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Environmental degradation in emerging-market economies of Africa: evaluating impacts of human capital development, international trade, renewable energy consumption, and urbanization

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This research explores the impact of human capital development, international trade, financial development, renewable energy consumption, and urbanization on environmental degradation in emerging-market economies in Africa. The study adopts a quantitative approach using panel data from 8 African countries between 1991 and 2021. The study adopted the method of Mean Group Dynamic Least Squares and Method of moments quantile regression methods to estimate the empirical relationship between the variables of interest. The findings indicate that urbanization, energy consumption, economic growth, and human capital development have significant and positive effects on environmental degradation, while financial development, renewable energy consumption, manufacturing activities, and international trade have a significant negative effect on environmental degradation. The study concludes that policymakers in emerging-market economies in Africa need to promote financial development and renewable energy consumption while simultaneously addressing the negative impacts of urbanization on the environment to achieve sustainable economic growth.

KEYWORDS

human capital development, urbanization, emerging market economies, environmental degradation, manufacturing activities

Abbreviations: GDP, Gross Domestic Product; UB, Urbanization; ENC, Energy Consumption; CO2, Carbon Dioxide; HCD, Human Capital; RE, Renewable Energy; TOP, Trade Openness; NRE, Nonrenewable Energy; FD, Financial Development; FMOLS, Fully Modified Ordinary Least Squares; GMM, Generalized Method of Moment; DOLS, Dynamic Ordinary Least Squares; PMG-ARDL, Pooled Mean Group–Autoregressive Distributed Lag; EKC, Environmental Kuznets Curve; MVA, Manufacturing Value-Added; VIF, Variance Inflation Factor; MMQR, Method of Moments Quantile Regression; DOLSMG, The Mean Group Dynamic Least Squares; IEA, International Energy Agency.

1 Introduction

Emerging-market economies in Africa have experienced significant economic growth (GDP) recently, resulting in increased financial development, urbanization (UB), and demand for energy. However, this has also contributed to an increase in pollution and environmental degradation and deterioration. This study aims to analyze the impact of financial development, energy consumption (ENC), and UB on environmental deterioration in these economies. It will examine how these factors affect the environment and explore potential policies and strategies to mitigate the adverse impact of economic growth on the environment. The findings of this study could have significance for stakeholders and policymakers working to seek a balance between economic-growth and environmental sustainability in developing market economies in Africa.

The current levels of CO2 emissions are a significant environmental issue since they contribute to ecological imbalances such as global warming, with all related impact from rising sea levels, ice caps melting and biodiversity loss. To tackle this issue, global cooperation is necessary, and governments should take a leading role in implementing policies to reduce greenhouse gas emissions. Sustainable development is crucial to economic growth and social welfare, but it must be based on a balance between economic, social, and environmental aspects.

It is essential to educate the public on climate change in order to create awareness and change behaviors to reduce environmental impact and adopt practices that promote sustainable development. Strengthening human capital (HCD) is crucial for sustained economic growth, according to the World Development Report (2019). Enhancing human capital is a crucial policy to put into action since it raises awareness of environmental issues and promotes energy efficiency by changing how people use and consume energy. Fostering renewable energy (RE) is another strategic action that could help in lowering CO2 emissions, but it must be undertaken gradually to guarantee that the long-term sustainability of the energy transition. On the other hand, urbanization and its associated infrastructure are significant contributors to global CO2 emissions, and policies to reduce the impact of urbanization on the environment should be implemented urgently. Blue and green infrastructure, for example, is seen as a sustainable and long-term solution to mitigate the effects of urbanization on the ecosystem. Therefore, these policies can include promoting public transport, creating green spaces and permeable sidewalks, enhancing parks, and promoting constructed wetlands. Addressing climate change related issues requires cooperation from all sectors to implement policies that promote sustainable development while reducing global CO2 emissions. Education, improving human capital, and encouraging RE are specific policies that can support the transition towards more sustainable development practices.

