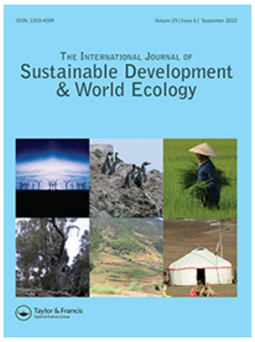

International Journal of Sustainable Development & World Ecology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tsdw20

On the shadow economy-environmental sustainability nexus in Africa: the (ir)relevance of financial development

James Temitope Dada, Folorunsho Monsur Ajide, Marina Arnaut & Adams Adeiza

To cite this article: James Temitope Dada, Folorunsho Monsur Ajide, Marina Arnaut & Adams Adeiza (2022): On the shadow economy-environmental sustainability nexus in Africa: the (ir)relevance of financial development, International Journal of Sustainable Development & World Ecology, DOI: 10.1080/13504509.2022.2115576

To link to this article: https://doi.org/10.1080/13504509.2022.2115576

Published online: 28 Aug 2022.

INTERNATIONAL JOURNAL OF SUSTAINABLE DEVELOPMENT & WORLD ECOLOGY
https://doi.org/10.1080/13504509.2022.2115576

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

On the shadow economy-environmental sustainability nexus in Africa: the (ir) relevance of financial development

James Temitope Dada[a], Folorunsho Monsur Ajide[b], Marina Arnaut[c] and Adams Adeiza[d]

[a]Department of Economics, Obafemi Awolowo University, Ile-Ife, Nigeria; [b]Department of Economics, University of Ilorin, Ilorin, Nigeria; [c]Dubai Business School, University of Dubai, Dubai, United Arab Emirate; [d]Malaysian Graduate School of Entrepreneurship and Business (MGSEB), Universiti Malaysia, Kelantan (UMK), Malaysia

ABSTRACT

Recent studies suggest that shadow economy has several implications for environmental sustainability. However, the relevance of financial development in the nexus between shadow economy-environmental sustainability remains an open question. This study examines the role of shadow economy and financial development in addition to economic growth, trade openness, and urbanization on the environmental sustainability of a panel of 30 African countries from 1991 to 2017. Specifically, the study investigates the effect of these variables on African countries' ecological footprint and bio-capacity. Findings based on the augmented mean group estimator reveal that shadow economy, financial development, economic growth, and urbanization intensify ecological footprint, while trade openness reduces it. Further investigations reveal that shadow economy, economic growth, and urbanization reduce bio-capacity while trade openness increases it. The interactive term of the shadow economy and financial development shows that a strong financial system significantly moderates the adverse impact of shadow economy on environmental degradation. These results persist when common correlated effect mean group is used to re-estimate the models. Furthermore, Dumitrescu and Hurlin's non-causality tests show two-way causality between ecological footprint and shadow economy, bio-capacity and shadow economy, and financial development. Nevertheless, unidirectional causality is found from financial development to ecological footprint and shadow economy, economic growth to ecological footprint, biocapacity, and financial development. Lastly, the policy implications of the results are discussed in line with these economies.

ARTICLE HISTORY
Received 10 May 2022
Accepted 17 August 2022

KEYWORDS
Shadow economy; financial development; environmental sustainability; africa

1. Introduction

Beginning from the era of Millennium Development Goals (MDGs) to the current global agenda (i.e., Sustainable Development Goals), every economy has been at the forefront of emphasizing the need for environmental sustainability (World Bank 2015; Denny and Marquart-Pyatt 2018). Environmental sustainability comprises clean water, sanitation, and a healthy ecological ecosystem addressing climate challenges (UNDP 2014). Africa is among the developing regions that have experienced remarkable economic growth over the years (Ajide 2022). However, this region also emits a large volume of pollutants, creating environmental and health challenges within the continent. For instance, there is a problem of gas flaring in the Niger-Delta region of Nigeria, oil spillage in Angola, and the concern of malnutrition in Somalia. These issues lead to health crises (Adekunle 2021; Dada and Akinlo 2021). Development is often linked to industrial activities. Therefore, carbon emission has increased in the continent while poverty and inclusive growth problems continue. Despite this trend, little attention has been given to the significance of environmental degradation in Africa (Jolley and Douglas 2014). Denny and Marquart-Pyatt (2018) explain that research on environmental sustainability should address easing pressure on the environment through industrialization, which can be linked to human activities' development and consumption behavior.

African literature on ecological footprints (an indicator of environmental sustainability) is affected by socio-economic, ecological, and political factors (Denny and Marquart-Pyatt 2018; Dada et al. 2022c). Shadow economy is one of the socio-economic factors (Ajide et al. 2022), which comprises all economic activities that are not within the purview of public and private formations (Ajide and Dada 2022; Ajide et al. 2022). It can also be called illegal operations or any activity not covered within the official calculations of gross domestic products (GDP). The unrecorded activities and untaxable operations are not revealed to the public authorities (Ihrig and Moe 2004).

Table 1 shows that shadow economic activities account for more than 38% of GDP in Africa from

CONTACT Adams Adeiza adams.a@umk.edu.my MK-MGSEB Kuala Lumpur Office, M-01-07, Urbanhive, Conezion Commercial, Persiaran IRC, 62052 Putrajaya

Table 1. Average shadow economy (as a % of GDP) in developing regions (1991–2017).

	Years		
Developing regions	1991–1999	2000–2009	2010–2017
Sub-Saharan Africa	41.9	39.3	34.4
Latin America	41.4	38.9	34.0
South Asia	34.7	33.2	28.1
The Middle East & North Africa	27.3	24.1	21.9
East Asia	26.5	24.7	21.3

Source: Extracted from Medina and Schneider (2019).

1991 to 1999 and 2000 to 2009. Compared with other developing regions, size of the shadow economy is significant in sub-Saharan Africa and provides 90% of youth employment in the non-agricultural sector (Medina and Schneider 2018 and 2019).

In line with the latest literature, further questions have been raised on whether shadow economy affects the environment (Dada et al. 2021a, b; Dada and Ajide 2021), mainly because it affects climate change and pollutant emissions. The literature hints that the existence of shadow economy has created economic transactions outside the purview of an official economy to the extent of producing 70% employment in countries like Gambia, Nigeria, and Ghana. Most firms within this shadow economy do not obey environmental laws and engage in pollutant-intensive activities, including transporting with outdated vehicles, automotive repairs, artisanal mining, brick and tile making, metal works, and leather tanning. These activities have significant implications on environmental sustainability and further worsen the quality of the African environment (ILO 2012; Cervero 2000). Nevertheless, the relevance of financial development in the link between shadow economy-environmental sustainability remains unanswered. The existing literature neglects the financial development policy impact mechanisms in the discourse. This article makes significant contributions in this respect. Therefore, the core objective of this study is to investigate the moderating impact of financial development in the relationship between environmental sustainability and shadow economy in selected African countries.

Theoretically, financial development may impact and moderate the link between environmental quality and shadow economy in several ways. Backward integration of firms may produce enormous pollution due to its nature. However, financial flows from inefficient entrepreneurial firms driven by financial development to efficient firms may reduce waste and pollution (Zhang 2011). Efficient intermediaries will boost technological innovation and stimulate technological progress (Frankel and Romer 1999). Jalil and Feridun (2011) and Frankel and Rose (2002) indicate that financial access enables households and firms to acquire environmentally friendly technology, significantly reducing environmental pollution, thereby guaranteeing ecological sustainability in Africa.

On the other hand, financial development may enable heavy industries such as manufacturing sectors to invest extensively in new equipment and facilities in a bid to improve production capabilities which increases the level of environmental pollution in the economy (Tamazian et al. 2009; Zhang 2011; Shahbaz et al. 2013; Dar and Asif 2018). A mature financial development would monitor funds and ensure financial commitment to green investment activities (Dar and Asif 2018). This suggests that the role of financial development in environmental sustainability is ambiguous in the literature (Dada et al. 2022c). Unlike the existing studies, this study is unique in many ways. It is the first attempt to probe the role of financial development in the environment-shadow economy nexus in with reference to Africa. Second, it is realized that the ambiguity in the literature may occur probably due to an inappropriate proxy for environmental quality. Our study deviates from this tradition by employing two efficient proxies of ecological indicators: ecological footprint (henceforth, EF) and biocapacity.

This adequately captures the peculiarity of African regions. As shown in Figure 1, before 2002, the African region had rich ecological reserves, and the biocapacity reserves were within 3.5 global hectares per head compared to the EF of 1.2 global hectares (Global Footprint Network 2021). After 2002, African ecological reserves reduced to about 0.2 global hectares per head to the extent that in 2017, the region recorded an ecological deficit due to indiscriminately exploring and exporting non-renewable natural resources, including ore, crude oil, diamonds, and so on, for revenue purpose. The biodiversity shrinks day by day to nearly 40%. This reflects the level of damage done to the environmental ecosystem (Global Footprint Network 2021).

