in obtaining the data. Economic growth is used to capture the official economy, and it is a proxy using per capita gross domestic product. Other control variables added are urbanization, trade openness, governance, and financial development. Urbanization is measured as the number of individuals living in the urban centers to the total population. Trade openness is calculated as the import and export ratio to gross domestic product. Governance is measured using the average value of five indicators—corruption control, law and order, government stability, bureaucracy quality, and democratic accountability. These indicators are averaged to compute an index of governance following the works of Agbloyor et al. (2016) and Dada and Abanikanda (2021). Credit to the private sector is used to capture financial development. Data on economic growth, urbanization, trade openness, and financial development are sourced from World Bank Development Indicators (2018), while governance data is sourced from International Country Risk Guide (2019).

Model specification

The existing model in environmental literature is modified to include the informal economy (Dada et al. 2022a; Ahmed et al. 2020b; Alola et al. 2019). Thus, the baseline model of the cross-country equation is stated as follows:

$$EFP_{i,t} = \alpha + \beta_1 GDP_{i,t} + \gamma_1 IFE_{i,t} + \delta_1\, TOP_{i,t} + \kappa_1 URB_{i,t} + \lambda_1 GOV_{i,t} + \varphi_1 FD_{i,t} + \mu_i + \varepsilon_{i,t} \quad (1)$$

EFP represents ecological footprint; GDP represents economic growth (formal economy), IFE stands for the informal economy; and TOP, URB, GOV, and FD are trade openness, urbanization, governance, and financial development. μ_i is the country-specific effect, and $\varepsilon_{i,t}$ is the error term.

Estimation procedures

This subsection presents the highlights of the procedural approaches and methods adopted to capture the main objectives of this work. It is necessary because the unique characteristics of the panel data must be thoroughly considered. Figure 3 shows the methodology flow chart to achieve the study's objective. Thus, the procedures are carefully explained in sequential orders.

Cross-sectional dependence (CD)

An empirical examination of CD in panel data analysis is becoming a rule rather than an exception (Olaniyi 2022; Meo et al. 2020). In the era of globalization and financial liberalization, countries are integrated, interdependent, and intertwined. A country's shock tends to be transmitted to other countries via the contagion effect. Thus, assuming independence among countries in Africa could be unrealistic. There is a high likelihood for CD to exist in the panel dataset. African countries are highly integrated, which could make shocks in a country transmit to others through contagion (Aluko et al. 2021; Ajide et al. 2021; Akinlo and Dada 2022). The CD model is given as follows under the null hypothesis of the absence of CD in the panel data:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=0}^{N-1}\sum_{j=i+1}^{N-1}\rho ij\right) \qquad N(0,1) \quad (2)$$

From Equation 2, ρij is the cross-sections' correlation of errors between i and j. To ensure the robustness of results, other variants of CD tests such as Pesaran et al. (2008),