The high-energy consumption in urban areas is due to the increasing demand for transportation, sanitation, infrastructure development, sewages, and housing. To manage and reduce CO2 emissions and energy consumption, there is a need to analyze the correlation between RE, ENC, GDP, industrialization, trade openness (TOP), HCD, and environmental impact in emerging market economies. These economies have experienced significant transformation in the current century, including strong GDP, high *per capita* income, industrialization, and UB. While previous studies have examined the impact of RE, nonrenewable energy (NRE), governance quality, and HCP on GDP and environmental characteristics, few have taken into account the interaction between HCD and the key variables, and their conditional and nonlinear effects on the correlation between RE, NRE, GDP, and environmental quality. Consequently, this investigation aims to study the relationship between, HCD, energy sources, GDP, and CO2 emissions for sustainable development in newly emerging market economies. The study add up to the current understanding of the literature on sustainable development and environmental protection, mainly through the analysis of the conditional impact of HCD on RE, and CO2 emissions, GDP nexus. Additionally, the study examines the nonlinear effect of HCD on environmental quality and the impacts of UB, TOP, and industrialization on sustainable development. Finally, the study utilizes two econometric techniques to generate robust and consistent estimates of the relationship between the variables under investigation. Our primary focus is on the emerging African market economies, driven by their vibrant GDP and abundant RE resources, as well as the environmental challenges resulting from the rapid urbanization needed to support their expanding populations. Consequently, the findings of this study carry policy implications that can significantly contribute to the sustainable development of these nations and the global environment's betterment. The subsequent sections of this study are structured as follows: Section 2 offers the literature review, while Section 3 outlines the materials and methods used. It is also dedicated to presenting and discussing our empirical results, and in Section 4, we conclude the research article by offering policy recommendations and suggesting others for future research.

2 Literature review

Different research articles around energy, especially RE, NRE and CO2 emissions, have been deeply discussed through the recent literature review. However, our study introduces a novel dimension to this discussion by examining the moderating influence of HCD on the relationship between these variables, which has not been explored in prior research. Previous empirical studies have primarily concentrated on elucidating the relationship between energy consumption and CO2 emissions (Mohsin et al., 2021; Bilan et al., 2019; Ibrahim and Ajide, 2021; Radoine et al., 2022). There is a research gap in the existing literature in terms of considering newly emerging market economies in the analysis and exploring the conditional and nonlinear effects of HCD on the interplay between RE, NRE, GDP, and CO2 emissions.

Shahnazi and Shabani (2021) focused their analysis on the European Union, while Mahalik et al. (2021) concentrated on BRICS countries. Additionally, these previous studies often did not adequately address cross-dependence analysis in their methodologies. They primarily utilized various methods such as FMOLS and Markov switching regression models (Feng, 2022), dynamic fixed effect and GMM (Muhammad et al., 2021), PMG-ARDL (Berkun et al., 2019), ARDL (Pata, 2018), and DOLS (Dogan

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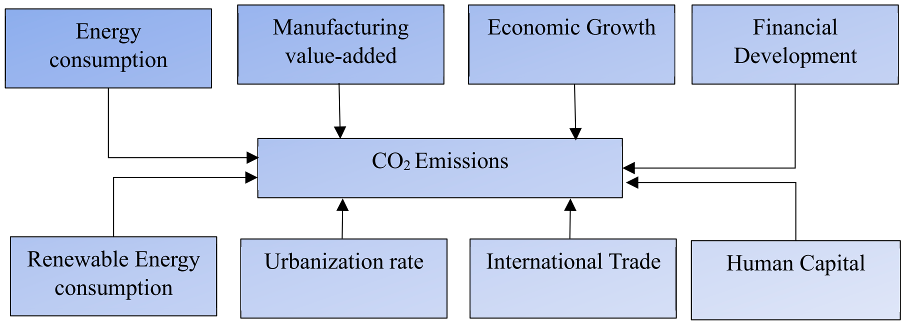