In addition, previous studies employ either inappropriate or ineffective proxies of financial development. Our study ameliorates this by utilizing the recently developed IMF broad-based financial development index (FD) that captures financial depth, access, and efficiency in the African financial system (Svirydzenka 2016; Aluko and Ibrahim 2020; Shobande and Ogbeifun 2022). Figure 2 shows the trend of FD in Africa. In 1991, FD was below 9% and increased to 16% in 2017. This study intends to examine the developmental trend's implication in Africa's shadow economy-environmental sustainability. The study also makes methodological contributions by applying robust second-generation panel data econometric techniques, including Augmented Mean Group (AMG), Common Correlated Mean Group Estimator (CCEMG), and Dumitrescu and Hurlin (DH) non-causality test. These techniques account for interconnection between nations in African setting. The findings emphasize the role of financial development in promoting a clean environment within the panel

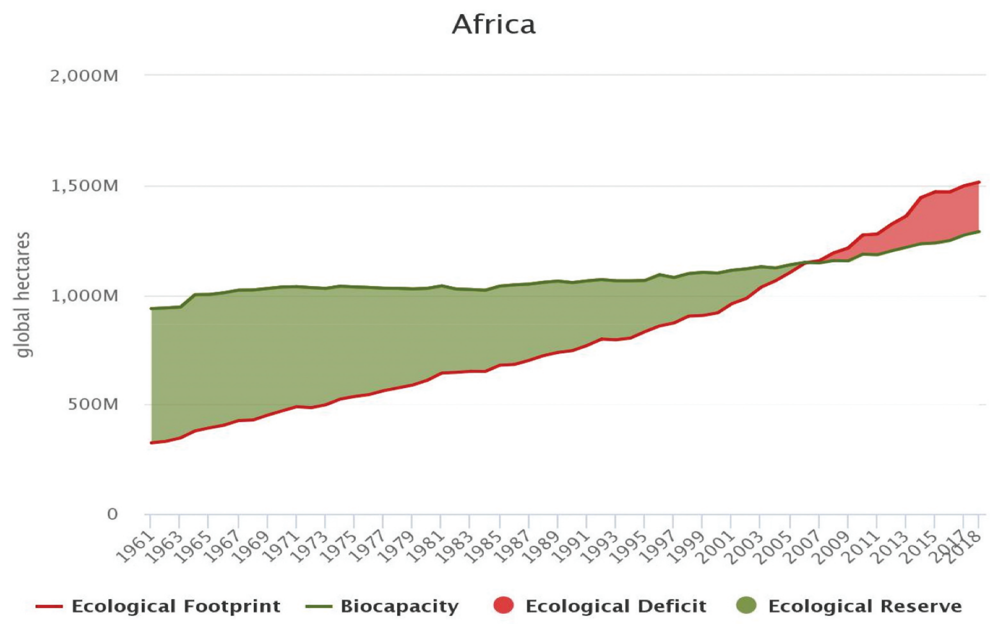

Figure 1. African ecological deficit (Source: Global Footprint Network, 2021).

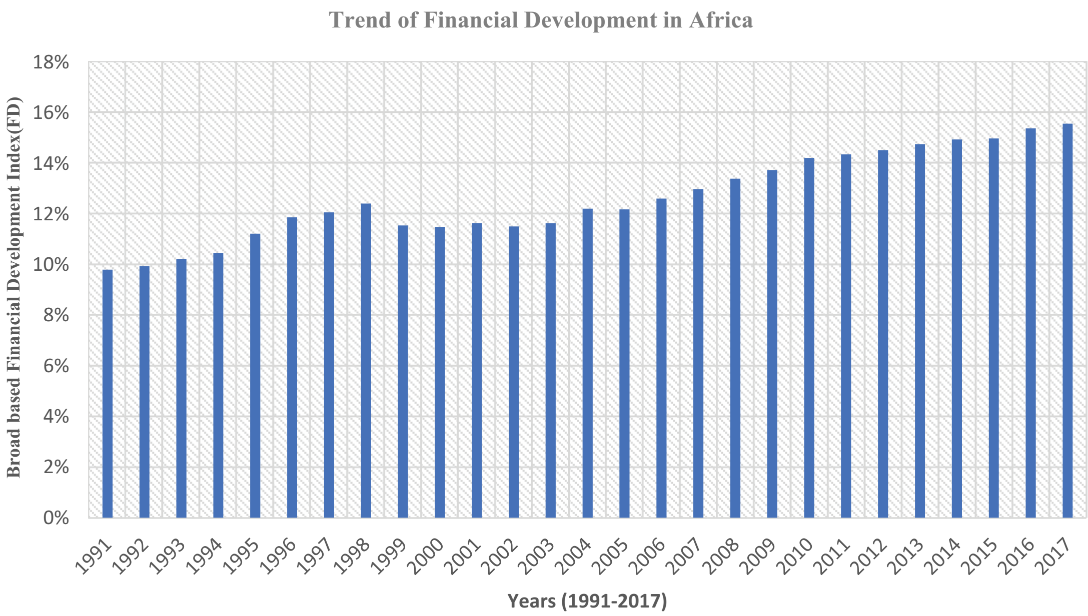

Figure 2. Trends of financial development in Africa (source: own chart, but data from IMF).

countries in Africa. The rest of the study is presented as follows. Part 2 deals with the literature review and the testable hypotheses. In section 3, the methods and materials for the analysis are discussed. Section 4 discusses the results, while section 5 concludes the study.

2. Literature and hypothesis development

The literature on the shadow economy-environment nexus derives its theoretical basis from the Environmental Kuznets Curve (EKC) (Grossman and Krueger 1991; Biswas et al. 2012; Dada et al. 2021a, b). This framework provides the connection between economic and environmental variables. Biswas et al. (2012) and Chen et al. (2018) explain that the presence of a higher size shadow economy may accelerate pollution, which may have a significant effect on environmental sustainability (Neumayer 2002). In the theoretical analysis provided by Chen et al. (2018), it was discussed that ecological sustainability might be impaired through the significant presence of shadow economy, especially where there is weak regulation (Nkengfack et al. 2020; Ajide et al. 2022). Elgin and Oztunali (2014) give an empirical analysis that also testifies to this theoretical prediction after using global samples of 152 countries. The results from 1999 to 2009 reveal that shadow economy accelerates the level of pollution in an economy. Chen et al. (2018) document a positive link between shadow economy and environmental degradation (also see Elgin and

Mazhar, 2013 for 161 economies). Imamoglu (2018) confirms a long-run positive relationship between the shadow economy and pollution in Turkey. Huynh (2020) further extends this result to capture the analysis of 22 Asian economies from 2002 to 2015, where fiscal policy is examined to alleviate the situation. Using dynamic panel analysis, Pang et al. (2020) discovered that pollution occurred in China, where there was a large size of shadow economy between 2000 and 2016.

The recent study of Şenhaz et al. (2021) in OECD countries reveals similar results, while the Pakistan study of Baloch et al. (2021) shows that the shadow economy boosts environmental pollution. Some studies proxied environmental indicators as EF while relating to the shadow economy. For instance, Köksal et al. (2020) examine the impact of shadow economy on the EF in Turkey and discover that direction of the association is positive. Chu and Hoang (2022) also discuss the nexus between shadow economy and ecological footprint in 32 OECD economies within a period of 1990 and 2015. Applying panel quantile regression, the results show a U-shaped relationship between the two variables, implying a threshold at which the informal economy increases environmental sustainability. The study by Alvarado et al. (2022) shows that the informal economy adversely affects the ecological footprints of 95 economies from 1990 to 2018. Similarly, Dada et al. (2022c) submit that informal economy worsens the long-run ecological sustainability of African countries. These results further show that the accumulation of the effects may put the ecosystem at risk. Following the previous studies, we propose that:

Hypothesis 1: Shadow economy has a significant positive association with environmental indicators proxied by ecological deficit and biocapacity in Africa.

Godil et al. (2020) explain that where there is financial intermediation efficiency, financial development can enhance economic prosperity and assist the country in improving capital and money markets (Katircioglu 2014). Financial development may also help in boosting investment and create opportunities to utilize advanced-level technologies. As it continues to improve the country's position, financial development has many impacts on the environment (Dar and Asif 2017). Financial intermediation allows consumers have access to durable consumer goods, increasing greenhouse gas emissions. This increases energy-prone activities in the economy (Zhang 2011). Financial development may reduce financial costs and minimize financial and operating risk, encouraging new domestic and foreign investment and leading to a rise in energy consumption and CO2 emissions. This implies that there could be a positive relationship between financial development and environmental degradation (Bello and Abimbola 2010; Sehrawat et al. 2015).