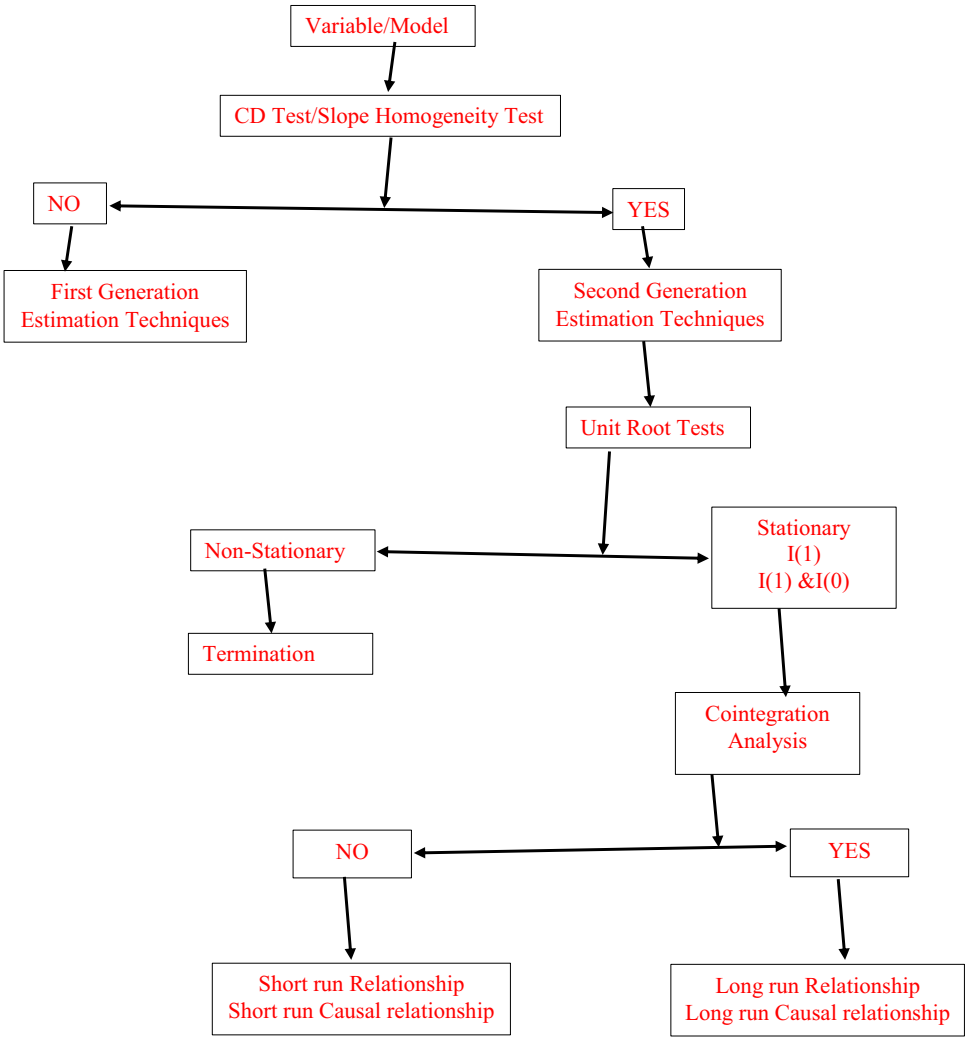

Fig. 3: Methodology flow chart

Breusch and Pagan (1980), and Baltagi et al. (2012) are also examined, but the equations are not presented.

Slope homogeneity test

Consistent with the work of Pesaran and Yamagata (2008), the slope heterogeneity test is carried out to reveal whether there is the existence of slope homogeneity between cross-sections in the dataset of African countries. Pesaran and Yamagata's (2008) test is preferred to other conventional tests. Other approaches do not account for CD. The slope homogeneity test's model is specified as follows:

$$\tilde{\Delta} = (N)^{\frac{1}{2}}(2K)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \tag{3}$$

$$\tilde{\Delta}_{adj} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \tag{4}$$

$\tilde{\Delta}$ is the delta tilde while $\tilde{\Delta}_{adj}$ stands for the adjusted delta tilde. The models in Equations 3 and 4 are based on the null hypotheses of slope homogeneity across cross-sections.

Panel unit root

To ensure the adoption of the proper estimation techniques, the stationarity characteristics of the series are investigated. Building up to the existence of CD, second-generation panel unit root tests are used. The first-generation panel unit root tests provide misleading results in the presence of CD (Nathaniel 2021; Ahmad et al. 2020). Thus, cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectionally augmented IPS (CIPS) tests by Pesaran (2007) are used in this study. Meanwhile, it has been confirmed that CIPS performs better in the presence of CD and heterogeneity. CIPS also produces more reliable estimates. CIPS model is presented in Equation 5.