FIGURE 1
Conceptual framework. Source: authors constructed

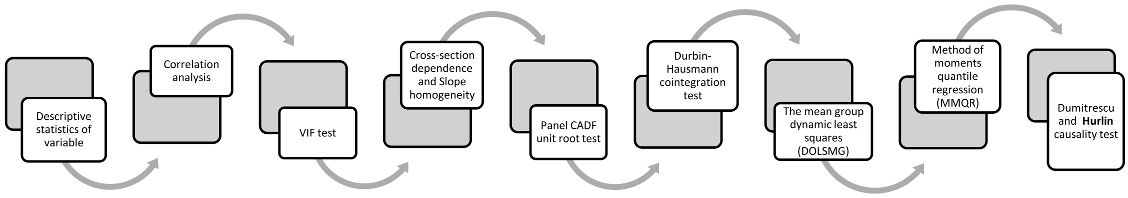

FIGURE 2
Steps of research.

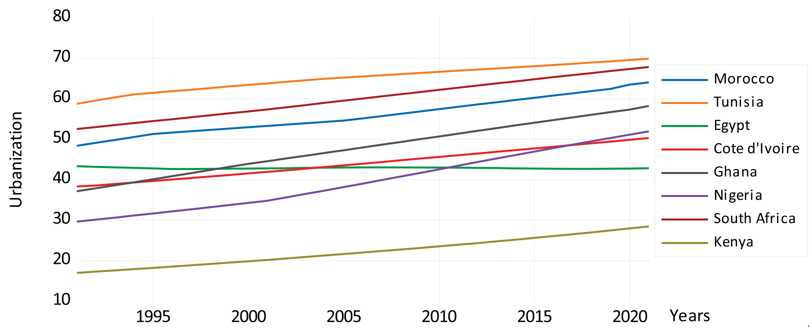

FIGURE 3
Urbanization rate levels from 1991 to 2021.

and Seker, 2016), and finally Timmons et al. (2014) suggested that higher prices of RE can lead to a greater reliance on fossil fuels. Therefore, it is recommended that policymakers implement measures to reduce the cost of RE and promote the development of environmentally friendly technologies. Chen et al. (2019) found a negative association between RE, TOP, and CO2 emissions. Dong et al. (2018) applied the Kuznets Curve hypothesis and revealed that RE has a negative impact on carbon emissions. Shahnazi and Shabani (2021) found that RE mitigated CO2 emissions during the period from 2000 to 2017. In the article of De Souza Mendonça et al., 2020, a study involving 50 largest countries, they identified that growth and population growth were contributors to CO2 emissions, while RE was not. Furthermore, there is evidence, as suggested by Pata (2018), of an inverted U-shaped relationship between CO2 emissions and GDP *per capita*. Pata's study also indicated that RE had no significant impact on CO2 emissions, while UB was linked to environmental degradation. According to Awosusi et al. (2022), globalization and the adoption of RE can help mitigate CO2 emissions in the case of Colombia country. In the research article of Adebayo and Kirikkaleli (2021), using quarterly data, they found that in Japan the RE use effectively reduced CO2 emissions.

On the other hand, RE consumption, UB, and secondary education were associated with reduced carbon emissions. Oke et al. (2021) while analyzing 51 African countries over the same time have demonstrated similar findings. Substantial evidence for the EKC hypothesis was offered by Sarkodie and Ozturk (2020), who

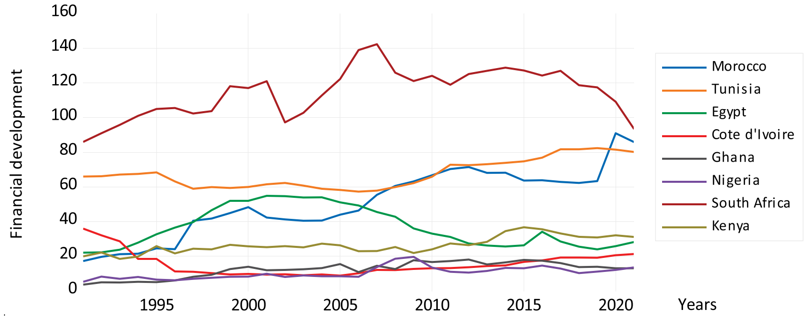

FIGURE 4
Financial development levels from 1991 to 2021.