However, some authors show that financial development may spur the level of environmental quality. They argue that financial development supports firms listed in the capital markets to obey ecological laws, ensure energy efficiency, and reduce carbon emissions intensity (Jalil and Feridun 2011; Shahbaz et al. 2013). The study of Dar and Asif (2018) confirms that financial development improves environmental quality in Tukey. Charfeddine and Mrabet (2017) study also suggest a nexus between financial development and the environment. In supporting this view, the recent research of Baloch et al. (2019) confirms that financial development decreases EF (also see Godil et al. 2020). Shobande and Ogbeifun (2022) study proves that financial development increases environmental sustainability in OECD economies. Klobodu (2018) empirically suggests that financial access is vital in reducing carbon emissions in Africa. Rjoub et al. (2021) explain that financial development moderates Turkey's extent of carbon emissions. Usman and Hammar (2021) document that financial inclusion has an essential effect on EF. Dada et al. (2022a) submit that financial development improves Malaysia's environmental quality in the short run while it deteriorates the environment in the long run. Furthermore, in Nigeria, Dada et al. (2022b) conclude that financial development reduces ecological footprint. Since the literature suggests that financial development may reduce the level of environmental degradation, this study claims this stance by proposing the second hypothesis:

Hypothesis 2: Financial development promotes environmental sustainability in Africa.

Furthermore, Straub (2005) provides a cost and benefit analysis model associated with the official and shadow economy. The model explains that firms' operation in the official economy enables them to benefit from public goods and property rights. In a simple model by Blackburn et al. (2012), it was explained that tax evasion and financial development interact most especially where the rational choice is assumed and concludes that financial development enhances disclosure and reduces the level of the shadow economy. Capasso and Jappelli (2013) theoretically hint that entrepreneurial firms would like to function in the formal economy due to the up-to-date technology used in operation. Financial development would decrease the cost of credits and increase the opportunity cost of shadow economic operation. This implies that financial development may reduce the shadow economy, which may moderate the positive connection between the shadow economy and environmental degradation in Africa. For instance, Shujah-ur-Rahman et al. (2019) examine the effect of financial development and energy consumption on the environment in central and Eastern Europe. The results confirm that financial development moderates the connection between the official economy and environmental pollution. An African study by Ajide (2021) discovered that financial inclusion decreases the size of the shadow economy after using batteries of econometric panel techniques. The empirical research of Vo and Zaman (2020) reveals, based on the GMM estimation technique, that financial development moderates the relationship between energy demand and carbon emissions in 101 economies from 1995 to 2018. Shen et al. (2021) show that financial development can moderate the relationship between carbon emissions and energy consumption and, at the same time, encourage green investment. Eren et al. (2022) inspect the shadow economy's impact on Turkey's environmental performance. The interactive effect of financial development in the relationship distorts the positive impact of the shadow economy on the environment's performance. Supporting this analysis is the study of Al-Mulali and Sab (2012), who analyze the effects of energy consumption on CO2 emissions from 1980 to 2008. The authors discover that financial development performs a moderating role in the energy consumption-carbon emission nexus. Since the few studies available testify that financial development performs a moderating role, we claim that:

Hypothesis 3: financial development moderates the relationship between environmental sustainability and the shadow economy in Africa.

3. Data and methodology

3.1 Data

This empiric employs the annual panel data for 30 nations in Africa between 1991 and 2017. The list of the nations is presented in appendix A. The data of ecological footprint (EF) and biocapacity (BC) series (per capita global hectares) are sourced from Global Footprint Network (GFN 2019). Shadow economy (SHA) variable is sourced from Medina and Schneider (2019) due to the comprehensive, robustness, and flexibility in obtaining the data. Shadow economy data is calculated as a percentage of gross domestic product. Financial development (FD) index is obtained from International Monetary Fund (IMF 2019). Other variables include gross domestic product per capita (GDP) expressed in constant 2010 $US, urbanization (URB), measured as the number of individuals living in the urban centers to the entire population. Trade openness (TOP), calculated as the export and import ratio to GDP, is obtained from World Development Indicators (WDI 2019).

Table 2 presents the descriptive statistics and correlation matrix of the series. The average values of biocapacity, EF, shadow economy, financial development, gross domestic product per capita, trade openness, and urbanization during the study period are 3.301, 1.419, 38.358, 0.146, 1992.692, 67.688, and 41.422, respectively. Thus, the series lies within their respective minimum and maximum values. Similarly, all the series are positively skewed, while the kurtosis statistics reveal that all the series are peak and leptokurtic except urbanization, whose magnitude is less than three. Furthermore, the bivariate correlation between the series suggests that the variables are moderately correlated. In addition, the variance inflation factor (VIF) was used to detect collinearity and multicollinearity among the series in Table 3. The results imply lower VIF and mean VIF values. Hence, the assumption of multicollinearity among the series can be rejected.

BIO is biocapacity, EF is ecological footprint, SHA is shadow economy, FD is financial development, GDP is gross domestic product, TOP is trade openness, and URB is urbanization.

3.2 The empirical models

This current study investigates the role of shadow economy and financial development in the environmental sustainability of 30 countries in Africa. In this respect,

Table 2. Descriptive Statistics and Pairwise Correlation.

	BIO	EFP	SHA	FD	GDP	TOP	URB
Mean	3.301	1.419	38.358	0.146	1992.692	67.688	41.422
Median	1.403	1.238	37.600	0.113	1037.569	61.538	40.337
Maximum	43.364	3.818	64.000	0.627	11,937.640	172.449	89.158
Minimum	0.403	0.627	21.900	0.000	164.943	5.315	11.454
Std. Dev.	6.035	0.614	7.954	0.102	2295.651	26.735	16.257
Skewness	4.246	1.645	0.552	1.955	2.019	1.238	0.335
Kurtosis	22.501	5.563	3.062	7.618	6.967	4.952	2.794
Observations	810	810	810	810	810	810	810
BIO	1	0.113	0.340	−0.126	0.649	0.336	0.450
EFP		1	−0.443	0.664	0.667	0.040	0.417
SHA			1	−0.451	−0.109	−0.048	−0.004
FD				1	0.518	0.061	0.337
GDP					1	0.344	0.744
TOP						1	0.428
URB							1

Table 3. Variance inflation factor.

Variables	Coefficient Variance	Uncentered VIF	Centered VIF
C	0.008	53.808	NA
SHA	3.29E-06	32.006	1.317
FD	0.027	5.426	1.795
GDP	8.30E-11	4.860	2.770
TOP	2.79E-07	9.383	1.264
URB	1.47E-06	18.444	2.459

two econometric models are proposed (EF and biocapacity models). The EF captures the demand side, while biocapacity measures the supply side of the environment (Wackernagel and Rees 1996; Galli et al. 2020; Dada et al. 2022c). The models are expressed thus:

$$EF_{i,t} = f\left(SHA_{i,t}, FD_{i,t}, GDP_{i,t}, URB_{i,t}, TOP_{i,t}\right) \quad (1)$$

$$BIO_{i,t} = f\left(SHA_{i,t}, FD_{i,t}, GDP_{i,t}, URB_{i,t}, TOP_{i,t}\right) \quad (2)$$

Where BIO is biocapacity, EF is ecological footprint, SHA is shadow economy, FD is financial development, GDP is gross domestic product, TOP is trade openness, and URB is urbanization. i connotes the cross-sections; t signifies the periods. The included control variables have been found to influence the environment in the literature (Dada et al. 2022a, b; Akinlo and Dada 2021; Ahmed et al. 2020b; Alola et al. 2019). Equations (1) and (2) are EF and biocapacity models, respectively.

To account for the mediating role of financial development in the link between shadow economy and environmental sustainability, an interactive term of financial development and shadow economy is included in equations (1) and (2).

$$EF_{i,t} = \alpha + \beta SHA_{i,t} + \gamma FD_{i,t} + \delta(SHA * FD)_{i,t} + \zeta GDP_{i,t} + \eta URB_{i,t} + \theta TOP_{i,t} + \varepsilon_{it} \quad (3)$$

$$BIO_{i,t} = \varrho + \sigma SHA_{i,t} + \tau FD_{i,t} + \varphi(SHA * FD)_{i,t} + \phi GDP_{i,t} + \chi URB_{i,t} + \psi TOP_{i,t} + \varepsilon_{it} \quad (4)$$

Where $SHA * FD$ is the interactive term that moderates the impact of shadow economy on the environment.

3.3 Estimation strategy

Five basic estimation techniques are used to achieve the objectives of this study – first, the study tests for the likelihood of cross-sectional dependency (CD) in the panel data. The presence of CD in the panel data can generate biased, inconsistent, and inefficient results if it is not adequately taken care of. CD in panel data arises due to globalization, and financial and economic integration of the world economies, thereby allowing shocks or externalities in one economy to be easily transmitted to other economies irrespective of the distance (Usman et al. 2020; Ajide et al. 2021; Akinlo and Dada 2022; Dada 2022). Thus, it is essential to account for CD in the series to select the best estimation technique (either first- or second-generation). The null hypothesis of the absence of CD in the panel series is tested against the alternative hypothesis of the existence of CD in the series. Four different CD tests – Pesaran (2004); Pesaran et al. (2008); Breusch and Pagan (1980); and Baltagi et al. (2012) are utilized to verify the existence or otherwise of CD in the panel. The model for testing the CD is stated as

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=0}^{N-1}\sum_{j=i+1}^{N-1} \rho ij\right) N(0,1) \quad (5)$$

From Equation (5), ρij is the cross-sections' correlation of errors between i and j. Once CD is established, second-generation estimation techniques are more appropriate than first-generation estimation.