$$\Delta X_{i,t} = \alpha_i + \alpha_i Y_{i,t-1} + \alpha_i \overline{Y}_{t-1} + \sum_{l=0}^{p} \alpha_{il} \Delta \overline{X}_{t-1} + \sum_{l=0}^{p} \alpha_{il} \Delta X_{i,t-1} + \mu_{it} \tag{5}$$

where $\overline{X}$ is the average cross-section of each of the series. The statistical test of CIPS is specified as follows:

$$\widehat{CIPS} = N^{-1} \sum_{i=0}^{n} CADF_i \tag{6}$$

Cointegration test

If the unit root test indicates that the series is stationary at the first difference, *I*[1], or a mixture of integration of order one and zero, it implies the likelihood of a long-run relationship among the series. To ensure endogeneity concerns and CD are well accounted for in the cointegration test, Westerlund's (2007) approach is more appropriate to resolve these problems. It equally has the potency to give better explanatory power than other dynamic cointegration techniques. The test produces four statistics. The first two are the group mean statistics, which are stated as follows:

$$G_\tau = \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{\beta}_i}{SE(\hat{\beta}_i)} \quad and \; G_\alpha = \frac{1}{N} \sum_{i=1}^{N} \frac{T\hat{\beta}_i}{\beta_i(1)} \tag{7}$$

The two statistics in Equation 7 investigate the cointegration of the whole panel. The remaining two statistics are as follows:

$$P_\tau = \frac{\hat{\beta}_i}{SE(\hat{\beta}_i)} \; and \; P_\alpha = T\hat{\alpha} \tag{8}$$

The two statistics in Equation 8 examine the long-run relationship in at least one of the cross-sectional units.

Driscoll and Kraay's nonparametric covariance matrix estimator

Following the position of extant studies (Kongbuamai et al. 2020), Driscoll-Kraay's nonparametric estimator is deployed to investigate the long-run estimates to establish the impacts of the variables on EFP. This approach is robust to CD and heterogeneity (Kongbuamai et al. 2020; Baloch and Wang 2019). It is suitable for balanced and unbalanced panel datasets, as it counts missing values. Thus, this study adopts the Driscoll-Kraay estimator to estimate the linear model specified in Equation 1. Furthermore, to account for econometrics' pitfalls such as endogeneity problems in the estimated model, the system generalized method of moments (GMM) is used as a robustness check to ensure more reliable and consistent estimates (Dada 2021).

Causality tests

The direction of causality among the variable, with a biased interest in the nexus between the informal economy and EFP, is examined for sound policy prescriptions. A second-generation causality of Dumitrescu and Hurlin (2012) that uses a block bootstrapping approach is considered to account for CD and heterogeneity. This method produces strong critical values which address CD and heterogeneity concerns. The model is described thus:

$$x_{i,t} = \propto_{1i} + \sum_{k=1}^{K} \propto_{1i}^{(k)} x_{i,t-k} + \sum_{k=1}^{K} \beta_{1i}^{(k)} y_{i,t-k} + \mu_{1i,t} \tag{9}$$

$$y_{i,t} = \propto_{2i} + \sum_{k=1}^{K} \propto_{2i}^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_{2i}^{(k)} x_{i,t-k} + \mu_{2i,t} \tag{10}$$

x and y are stationary dependent and independent variables, respectively, while $\propto_{1i}$ and $\propto_{2i}$ are the individual country-specific effects. K is the lag length, and it is determined using Bayesian information criteria (BIC) in each case. The optimal lag length is endogenously chosen following the Stata code supplied by Lopez and Weber (2017). $\left(\propto_{1i}^{(k)} \; and \; \propto_{2i}^{(k)}\right)$ and $\left(\beta_{1i}^{(k)} and \; \beta_{2i}^{(k)}\right)$ are autoregressive parameters and regression coefficients, respectively. These parameters and coefficients tend to differ across the cross-sectional units. The existence of causality is determined through the Wald statistics and their respective probability values, which confirm or reject the significance of $\beta_{1i}^{(k)}$ and $\beta_{2i}^{(k)}$ in Equations (9) and (10).