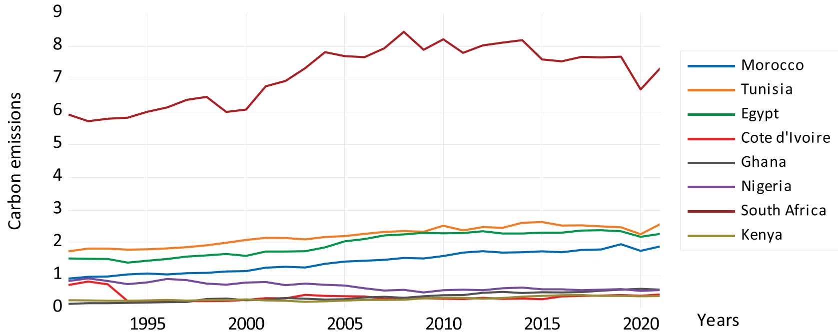

FIGURE 5
CO2 emissions levels from 1991 to 2021.

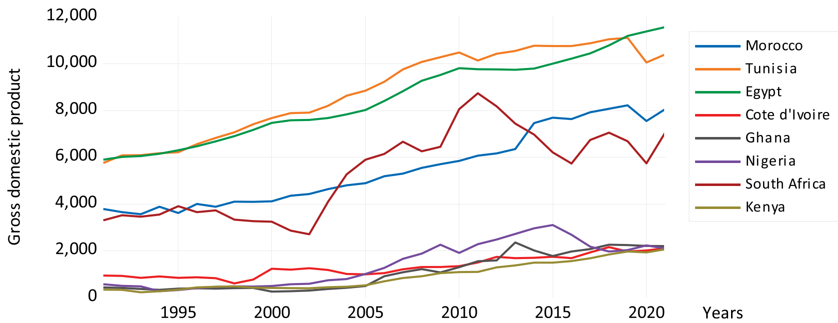

FIGURE 6
Gross Domestic Product levels from 1991 to 2021.

noted that energy consumption has a positive effect on CO2 emissions whereas RE has a negative effect on CO2 emissions. In a panel of G-7 nations from 1991 to 2016, Raza and Shah (2018) investigated the role of RE consumption in the context of the EKC hypothesis. Their study employed various regression models to establish evidence of cointegration and suggested that the development of RE in G7 countries was a significant factor in long-term decarbonization policy. When trade indicators were integrated with RE use and GDP, the results lent support the G-7 countries validity of the EKC hypothesis. The relationship between RE and CO2 emissions has been the subject of numerous studies, including those by Lau et al. (2019), Cai et al. (2018), Zoundi (2017), and Ito (2017), but many of these studies omitted the important role of HCD, which can have significant effects on environmental quality. In their research, Szetela et al. (2022) explored the connection between RE and CO2 emissions in major natural resource-dependent countries from 2000 to 2015, emphasizing the role of governance. They used Ordinary Least Squares Fixed effects in their study. Panel data were analyzed using Generalized Least Squares methods and