Second, a panel unit root test is conducted on the series. It is imperative to know the stationarity level of the series since CD is likely to exist in the variables. More than one unit root test is used to account for the stationarity properties of the variables, given that no single unit root test is devoid of limitations. Consequently, second-generation unit root tests- cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectionally augmented Im, Pesaran and Shin (CIPS) unit root tests are used to check if the series follows the unit root process or otherwise. The unit root equation is stated as

$$\Delta X_{i,t} = \alpha_i + \alpha_i Y_{i,t-1} + \alpha_i \bar{Y}_{t-1} + \sum_{l=0}^{p} \alpha_{il} \Delta\bar{X}_{t-1} + \sum_{l=0}^{p} \alpha_{il} \Delta X_{i,t-1} + \mu_{it} \quad (6)$$

Where $\bar{X}$ is the average cross-section of each of the series. The test statistic of CIPS is defined as:

$$\widehat{CIPS} = N^{-1}\sum_{i=0}^{n} CADF_i \quad (7)$$

Third, the study tests for panel cointegration in the variables. Since the traditional cointegration tests become inapt in the presence of CD, thus, Westerlund panel cointegration test, which is based on structural-based cointegration and free common-factor restrictions, is used to address CD's issue and heterogeneity. Four statistics are generated from the Westerlund cointegration test. These statistics are groups mean (equation 8) and panel mean (equation 9).

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{\beta_i}}{SE\left(\widehat{\beta_i}\right)} \; and \; G_\alpha = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{\beta_i}}{\beta_i(1)} \quad (8)$$

$$P_\tau = \frac{\widehat{\beta}_i}{SE\left(\widehat{\beta}_i\right)} \; and \; P_a = T\hat{a} \tag{9}$$

Fourth, the long-run estimate of equations (3) and (4) is obtained using the Augmented Mean Group (AMG). The AMG estimation technique provides robust and consistent results in the presence of CD and addresses heterogeneity in the long run cointegration and unknown common dynamic effect among the cross-sectional unit. The AMG technique consists of a two-stage process:

Stage 1

$$\Delta y_{it} = \alpha_i + \beta_i \Delta x_{it} + \tau_i f_i + \sum\nolimits_{t=2}^{T} \delta_i \Delta D_i + \varepsilon_{it} \tag{10}$$

Stage 2

$$\widehat{\beta_{AMG}} = N^{-1} \sum\nolimits_{i=1}^{N} \widehat{\beta}_i \tag{11}$$

Where Δ is the change sign, y and x are the observables series, βi is the country-specific estimators of coefficient, f_i is the unobserved common factor with the heterogeneous factor δi is the coefficient of the time dummy, which is known as a standard dynamic process and $\widehat{\beta_{AMG}}$ is the mean group estimator of AMG. Common Correlated Effect Mean Group (CCEMG) is used for sensitivity analysis. CCEMG is consistent and reliable in the presence of CD and slope heterogeneity. CCEMG considers the heterogeneous slope across individual cross-sections by taking the mean of each country's elasticity. The CCEMG model is expressed as

$$\Delta y_{it} = \alpha_i + \beta_i x_{it} + \psi_i \bar{y}_{it} + \eta_i \bar{x}_{it} + \tau_i w_i + \varepsilon_{it} \tag{12}$$

Where y and x are the series, β_i is the unit slope, α_i is the heterogeneous constant factor of an individual unit, W_i is the unobserved common factor and ε_{it} is the random error term.

$$CCEMG = N^{-1} \sum_{i=1}^{N} \widehat{\eta}_i \tag{13}$$

Where $\widehat{\eta}_i$ is the individual cross-sectional coefficient obtained from equation (13). Lastly, the study employs Dumitrescu and Hurlin's (2012) (DH) causality test to examine the direction of causation among the series in the presence of CD. It is imperative to investigate the causal flow of the series to another in the presence of cointegration among the variables. The DH causality test rests on Wald test statistics. The functional linear model of the DH is stated as:

$$x_{i,t} = \propto_{1i} + \sum_{k=1}^{K} \propto_{1i}^{(k)} x_{i,t-k} + \sum_{k=1}^{K} \beta_{1i}^{(k)} y_{i,t-k} + \mu_{1i,t} \tag{14}$$

$$y_{i,t} = \propto_{2i} + \sum_{k=1}^{K} \propto_{2i}^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_{2i}^{(k)} x_{i,t-k} + \mu_{2i,t} \tag{15}$$

xandy 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 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 (18) and (19).

4. Empirical results

This section begins by testing the validity or otherwise of CD among the variables. Two approaches are used to test the presence of CD- within the function and the series. The results of the CD tests are reported in Tables 4 and 5. The results establish the existence of CD in the function and within the series by discarding the null hypothesis of no CD across the cross-sectional unit at the conventional significance level. These results suggest that nations in Africa are connected, such that any shock or policy in any of these countries spreads quickly to other countries. The validation of CD among the unit necessitates the use of second-generation estimation techniques.

The result of second-generation unit root tests that address the issue of CD is reported in Table 6. The fallouts of CIPS and CADF in Table 6 show that the variables are stationary at first difference using both intercepts and intercept with the trend. Hence, the series follows the stationarity properties, and long-run estimates can be obtained.

Table 4. Cross-sectional dependence (CD) tests (within the function).

	Ecological Footprint Function		Biocapacity Function	
Variables	Statistic	Prob	Statistic	Prob
Pesaran CD	−0.388	0.697	9.524***	0.000
Pesaran scaled CD	73.404***	0.000	161.941***	0.000
Breusch-Pagan LM	2196.446***	0.000	4453.722***	0.000

***, **, * represent 1%, 5% and 10% respectively

Table 5. Cross-sectional dependence (CD) tests (within the series).

Variables	Breusch-Pagan LM	Pesaran Scaled LM	Bias-corrected Scaled	Pesaran CD
	Stats.	Stats.	Stats.	Stats.
EFP	3202.829***	89.776***	89.181***	3.776***
BIO	7050.530 ***	215.948***	215.352***	69.171***
SHA	7457.254***	229.285***	228.688***	82.328***
FD	2934.084 ***	102.336***	101.836***	37.896***
GDP	6816.663 ***	208.279***	207.683***	53.540***
TOP	2430.617 ***	64.455***	63.858***	18.492***
URB	10225.14 ***	320.047***	319.451***	93.915***

***, **, * represent 1%, 5% and 10% respectively

Table 6. Panel unit root test.

	At Level		At First Difference	
Series	Intercept	Intercept and Trend	Intercept	Intercept and Trend
Cross-sectionally augmented Dickey-Fuller (CADF)				
EF	−1.892	−2.034	−5.353***	−5.549***
BIO	−1.857	−1.853	−5.128***	−5.325***
SHA	−1.840	−1.984	−2.801***	−5.258***
FD	−1.043	−2.077	−5.610***	−5.802***
GDP	−1.553	−2.010	−4.320***	−4.579***
TOP	−1.990	−2.276	−5.108***	−5.185***
URB	−1.876	−2.412	−2.068*	−2.871**
Cross-sectionally augmented Im, Pesaran, and Shin (CIPS)				
EF	−1.939	2.458	−4.356***	−4.641***
BIO	−2.038	−1.973	−3.919***	−3.947***
SHA	−1.793	−1.728	−3.730***	−3.850***
FD	−1.756	−2.038	−4.199***	−4.495***
GDP	−1.460	−2.085	−3.368***	−3.634***
TOP	−1.951	−2.329	−3.710***	−3.803***
URB	−1.783	−1.963	−2.454	−2.310***

***, **, * represent 1%, 5% and 10% respectively

Table 7. Panel cointegration test (Westerlund).

Statistics	Value	Z-value	P-value
Ecological Footprint Function			
Gt	−2.115**	−2.022	0.022
Ga	−3.851	1.839	0.967
Pt	−11.774**	−1.759	0.039
Pa	−4.011*	−1.574	0.058
Biocapacity Function			
Gt	−1.665*	−1.379	0.084
Ga	5.674	0.140	0.556
Pt	−75.77**	−2.106	0.018
Pa	−2.697	−0.207	0.418

***, **, * represent 1%, 5% and 10% respectively

The second-generation estimation technique is used to evaluate the level of cointegration among the series. The Westerlund (2007) panel cointegration test presented in Table 7 shows cointegration among the series in both functions. Specifically, all the test statistics rejected the assumption of no cointegration among the variables except the Ga statistic in the EF function. Furthermore, in the biocapacity function, Gt and Pt statistics establish the presence of cointegration by rejecting the null hypothesis. In summary, the Westerlund cointegration test verifies long-run cointegration in both functions; hence there is a tendency for at least one direction of causation among the series (Khan et al. 2019; Usman et al. 2020).