Results and discussion

Preliminary tests

This analysis begins with examining the characteristics of the series used in the study. First, the descriptive and correlation relationship among the series is reported in Table 1. The result shows that the series is evenly distributed, i.e., the values of the measure of central tendency (mean and median) are close. The standard deviation also indicates that per capita income is the most widely spread series during the study period. The skewness statistics reveal that all the series are positively skewed, excluding the governance indicator, which has a negative value.

Furthermore, the kurtosis statistic that indicates the peakedness or flatness of the distribution suggests that all the series are leptokurtic except informal economy and urbanization, whose values are less than three, thus platykurtic. Apart from the descriptive statistics, the correlation matrix suggests the absence of either exact or high

Table 1: Descriptive and correlation matrix

	EFP	IFE	GDP	TOP	URB	GOV	FD
Mean	1.415	38.858	1967.760	67.778	41.145	3.542	22.023
Median	1.241	37.900	1063.975	61.966	39.891	3.575	13.510
Maximum	3.818	64.000	11937.640	172.449	89.158	5.583	160.125
Minimum	0.627	21.900	164.943	5.315	11.454	0.600	-1.354
Std. Dev.	0.605	8.332	2262.764	26.450	16.066	0.695	26.279
Skewness	1.681	0.546	2.071	1.230	0.382	-0.302	2.901
Kurtosis	5.751	2.893	7.234	4.999	2.863	3.608	12.520
Observations	837	837	837	837	837	837	837
EFP	1	0.425	0.667	0.041	0.418	0.360	0.638
IFE		1	-0.122	-0.035	-0.035	-0.313	-0.419
GDP			1	0.340	0.745	0.235	0.447
TOP				1	0.423	0.011	0.066
URB					1	0.126	0.319
GOV						1	0.313
FD							1

Where EFP is ecological footprint, IFE is the informal economy, GDP is the official economy, TOP is trade openness, URB is urbanization, GOV is governance indicator, and FD is financial sector development

Table 2: Cross-sectional dependence (CD) tests

CD tests	EFP	IFE	GDP	TOP	URB	GOV	FD
Breusch-Pagan LM	3202.829***	7457.254***	6816.663***	2430.617***	10225.14***	3327.840***	4314.630***
Pesaran scaled LM	89.776***	229.285***	208.279***	64.455***	320.047***	93.876***	126.234***
Bias-corrected scaled LM	89.180***	228.688***	207.683***	63.858***	319.451***	93.280***	125.638***
Pesaran CD	3.776***	82.328***	53.540***	18.492***	93.915***	40.393***	47.372***

Where *, **, and *** indicates 10%, 5%, and 1% level of significant respectively

correlation among the variable—specifically, the coefficients of the correlation matrix range between −0.419 and 0.745. In terms of relationship, the correlation matrix result reveals that all the variables have a positive relationship with EFP in Africa, thus contributing to environmental degradation.

Since the statistical attribute of the variables has been discussed, this section examines the econometric criteria such as the CD test, slope homogeneity test, and unit root test. It is imperative to account for CD and slope homogeneity in the data since its presence may lead to biases in the unit root, cointegration, and, ultimately, regression results (Khan et al. 2020; Westerlund 2007). To test for CD in the series, four different tests are used. The results of the CD tests are presented in Table 2. The outcomes in Table 2 discard the null hypothesis of no CD in the panel data. These results show that countries in Africa are knitted together, such that any shock or policy in one of the nations quickly spreads to other countries.

Table 3: Slope homogeneity tests

T-statistics	Value	*p* value
Δ	16.006***	0.000
Δ_{adj}	19.080***	0.000

Where *, **, and *** indicates 10%, 5%, and 1% level of significant respectively

Furthermore, globalization and liberalization of the world economies have also made the world glued together. Apart from the CD test, Table 3 reports the result from the slope homogeneity test. The results confirm the presence of heterogeneity in the data, which suggests that the slope and coefficient of the model vary across countries (Ahmad et al. 2020; Bao and Xu 2019). Since CD and heterogeneity have been established in the panel, the application of first-generation estimation techniques such as traditional unit root becomes inapt (Akinlo and Dada 2022; Ajide et al.

Table 4: Panel unit root tests (second-generation approach)

Variables	Intercept				Intercept with trend			
	Level		First difference		Level		First difference	
	CADF	CIPS	CADF	CIPS	CADF	CIPS	CADF	CIPS
EFP	−2.015*	−2.506***	-	-	−2.458	−2.907***	−4.641***	-
IFE	−2.470***	−2.752***	-	-	−2.614**	−2.801***	-	-
GDP	−1.460	−1.553	-3.368***	-4.320***	−2.085	−2.010	−3.634***	−4.579***
TOP	−1.951	−2.111**	-3.710***	-	−2.329	−2.586*	−3.803***	
URB	−2.055**	−2.511***	-	-	−3.258***	−2.957***	-	-
GOV	−2.845***	−2.905***	-	-	−2.982***	−3.444***	-	-
FD	−2.128**	−2.349***	-	-	−2.093	−2.489	−3.822***	−5.128***

Where *, **, and *** indicates 10%, 5%, and 1% level of significant respectively

2021). Thus, this study applies second-generation unit root and estimation techniques. Cross-sectionally augmented Im, Pesaran, and Shin (CIPS) and cross-sectionally augmented Dickey-Fuller (CADF), which take care of both CD and heterogeneity, are used.

The unit root tests presented in Table 4 reveal that the variables are integrated of orders 0 and 1, using both intercepts, and intercept and trend. Cointegration among the variables is also tested using Westerlund's (2007) panel cointegration test. As presented in Table 5, the cointegration test results show evidence of cointegration among the variables. Specifically, the group statistic (G_t) and panel statistic (P_t) are significant, thus discarding the null hypothesis of no cointegration.

Effect of informal economy on ecological footprint

Having examined the descriptive and econometric characteristics of the data, the next is to explore the role of the informal economy and other factors in the EFP in Africa. Two approaches are used to achieve this objective. First, the generalized method of moment (GMM) corrects endogeneity commonly found in environmental literature (Dada et al. 2021b). Second, Driscoll and Kraay's standard errors correct for CD. The regression outputs are presented in Table 6.

Table 5: Westerlund ECM panel cointegration tests

H_0: no cointegration	Value	Robust *p* value
G_t	−3.146***	0.000
G_a	−3.446	0.702
P_t	−15.857***	0.000
P_a	−3.679	0.912

Where *, **, and *** indicates 10%, 5% and 1% level of significant respectively

The result from both regressions reveals that the informal economy positively affects EFP. This result suggests that the informal economy does constitute a threat to the environment in the region. In specific terms, a percentage increase in informal activities increases the EFP by 1.5%. The increasing impact of the informal economy on EFP supports most empirical studies examining the effect using environmental degradation proxies such as CO_2 emissions, methane emissions, nitrous oxide emissions, and PM4. This finding also buttresses the result gotten

Table 6: Estimation results

Dependent variable: EFP		
Variable	System GMM estimator	Driscoll-Kraay's regression
EFP(-1)	0.587*** (54.265)	
IFE	0.001** (2.166)	0.015*** (12.02)
GDP	0.007*** (3.978)	0.002*** (14.40)
TOP	−0.005** (−2.081)	−0.004*** (−5.98)
URB	0.008*** (3.079)	0.008** (2.17)
GOV	−0.013 (−1.322)	0.062*** (6.70)
FD	0.002*** (2.972)	0.007*** (7.33)
Constant	0.043*** (2.623)	1.705*** (23.99)
Sargan test (*p* value)	0.248	
AR(1)	0.034**	
AR(2)	0.591	

Where *, **, and *** indicates 10%, 5%, and 1% level of significant respectively

from the correlation matrix, where a positive correlation between the informal economy and EFP is found. The reason for the informal economy having an increasing impact on the EFP in Africa is not far-fetched. One, the informal sector in Africa employs a more significant percentage of the working population, with many of these firms using outdated and inefficient technology, thereby intensifying environmental pollution.