To investigate the long-run estimates of the shadow economy, financial development, and other variables on EF, this study uses AMG. The results for the EF function are reported in Table 8. Table 8 shows that four factors (shadow economy, financial development, economic growth, and urbanization) spur EF in Africa. However, interactive terms of shadow economy, financial development, and trade openness significantly and negatively impact EF in Africa in the long run. Specifically, the AMG results of the EF function are as follows. A 1% increase in the shadow economy will increase EF by 0.011%. This statistic suggests that the shadow economy deteriorates the environment in African countries. This validates hypothesis 1 of the study. The positive sign indicates that activities in the underground economy have not been tailored towards a sustainable environment through environmentally friendly technologies and equipment. The Shadow economy employs a more significant percentage of the working population in Africa, with many of them using inefficient and outdated technologies, worsening environmental sustainability (Cervero 2000; Dada et al. 2021a). The outcome of this empiric is in support of previous literature like Biswas et al. (2012), Swain et al. (2020), and Dada et al. (2021a), 2021b) that examine the effect of shadow economy on environmental degradation/pollution. Also, Köksal et al. (2020) and Baloch et al. (2021) find that shadow economy worsens EF. In the long run, a 1% increase in financial development increases the EF in the region by 0.6%. This rejects the second hypothesis of the study. It reveals that financial development in Africa is not channeled towards eco-friendly activities. Furthermore, financial development has not been directed to the agricultural sector, green and renewable energy. This outcome supports the research output of Nathaniel et al. (2019) and Dada et al. (2022b) but is at variance with the submissions of Klobodu (2018), Rjoub et al. (2021), and Shobande and Ogbeifun (2022).

Table 8. Result of long-run estimate of ecological Footprint.

	AMG		CCEMG	
Variable	Coefficient	P-value	Coefficient	P-value
SHA	0.011**	0.045	0.110**	0.025
FD	0.633*	0.080	0.869	0.486
SHA*FD	−0.003**	0.035	−0.107**	0.047
GDP	0.0003*	0.075	0.0002**	0.028
TOP	−0.003***	0.003	−0.001	0.215
URB	0.008*	0.083	0.058*	0.063
Constant	1.305	0.281	3.102**	0.019
RMSE	0.113		0.13	

***, **, * represent 1%, 5% and 10% respectively

The negative sign of the moderating effect of financial development in the shadow economy EF relationship reveals that a 1% increase in the interactive term of financial development and shadow economy reduces EF by 0.003%. This result shows that the financial sector is central to the activities of the informal economy. A solid or well-developed financial system will provide financial services such as credit facilities, at low-interest rates, to those in the shadow economy. These credit facilities could then be used to buy modern and energy-efficient technologies. Also, access to funds can increase the level of research and development in the shadow economy, making the economy better off in the long run. The economic implication suggests that financial development is essential for environmental sustainability. The third hypothesis of the moderating effect of financial development in the link between shadow economy and environmental sustainability is also validated in this study.

The official economy captured by economic growth has a significant positive long-run effect on EF. A 1% rise in economic growth will increase EF by 0.003% in the long run. In terms of size, the positive impact of the shadow economy is more felt in the environment than in the official economy – a rise in economic growth results in demand for more energy. In contrast, these demands are usually met using non-renewable energy such as fossil fuel, which is one of the factors responsible for environmental degradation. Also, an increase in economic growth comes with an increase in the production and consumption of waste, which negatively affects the environment. This study is in line with existing studies such as Uddin et al. (2017), Zafar et al. (2019), Ibrahiem and Hanafy (2020), and Dada et al. (2022a).

Similarly, urbanization increases EF in Africa. This suggests that present urbanization conditions do not support environmental sustainability. On the other hand, a 1% increase in trade openness decreases EF by 0.003% in the long run. This suggests that trade openness improves the environmental quality in Africa. Furthermore, the African countries benefit from trade openness's scale, composition, and technique effects. International trade opens the door for the transfer of environmentally friendly technologies and allows the subcontracting of production to other countries, which can lessen the EF. This outcome is similar to the conclusion of Destek et al. (2018) and Fakher (2019), Ahmad et al. (2020), and Dada et al. (2021b) but contrary to the study of Dada and Akinlo (2021) that used CO2 to measure environmental quality. The sensitivity analysis of the AMG estimates for the long-run EF model is achieved using the CCEMG. The output of the CCEMG estimate also corroborates the long-run result of the AMG.

Where SHA*FD is the interactive term for shadow economy and financial development

Apart from the EF model, this study also finds the long-run estimates for biocapacity function in 30 African countries. The long run of the biocapacity function is presented in Table 9. The outcome suggests that the shadow economy has a significant and negative effect on biocapacity, depicting that a 1% increase in the shadow economy reduces biocapacity by 0.049% in the long run. Besides, these findings corroborate the result obtained from the EF function, which shows that the shadow economy hurts the environment. These results suggest that shadow economy is one of Africa's essential determinants of environmental sustainability. The interactive term of shadow economy and financial development significantly but negatively affect biocapacity. In detail, a 1% increase in the interactive term reduces biocapacity by 0.25%. This suggests that the weak financial development coupled with the rising level of shadow economy worsens the environmental quality in the long run. The weak financial development has not been able to channel credit to cleaner and renewable energies, which can increase biocapacity. Furthermore, the fragile financial development is further demonstrated by the insignificant effect of financial development on biocapacity. In addition, the finding shows that economic growth has a negative but significant impact on biocapacity in the long run. More specifically, a 1% increase in economic growth reduces biocapacity by 0.0004%. This finding is in line with the work of Marti and Puertas (2020).

Table 9. Result of long-run estimate of biocapacity.

	AMG		CCEMG	
Variable	Coefficient	P-value	Coefficient	P-value
SHA	−0.049*	0.082	−0.007*	0.087
FD	0.547	0.167	0.796	0.754
SHA*FD	−0.249*	0.070	−0.036**	0.042
GDP	−0.0004**	0.030	−0.0001***	0.002
TOP	0.001**	0.046	−0.0001	0.931
URB	−0.145***	0.002	−0.023**	0.027
Constant	9.226*	0.047	1.299	0.623
RMSE	0.081		0.06	

****, **, * represent 1%, 5% and 10% respectively*

Also, from Table 9, the effect of trade openness on biocapacity is positive and statistically significant. A 1% increase in the degree of trade openness increases biocapacity by 0.001% in the long run. This result reveals that trade openness boosts environmental quality in the region. Thus, policymakers in the region should reflect the benefit of trade openness on the environment in designing their trade policy. Lastly, it is observed that urbanization has a significant negative effect on biocapacity. A 1% increase in urbanization will cause biocapacity to decrease by 0.145% in the long run.

In summary, these results suggest that shadow economy, financial development, economic growth, and urbanization reduce biocapacity in Africa, while trade openness improves environmental quality. For a robustness check of the biocapacity function estimates, the CCEMG estimator is used. The results of the CCEMG are highly unswerving from the results obtained from AMG estimates.

Dumitrescu and Hurlin's (DH) panel causality test that addresses the issues of CD and slope heterogeneity across cross-sections is used to examine the direction of causation among the series, which is vital for policy prescription. Another benefit of this approach is that the test can be used for balanced and unbalanced panels; for short- and long- periods. Hence, the DH causality test is applied to the EF and biocapacity functions. The causality results of the two functions are presented in Table 10. Outcomes of the DH causality test suggest a unidirectional relationship from a shadow economy to EF, from EF to trade openness, from EF to urbanization, from biocapacity to shadow economy, from financial development to biocapacity,

Table 10. Dumitrescu And Hurlin (2012) granger non-causality test results (ecological footprint and biocapacity functions).