Furthermore, the informal sector does not have access to most financial services, such as credit facilities rendered by the financial industry. The non-availability of credit facilities to the informal sector reduces their chances of investing in research and development and utilizing environmentally friendly technologies which improve the environment. Furthermore, informal economies in Africa are widely dispersed, making it difficult for the official to track their activities.

In addition, the informal economy does not have access to green energy or environmentally friendly technology, which leads to the production of non-environmentally friendly products that deteriorate the environment. The submission of this study supports the works of Köksal et al. (2020) and Baloch et al. (2021), whose findings suggest that informal economic activities increase EFP, thus informal economic activities worsening the EFP. Similarly, studies by Biswas et al. (2012), Swain et al. (2020), Dada et al. (2021a, 2021b), and Dada and Ajide (2021) show that the shadow economy worsens environmental sustainability in their respective study areas. However, the empirical submissions of Nkengfack et al. (2020) and Sohail et al. (2021) found that the informal economy or underground economy reduces EFP.

The official economy, also known as the formal economy (GDP), has a positive and significant impact on EFP in Africa. In specific terms, a 1% increase in economic growth leads to a 0.2% increase in ecological footprint in Africa. This finding suggests that an increase in economic growth constitutes a threat to the environment. An increase in economic growth in the region demands more energy to meet the requirement of the growing economy. Still, these demands are usually met using fossil fuel and non-renewable energy, identified in the literature as significant sources of environmental pollution. This finding is supported by the empirical studies of Zafar et al. (2019) and Dada et al. (2021b). The effect of trade openness on the EFP in the region is negative and significant. A percentage increase in trade openness abates ecological footprint by 0.4%. This reveals that the openness of countries in the region to international trade enables them to benefit from both the scale, technique, and composition effects. The outcome of this study aligns with the submission of Chen et al. (2018) and Fakher (2019).

Governance indicator in the region also contributes to the growth of EFP. The significant positive impact of governance indicators on EFP suggests that institutional quality in the region is weak (Olaniyi and Oladeji 2021) to bring about the desired reduction in environmental degradation. This result reveals that economic agents could quickly get through their way by bribing officials enforcing environmental rules and regulations; thus, firms could produce goods that are not socially desirable, which affect the environment (Sohail et al. 2021; Fredriksson and Mani 2002). Ajide et al. (2022) and Ajide and Soyemi (2022) also confirm that weak institutional quality in Africa serves as a loophole for firms to operate in the informal economy, thereby practicing tax evasion.

The financial sector development has a positive and significant effect on the EFP in all the models. The result suggests that the financial sector contributes to the menace of environmental degradation in Africa. The result also indicates that finance has not been used to promote green energy products, R&D, and renewable energy. In addition, the agricultural sector, which is one of the prominent renewable sectors in the region, has been neglected in terms of finance. This finding complements the study of Charfeddine (2017), Nathaniel et al. (2019), and Dada et al. (2022b), who concluded that the financial sector spurs EFP.

Furthermore, this result is consistent with Shen et al. (2021), who investigate the nexus between financial development and carbon emission. They show that financial development increases carbon emissions. However, this submission is incongruent with the outcome of Shobande and Lawrence Ogbeifun (2022). The authors find that financial development promotes environmental sustainability in Organization for Economic Cooperation and Development (OECD) countries. Furthermore, urbanization has a significant positive effect on EFP. This suggests that urbanization has a deterioration effect on environmental sustainability in Africa.

Direction of causality between ecological footprint and its determinants

The direction of causation between EFP and its determinant is obtained using the heterogeneous Dumitrescu and Hurlin (DH) approach. This approach is beneficial to this study because it corrects CD and heterogeneity issues in panel data (Danish and SU-Din 2019; Dumitrescu and Hurlin 2012). The knowledge of the direction of transmission among the variable is necessary, especially in making informed policy decisions needed to bring about the desired changes. The D-H granger causality test reported in Table 7 shows a two-way causal relationship between the informal economy and EFP in Africa. This result suggests that any changes in the informal economy in terms of policy have a resultant effect