	W-stat	Z bar stat	Prob. Value	Remark
EF ≠> SHA	3.729	4.735	0.169	Unidirectional
SHA ≠> EF	4.551**	6.986	0.027	causality
EF ≠> FD	5.311**	7.590	0.014	Bidirectional
FD ≠> EF	4.859**	5.353	0.023	causality
EF ≠> GDP	5.299**	9.035	0.010	Bidirectional
GDP ≠> EF	3.975**	5.408	0.047	causality
EF ≠> TOP	3.161	3.179	0.234	Unidirectional
TOP ≠> EF	4.028**	5.555	0.042	causality
EF ≠> URB	7.552***	15.205	0.001	Unidirectional
URB ≠> EF	3.761	4.822	0.102	causality
BIO≠>SHA	2.643	1.761	0.550	Unidirectional
SHA≠>BIO	4.988*	8.183	0.051	causality
BIO ≠>FD	3.451*	3.974	0.078	Unidirectional
FD≠>BIO	4.251	6.166	4.474	causality
BIO≠>GDP	4.627**	7.194	0.020	Bidirectional
GDP≠>BIO	7.073***	13.895	0.002	causality
BIO≠>TOP	4.814**	5.230	0.034	Bidirectional
TOP≠>BIO	4.230*	6.107	0.076	causality
BIO ≠>URB	7.615***	15.379	0.001	Bidirectional
URB ≠>BIO	4.265*	6.204	0.082	causality
SHA ≠> FD	4.326**	6.370	0.036	Bidirectional
FD ≠> SHA	4.454*	6.722	0.074	causality
SHA ≠> GDP	4.506*	6.864	0.074	Bidirectional
GDP ≠> SHA	5.855*	7.342	0.095	causality
SHA≠>TOP	3.334	3.653	0.228	Unidirectional
TOP≠>SHA	4.410*	6.600	0.062	causality
SHA≠>URB	5.996	10.944	0.181	No causal
URB≠>SHA	2.725	1.985	1.108	relationship
FD≠>GDP	7.175***	14.173	0.000	Bidirectional
GDP≠>FD	5.490*	0.081	0.115	causality
FD≠>TOP	3.039	2.846	0.329	Unidirectional
TOP≠>FD	3.840*	5.039	0.068	causality
FD≠>URB	6.315*	11.818	0.060	Unidirectional
URB≠>FD	2.460	1.261	0.708	causality
TOP≠>URB	5.368	9.224	0.120	No causal
URB ≠>TOP	3.137	3.114	0.279	relationship

The p-values are computed using 1000 bootstrap replications. Where *, ** and *** indicates 10%, 5% and 1% level of significant respectively

from shadow economy to trade openness, from financial development to trade openness, and from urbanization to financial development in 30 African countries. These results indicate that the shadow economy drives the EF, while the biocapacity influences activities in the informal economy.

In addition, concerning the bidirectional causation, the DH test statistics show the two-way causal relations between EF and financial development, EF and economic growth, biocapacity and economic growth, biocapacity and trade openness, biocapacity and urbanization, shadow economy and financial development, shadow economy and economic growth, and financial development and economic growth. The bidirectional relationship, especially financial development with the EF, shadow economy, and economic growth, strongly suggests that financial development intensifies these variables, which have a feedback effect on financial development. Furthermore, the bidirectional causality of economic growth, EF, and biocapacity imply that economic growth is one of Africa's crucial factors responsible for environmental quality. Moreover, any economic activity can put pressure on the environment. Thus, policymakers in the region need to target clean production and consumption. The schematic representation of the DH causality test is reported in Figure 3.

5. Conclusion and policy

This empiric examines the role of shadow economy and financial development in addition to economic growth, trade openness, and urbanization on environmental sustainability in Africa. Specifically, the study investigates the direct effect of shadow economy and financial development and the indirect impact of the interactive term on EF and biocapacity of 30 African countries between 1991 and 2017 using various estimation procedures such as AMG CCEMG, and DH panel causality test.

The findings from the EF function reveal that shadow economy, financial development, economic growth, and urbanization positively affect EF, contributing significantly to an increase in EF. However, the interactive term of the shadow economy, financial development, and trade openness reduce EF significantly, thus contributing to environmental sustainability. Results from the biocapacity function suggest that the shadow economy and its interaction with financial development, economic growth, and urbanization reduce biocapacity. At the same time, trade openness increases the biocapacity of the 30 African countries examined. The findings indicate that shadow economy, financial development, economic growth, and urbanization reduce the environmental quality while trade openness improves the environmental quality in the long run. Furthermore, the DH causality test established the feedback relationship between EF and shadow economy, biocapacity and shadow economy, biocapacity, and financial development. Similarly, financial development accelerates EF and the shadow economy in the long run. In addition, unidirectional causation is found from economic growth to EF, biocapacity, and financial development. Besides, a two-way causal relationship exists between trade openness and the shadow economy, trade openness and financial development, and financial development and urbanization.

This study offers some important policy implications in light of the obtained results. First, activities in the shadow economy need to be monitored and regulated to reduce their harmful effect on the environment. Since integrating shadow economy into the official economy will further compound the menace of environmental degradation; thus environmental laws and regulations should be strictly implemented in countries where there is, while it should be formulated in countries where there is none. Both the formal (official) and informal (shadow) economies should move towards green production and consumption by adopting renewable energies and environmentally friendly

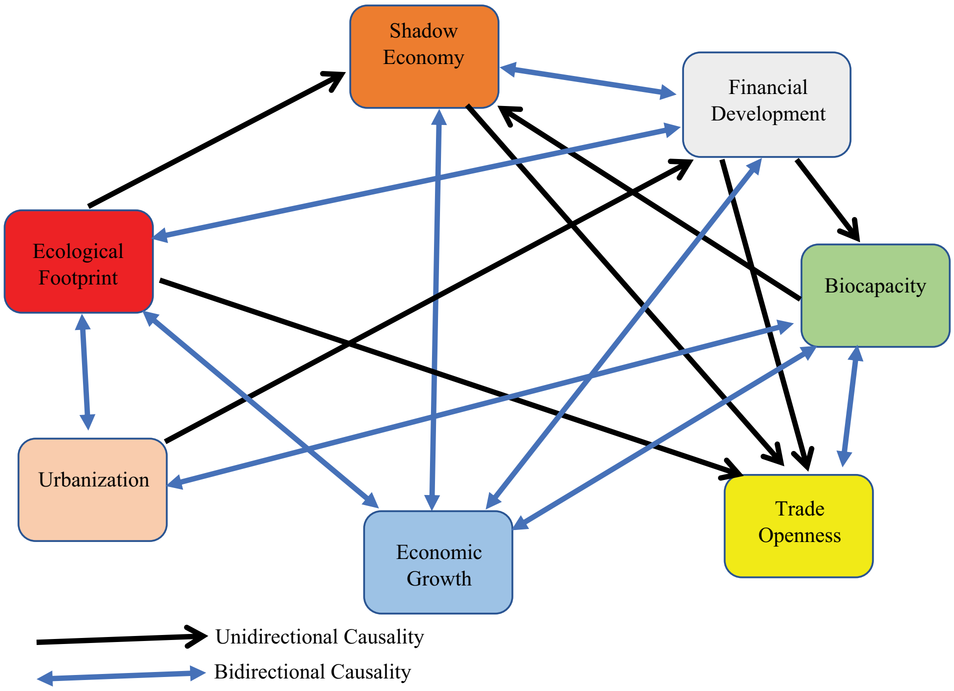

Figure 3. Flow of causal relation.

technologies. Traditional methods of production should be replaced by modern techniques, which are eco-friendly and consume less energy. This transition can be achieved through the help of the financial sector and government. The financial industry should target business entity that is ready to embark on cleaner production by providing credit facilities at a low-interest rate. Apart from giving the needed funds, the financial sector should also monitor these firms to ensure that the green environment funds are not diverted. In addition, the financial sector should be guided by strict financial rules and tailored towards sustainable finance to reduce excessive finance of non-environmentally friendly capital goods.

Research and development centers in the area of the sustainable environment should be established in each country and fully supported by the financial sector. This center(s) will help decarbonize the environment by providing advanced and efficient ways of production and consumption. Furthermore, the government should formulate laws that will make it compulsory for firms to set a certain proportion of their profit for research and development of green and renewable energies since there is a conflict between the government's growth target and the sustainable environment. These funds from both public and private sectors could then be used in environmental clean-up. The government should also embark on ecological awareness and be fully supported by the financial industry to increase the public awareness program about the damaging effect of environmental degradation. In addition, since trade openness benefits the region's ecological sustainability, policymakers should ensure that only green and environmentally friendly goods are allowed. At the same time, strict penalties should be enforced on erring importers of non-environmentally friendly products.

One limitation of this study lies in its scope and the use of African data only to scrutinize the role of the shadow economy and financial development in environmental sustainability. Future studies can expand this empirical exercise by replicating the same research in other developing countries like Latin America and Asia with a high level of shadow economy. Some environmental quality factors are not included due to data inaccessibility or the nature of the dataset. Future research can include social, institutional, and political variables influencing the link between shadow economy, financial development, and environmental quality.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Adams S, Klobodu EK, Apio A. 2018. Renewable and non-renewable energy, regime type and economic growth. Renewable Energy. 125:755–67.

Adekunle IA. 2021. On the search for environmental sustainability in Africa: the role of governance. Environ Sci Pollut Res. 28(12):14607–14620. doi:10.1007/s11356-020-11432-5.