Table 7: Dumitrescu and Hurlin (2012) Granger non-causality test results

	W-stat	Z bar stat	Prob. value	Decision
EFP ≠> IFE	3.729*	4.814	0.063	Bidirectional causality
IFE ≠> EFP	4.459**	6.845	0.033	
EFP ≠> GDP	5.161**	8.798	0.012	Bidirectional causality
GDP ≠> EFP	3.909*	5.315	0.050	
EFP ≠> TOP	3.086	3.024	0.271	Unidirectional causality
TOP ≠> EFP	4.156**	6.002	0.032	
EFP ≠> URB	7.310***	14.784	0.003	Unidirectional causality
URB ≠> EFP	3.732	4.823	0.113	
EFP ≠> GOV	2.726	2.022	0.516	Unidirectional causality
GOV ≠> EFP	3.611*	4.485	0.091	
EFP ≠> FD	5.056**	6.156	0.045	Unidirectional causality
FD ≠> EFP	2.984	2.739	0.273	

The *p* values are computed using 1000 bootstrap replications

Where *, **, and *** indicates 10%, 5%, and 1% level of significant respectively

on EFP, while the policy on the environment also influences the informal economy.

A bidirectional relationship also exists between economic growth and EFP. The two-way relationship suggests that a change in economic growth, for example, impacts ecological footprint, while in response, environmental degradation finds its way into affecting economic growth. However, a unidirectional causality exists between trade openness and EFP, urbanization and EFP, governance and EFP, and financial development and EFP. The two-way causation between economic growth and EFP supports the findings of Destek and Sarkodie (2019) and Danish and SU-Din (2019). The schematic representation of the causality test is presented in Fig. 4.

Study's limitation and direction for future study

It is imperative to note that this study has added to the ecological and environmental literature by unearthing the role of the informal economy on ecological footprint, which has been neglected in previous studies, especially in Africa. However, the study's limitations are raised to aid future research efforts. In a region with about 54 countries, this study uses thirty-one (31) African countries between 1991 and 2017. The number of countries included and the period is based on data availability. Future studies should overcome these challenges.

Furthermore, future studies can extend this study to other regions with high levels of the informal economy. Research can be developed to confirm the EKC intuition and dig out the relative effect of informal economy in such relations. Future research can also consider other measures of the informal economy like predictive mean matching (PMM) and currency demand approaches. It should be noted that these limitations and suggestions for future study are provided to complement this research. They do not undermine the uniqueness and novelty of this study.

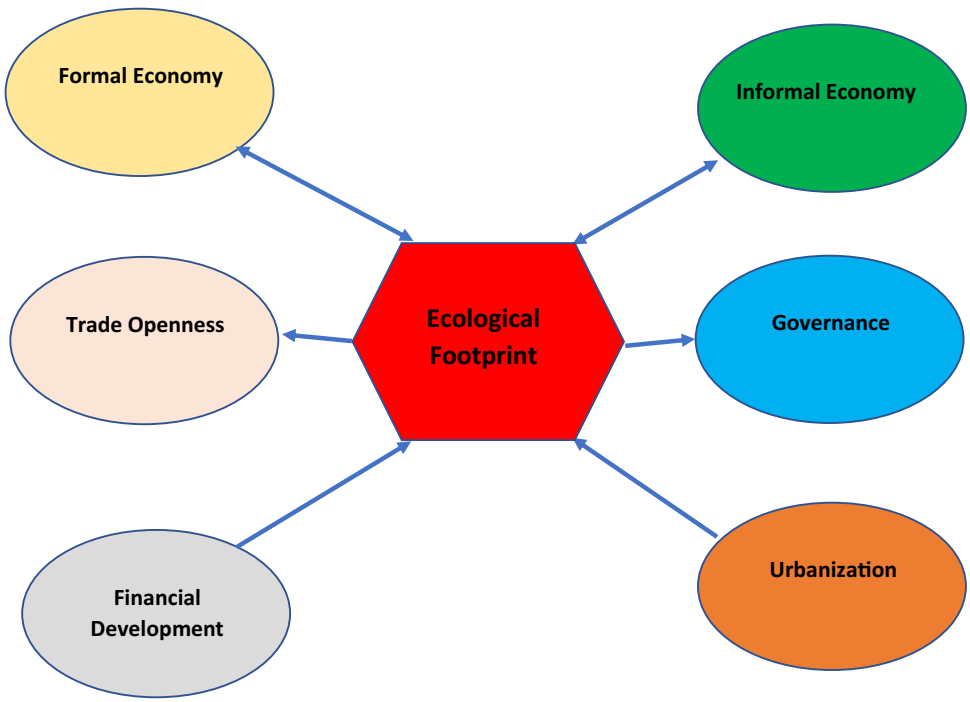

Fig. 4: Direction of causality

Concluding remarks and policy implications

Previous studies in the environmental literature have focused on the role of the formal economy in environmental quality, with little or no known research examining the impact of the informal economy in such relationships, especially in Africa. Therefore, this study deviates from past empirical studies by investigating the role the informal sector and the formal sector play in maintaining environmental sustainability in developing countries like Africa. Specifically, this study investigates the effect of the formal and informal economy, trade openness, governance, financial development, and urbanization on the EFP for 31 African nations between 1991 and 2017. Panel estimation techniques are used to capture the objective of the study.

Evidence from the estimation techniques confirms the presence of cross-sectional dependence among the cross-sectional units, heterogeneity in the panel data, and long-run cointegration among the series. Outcomes of the study are as follows: both formal (proxy by gross domestic product) and informal economy, governance, urbanization, and financial development contribute to the growth of EFP, hence worsening environmental quality in Africa. However, trade openness has a reducing effect on EFP. Regarding relative contribution to environmental degradation, the informal economy and the official economy contribute almost the same magnitude to EFP in Africa. The result from the D-H causality suggests evidence of bidirectional causality between the informal economy and EFP and economic growth and EFP and unidirectional causality from urbanization and financial development to EFP and EFP to governance indicators and trade openness.

Findings from this study have some important implications. Informal economy and economic growth contribute positively to EFP, and there is evidence of a feedback relationship between the two variables; hence, policies that target sustainable growth in the region should be targeted. Such policies include the imposition of a tax on carbon emission to curtail it, sensitization of the populace on the need for environmentally friendly technologies, and use of renewable energy, among others. In addition, economic growth should be channeled to research and development and renewable sources of energy to reduce over-dependence on fossil fuels. Since mainstreaming the informal economy into the official economy will further worsen the environmental sustainability in Africa, as demonstrated in our result, the informal economy should be coordinated and carried along in the green energy and green environment campaign.

Furthermore, the government should subsidize at a reduced cost and make renewable energy and green products available for firms both in the formal and informal economy. Environmental laws and regulations need to be formulated in countries where none exist, while they should be adequately enforced in countries with laws guiding the environment. Lastly, the financial sector should provide credit facilities to firms to diversify their source of energy from non-renewable energy to renewable sources of energy and to be able to invest in clean and environmentally friendly technologies.

Appendix

List of countries

Algeria, Angola, Botswana, Burkina Faso, Cameroon, Congo Democratic, Cote d'Ivore, Egypt, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Madagascar, Malawi, Mali, Morocco, Mozambique, Namibia, Niger, Nigeria, Senegal, Sierra Leone, South Africa, Togo, Tunisia, Uganda, Zambia, Zimbabwe

Data availability Data and materials are available upon reasonable request.

Author contribution This work was carried out in collaboration of all the authors. J.T.D wrote the introduction and discussion of result. C.O.O participated in its methodology design, and analyzed the data. F.M.A wrote the stylized fact and literature review. A.A wrote the conclusion and policy recommendation. M.A harmonized the study together. All authors read and approved the final manuscript.

Declarations

Ethics approval Not applicable

Consent to participate Not applicable

Consent to publish The journal is free to publish the manuscript.

Competing interests The authors declare no competing interests.

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