Ahmad M, Jiang P, Majeed A, Umar M, Khan Z, Muhammad S. 2020. The dynamic impact on natural resources, technological innovations and economic growth on ecological

footprint: an advanced panel data estimation. Resour Policy. 69:101817. doi:10.1016/j.resourpol.2020.101817.
Ahmed Z, Zafar MW, Ali S. 2020b. Linking urbanization, human capital, and the ecological footprint in G7 countries: an empirical analysis. Sustain. Cities Soc. 55:102064. doi:10.1016/j.scs.2020.102064.
Ajide FM. 2021. Shadow economy in Africa: how relevant is financial inclusion? J. Financial Regul. Compliance. 29 (3):297–316. doi:10.1108/JFRC-10-2020-0095.
Ajide, FM. 2022. Economic complexity and entrepreneurship: insights from Africa. International Journal of Development Issues. DOI 10.1108/IJDI-03-2022-0047
Ajide FM, Dada JT. 2022. The impact of ICT on shadow economy in West Africa. Int Soc Sci J. doi:10.1111/issj.12337
Ajide FM, Dada JT, Olowookere JK. 2022. Shadow economy and foreign direct investment in Nigerian manufacturing industry. Int J Econ. Bus. Res. 23(2):156. doi:10.1504/IJEBR.2021.10035378.
Ajide FM, Osinubi T, Dada JT. 2021. Economic globalization, entrepreneurship, and inclusive growth in Africa. J. Econ. Integr. 36(4):689–717. doi:10.11130/jei.2021.36.4.689.
Akinlo T, Dada JT. 2021. The moderating effect of foreign direct investment on environmental degradation-poverty reduction nexus: evidence from sub-Sharan African Countries, Environment. Dev. Sustain. 23 (11):15764–15784. doi:10.1007/s10668-021-01315-1.
Akinlo T, Dada JT. 2022. Information technology, real sector and economic growth in sub- Saharan Africa: a cross-sectional dependence approach. Qual Quant. doi:10.1007/s11135-021-01308-2
Al-Mulali U, Sab CN 2012. The impact of energy consumption and CO2 emission on the economic growth and financial development in the Sub Saharan African countries. Energy. 39(1):180–186. doi:10.1016/j.energy.2012.01.032.
Alola AA, Bekun FV, Sarkodie SA. 2019. Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci Total Environ. 685:702–709. doi:10.1016/j.scitotenv.2019.05.139
Aluko OA, Ibrahim M. 2020. On the macroeconomic determinants of financial institutions development in sub-Saharan Africa. International Review of Economics. 67(1):69–85.
Alvarado R, Tillaguango B, Murshed M, Ochoa-Moreno S, Rehman A, Isrik C, Alvarodo-Espejo J. 2022. Impact of the informal economy on the ecological footprint: the role of urban concentration and globalization. Econ Anal Policy. 75:750–767. doi:10.1016/j.eap.2022.07.001
Baloch A, Shah SZ, Rasheed S, Rasheed B. 2021. The impact of shadow economy on environmental degradation: empirical evidence from Pakistan. Geo J. doi:10.1007/s10708-020-10354-6
Baloch MA, Zhang J, Iqbal K, Iqbal Z. 2019. The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. Environmental Science and Pollution Research. 26(6):6199–6208. 10.1007/s11356-018-3992-9
Baltagi BH, Feng Q, Kao C. 2012. A Lagrange multiplier test for cross-sectional dependence in a fixed effects panel data model. J Econom. 170(1):164–177. doi:10.1016/j.jeconom.2012.04.004.
Bello A, Abimbola O. 2010. Does the level of economic growth influence environmental quality in Nigeria: a test of environmental Kuznets curve (EKC) hypothesis. Pak J Life Soc Sci. 7(4):325–329. doi:10.3923/pjssci.2010.325.329.
Biswas AK, Farzanegan MR, Thum M. 2012. Pollution, shadow economy and corruption: theory and evidence. Ecol Econ. 75:114–125. doi:10.1016/j.ecolecon.2012.01.007
Blackburn K, Bose N, Capasso S 2012. Tax evasion, the underground economy and financial development. Journal of Economic Behavior & Organization. 83(2):243–253. doi:10.1016/j.jebo.2012.05.019.
Breusch TS, Pagan AR. 1980. The Lagrange multiplier test and its applications to model specification in econometrics. Rev Econ Stud. 47(1):239–253. doi:10.2307/2297111.
Capasso S, Jappelli T. 2013. Financial development and the underground economy. J Dev Econ. 101:167–178. doi:10.1016/j.jdeveco.2012.10.005.
Cervero R. 2000. Informal transport in the developing world. UN-HABITAT.
Charfeddine L, Mrabet Z. 2017. The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries. Renewable and Sustainable Energy Reviews. 76:138–154. doi:10.1016/j.rser.2017.03.031.
Chen H, Hao Y, Li J, Song X. 2018. The impact of environmental regulation, shadow economy, and corruption on environmental quality: theory and empirical evidence from China. J Clean Prod. doi:10.1016/j.jclepro.2018.05.206
Chu LK, Hoang DP. 2022. The shadow economy-environmental quality nexus in OECD countries: empirical evidence from panel quantile regression. Environ Sci Pollut Res. doi:10.1007/s11356-022-20410-y
Dada JT. 2022. On the asymmetric effect of exchange rate on growth: evidence from Africa. Econ J Emerg. Mark. 14 (1):15–28. doi:10.20885/ejem.vol14.iss1.art2.
Dada JT, Adeiza A, Noor AI, Arnaut M. 2022b. Financial development and ecological footprint in Malaysia: the role of institutions. Manag. Environ. Qual 33 (4):913–937. doi:10.1108/MEQ-10-2021-0251.
Dada JT, Adeiza A, Noor AI, Marina A. 2022a. Investigating the link between economic growth, financial development, urbanization, natural resources, human capital, trade openness and ecological footprint: evidence from Nigeria. J Bioeconomics. 24(2):153–179. doi:10.1007/s10818-021-09323-x.
Dada JT, Ajide FM. 2021. The moderating role of institutional quality in shadow economy- pollution nexus in Nigeria. Manag. Environ. Qual.: Int J. 32(3):506–523. doi:10.1108/MEQ-10-2020-0238.
Dada JT, Ajide FM, Adeiza A. 2021b. Shadow economy and environmental pollution in West African countries: the role of institutions. Glob. J. Emerg. Mark. Econ. 097491012110490. doi:10.1177/09749101211049038
Dada JT, Ajide FM, Sharimakin A. 2021a. Shadow economy, institutions and environmental pollution: insights from Africa. World Rev. Sci. Technol. Sustain. Dev 18 (2):153–171. doi:10.1108/WJSTSD-12-2020-0105.
Dada JT, Akinlo T. 2021. Foreign direct investment and poverty reduction in sub-Saharan Africa: does environmental degradation matter? Future Business J. 7(21). doi:10.1186/s43093-021-00068-7.
Dada JT, Olaniyi CO, Ajide FM, Adeiza A, Marina A. 2022c. Informal economy and ecological footprint: the Case of Africa. Environ Sci Pollut Res. doi:10.1007/s11356-022-20919-2
Dar JA, Asif M 2017. Is financial development good for carbon mitigation in India? A regime shift-based cointegration analysis. Carbon Management. 8(5–6):435–443. doi:10.1080/17583004.2017.1396841.

Dar JA, Asif M. 2018. Does financial development improve environmental quality in Turkey? An application of endogenous structural breaks based cointegration approach. Manag. Environ. Qual.: Int J. 29(2):368–384. doi:10.1108/MEQ-02-2017-0021.

Denny RCH, Marquart-Pyatt S. 2018. Environmental sustainability in Africa. What drives the Ecological Footprint over time? Sociol. Dev 7(1):119–144. doi:10.1525/sod.2018.4.1.119.

Destek MA, Ulucak R, Dogan E. 2018. Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint. Environ Sci Pollut Res. 25 (29):29387–29396. doi:10.1007/s11356-018-2911-4.

Dumitrescu EI, Hurlin C. 2012. Testing for granger non-causality in heterogeneous panels. Econ Model. 29 (4):1450–1460. doi:10.1016/j.econmod.2012.02.014.

Elgin C, Mazhar U. 2013. Environmental regulation, pollution and the informal economy. SBP Res. Bull. 9:62–81.

Elgin C, Oztunali O. 2014. Institutions, informal economy, and economic development. Emerging Markets Finance and Trade. 50(4):145–62. 10.2753/REE1540-496X500409

Eren MB, Katircioglu S, Gokmenoglu KK. 2022. The moderating role of informal economy on financial development induced EKC hypothesis in Turkey. Energy Environ. 1–24. doi:10.1177/0958305X211070775

Fakher HA. 2019. Investigating the determinant factors of environmental quality (based on ecological carbon footprint index. Environ Sci Pollut Res. 26(10):10276–10291. doi:10.1007/s11356-019-04452-3.

Frankel JA, Romer D. 1999. Does trade cause growth? Am Econ Rev 89(3):279–399

Frankel J, Rose A. 2002. An estimate of the effect of common currencies on trade and income. The quarterly journal of economics. 117(2):437–66.

Galli A, Iha K, Pires SM, Mancini MS, Alves A, Zokai G, Wackernagel M, Murthy A, Wackernagel M. 2020. Assessing the ecological footprint and biocapacity of Portuguese cities: critical results for environmental awareness and local management. Cities. 96:102442. doi:10.1016/j.cities.2019.102442.

Godil DI, Sharif A, Agha H, Jermsittiparsert K 2020. The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: new insights from QARDL approach. Environmental Science and Pollution Research. 27 (19):24190–24200. doi:10.1007/s11356-020-08619-1.

Godil DI, Sharif A, Rafique S, Jermsittiparsert K 2020. The asymmetric effect of tourism, financial development, and globalization on ecological footprint in Turkey. Environmental Science and Pollution Research. 27 (32):40109–40120. doi:10.1007/s11356-020-09937-0.

Grossman GM, Krueger AB 1991. Environmental impacts of a North American free trade agreement. National Bureau of Economic Research Working Paper Series No. 3914, National Bureau of Economic Research, Cambridge (MA), 1–57, doi: 10.3386/w3914.

Huynh, CM 2020. Shadow economy and air pollution in developing Asia: what is the role of fiscal policy?. Environmental Economics and Policy Studies, 22(3), 357–381

Ibrahiem DM, Hanafy SA. 2020. Dynamic linkages amongst EFPs, fossil fuel energy consumption and globalization: an empirical analysis. Manag. Environ. Qual.: Int J. 31 (6):1549–1568. doi:10.1108/MEQ-02-2020-0029.

Ihrig J, Moe KS. 2004. Lurking in the shadows: the informal sector and government policy. Journal of Development Economics. 73(2):541–57.

Imamoglu H. 2018. Is the informal economic activity a determinant of environmental quality?. Environmental Science and Pollution Research. 25(29):29078–88.

Jalil A, Feridun M. 2011. The impact of growth, energy and financial development on the environment in China: a cointegration analysis. Energy Economics. 33 (2):284–291. doi:10.1016/j.eneco.2010.10.003.

Jolley D, Douglas KM 2014. The effects of anti-vaccine conspiracy theories on vaccination intentions. PloS one. 9(2): e89177.

Katircioglu ST. 2014. International tourism, energy consumption, and environmental pollution: The case of Turkey. Renewable and Sustainable Energy Reviews. 36:180–187. doi:10.1016/j.rser.2014.04.058.

Khan MTI, Yaseen MR, Ali Q. 2019. Nexus between financial development, tourism, renewable energy, and greenhouse gas emission in high-income countries: a continent-wise analysis. Energy Economics. 83:293–310. doi:10.1016/j.eneco.2019.07.018

Köksal C, Işik M, Katircioğlu S. 2020. The role of shadow economies in ecological footprint quality: empirical evidence from Turkey. Environ Sci Pollut Res. 27 (12):13457–13466. doi:10.1007/s11356-020-07956-5.

Marti L, Puertas R. 2020. Analysis of the efficiency of African countries through their ecological footprint and biocapacity. Sci. Total Environ. 722:137504. doi:10.1016/j.scitotenv.2020.137504.

Medina L, Schneider F. 2019. Shedding light on the shadow economy: A global database and the interaction with the official one. Available at SSRN 3502028.

Nathaniel S, Nwodo O, Adediran A, Sharma G, Shah M, Adeleye N. 2019. Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded. Environ Sci Pollut. 26(26):27168–27179. *Control* Ser. 1e12. doi:10.1007/s11356-019-05924-2.

Neumayer E. 2002. Do democracies exhibit stronger international environmental commitment? A cross-country analysis. Journal of peace research. 39(2):139–64.

Nkengfack H, Kaffo Fotio H, Totouom A. 2020. How does the shadow economy affect environmental quality in Sub-Saharan Africa? Evidence from heterogeneous panel estimations. Journal of the Knowledge Economy. 2(4):1635–51.

Pang J, Li N, Mu H, Zhang M. 2020. Empirical analysis of the interplay between shadow economy and pollution: with panel data across the provinces of China. Journal of Cleaner Production.

Pesaran MH 2004. General diagnostic tests for cross section dependence in panels. CESifo Working Paper Series No. 1229; IZA Discussion Paper No. 1240. Available at SSRN:http://ssrn.com/abstract=572504

Pesaran MH, Ullah A, Yamagata T. 2008. A bias-adjusted LM test of error cross-section Independence. Econom J. 11(1):105–127. doi:10.1111/j.1368-423X.2007.00227.x.

Rjoub H, Odugbesan JA, Adebayo TS, Wong WK. 2021. Sustainability of the moderating Role of financial development in the determinants of environmental degradation: evidence from Turkey. Sustainability. 13(4):1844. doi:10.3390/su13041844.

Sehrawat M, Giri AK, Mohapatra G. 2015. The impact of financial development, economic growth and energy consumption on environmental degradation: Evidence from India. Management of Environmental Quality: An International Journal. 26(5):666–682. doi:10.1108/MEQ-05-2014-0063.

Şenhaz Z, Katircioglu S, Katircioglu S 2021 Dynamic effects of shadow economy and environmental pollution on the energy stock prices: empirical evidence from OECD countries. Environmental Science and Pollution Research .28 (7):8520–8529. 10.1007/s11356-020-11226-9
Shahbaz M, Sakiru AS, Haider M, Mohamed A. 2013. Does financial development reduce CO2 emissions in Malaysian economy? A time series analysis. Econ Model. 35:145–152. doi:10.1016/j.econmod.2013.06.037
Shen Y, Su ZW, Malik MY, Umar M, Khan Z, Khan M. 2021. Does green investment, financial development and natural resources rent limit carbon emissions? A provincial panel analysis of China. Sci Total Environ. 755:142538. doi:10.1016/j.scitotenv.2020.142538.
Shobande OA, Ogbeifun L. 2022. The criticality of financial development and energy consumption for environmental sustainability in OECD countries: evidence from dynamic panel analysis. Int. J. Sustain. Dev World Ecol. 29 (2):153–163. doi:10.1080/13504509.2021.1934179.
Shujah-ur-Rahman S.U.R., Chen S, Saud, S., Bano, S., Haseeb, A.et al 2019. The nexus between financial development, globalization, and environmental degradation: Fresh evidence from Central and Eastern European Countries. Environmental Science and Pollution Research 26:24733–24247 24 10.1007/s11356-019-05714-w
Straub S 2005. Informal sector: The credit market channel. J Dev Econ. 78(2):299–321. doi:10.1016/j.jdeveco.2004.09.005.
Svirydzenka K 2016. Introducing a new broad-based index of financial development. IMF Working Paper WP/16/5
Swain RB, Kambhampati US, Karimu A. 2020. Regulation, governance and the role of the informal sector in influencing environmental quality. Ecol. Econ. 173:106649. doi:10.1016/j.ecolecon.2020.106649.
Tamazian A, Chousa JP, Vadlamannati KC. 2009. Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries. Energy Policy. 37(1):246–253. doi:10.1016/j.enpol.2008.08.025.
Uddin GA, Salahuddin M, Alam K, Gow J. 2017. EFP and real income: panel data evidence from the 27 highest emitting countries. Ecol Indic. 77:166–175. doi:10.1016/j.ecolind.2017.01.003
UNDP. 2014. Sustaining human progress: reducing vulnerabilities and building resilience (2014 human development report). New York: United Nations Development Programme. Retrieved 2016 Sept 20http://hdr.undp.org/sites/default/files/hdr14-report-en-1.pdf).
Usman M, Hammar N. 2021. Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific economic cooperation countries. Environ Sci Pollut Res. 28(12):15519–15536. doi:10.1007/s11356-020-11640-z.
Usman M, Kousar R, Makhdum MSA. 2020. The role of financial development, tourism, and energy utilization in environmental deficit: evidence from 20 highest emitting economies. Environ Sci Pollut Res. 27(34):42980–42995. doi:10.1007/s11356-020-10197-1.
Vo XV, Zaman K. 2020. Relationship between energy demand, financial development, and carbon emissions in a panel of 101 countries: “go the extra mile” for sustainable development. Environ Sci Pollution Res. 27 (18):23356–23363. doi:10.1007/s11356-020-08933-8.
Wackernagel M, Rees W. 1996. Our ecological footprint. Reducing human impact on the earth. British Columbia: New Society Publishers, Gabriola Island.
Westerlund J. 2007. Testing for error correction in panel data. Oxf Bull Econ Stat. 69(6):709–748. doi:10.1111/j.1468-0084.2007.00477.x.
World Bank. 2015. World development report 2015. Mind, society, and behavior. Washington (DC): World Bank. Retrieved 2021 Sept 20 (http://www.worldbank.org/en/publication/wdr2015).
Zafar MW, Zaidi SAH, Khan NR, Mirza FM, Hou F, Kirmani SAA. 2019. The Impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States. Resour Policy. 63:101428. doi:10.1016/j.resourpol.2019.101428.
Zhang YJ. 2011. The impact of financial development on carbon emissions: an empirical analysis in China. Energy Policy. 39(4):2197–2203. doi:10.1016/j.enpol.2011.02.026.

Appendix A

List of countries

Algeria, Angola, Botswana, Burkina Faso, Cameroon, Congo Democratic, Cote d'Ivoire, 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.