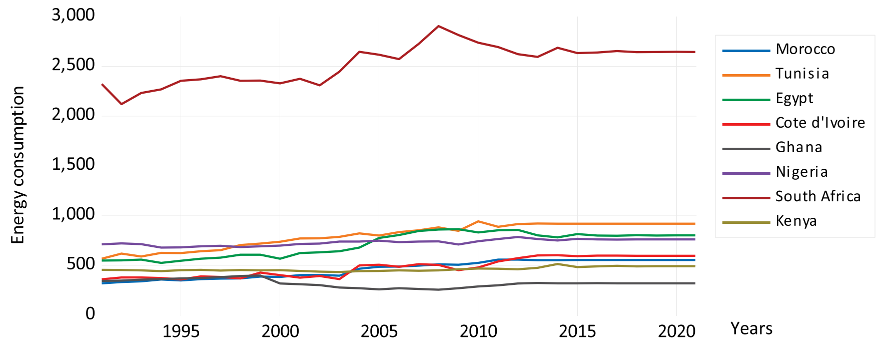

FIGURE 7
Energy consumption levels from 1991 to 2021.

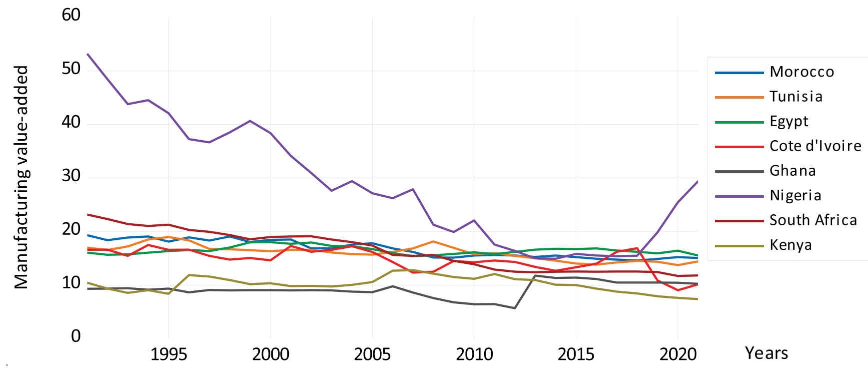

FIGURE 8
Manufacturing value-added levels from 1991 to 2021.

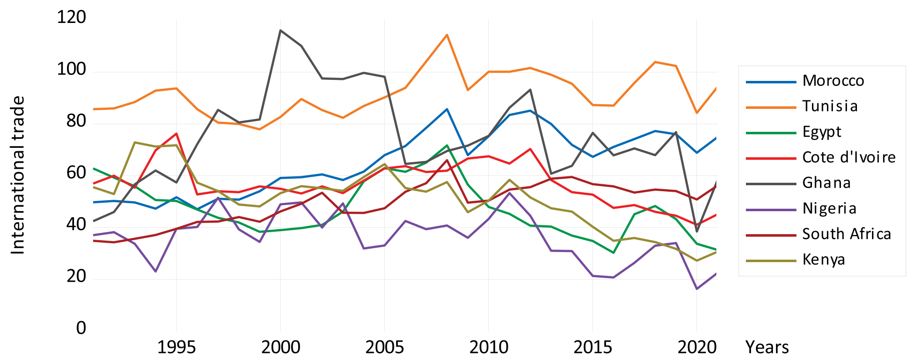

FIGURE 9
International trade levels from 1991 to 2021.

two-step GMM estimators, and it was found that RE significantly reduced *per capita* CO2 emissions.

Furthermore, the relationship between CO2 emissions and Gross Domestic Product *per capita* was found to be U-shaped. Qi et al. (2014) investigated RE targets in China and found that a 1.8% reduction in CO2 emissions could be achieved from 2010 to 2020. Inglesi-Lotz and Dogan (2018) demonstrated a long-term association between GDP, RE, NRE, and CO2 emissions in a study that focused on the top 10 electricity-producing nations in Sub-Saharan Africa from 1980 to 2011. Their findings also suggested causality running from RE to CO2 emissions and from CO2 emissions to TOP. Bajja et al. (2023) analyze the determinants of environmental quality in urban Morocco in the context of important factors, such as ENC, UB, manufacturing, and financial development. The study draws on time series data covering the period from 1971 to 2019. Fatima et al. (2021) have made a

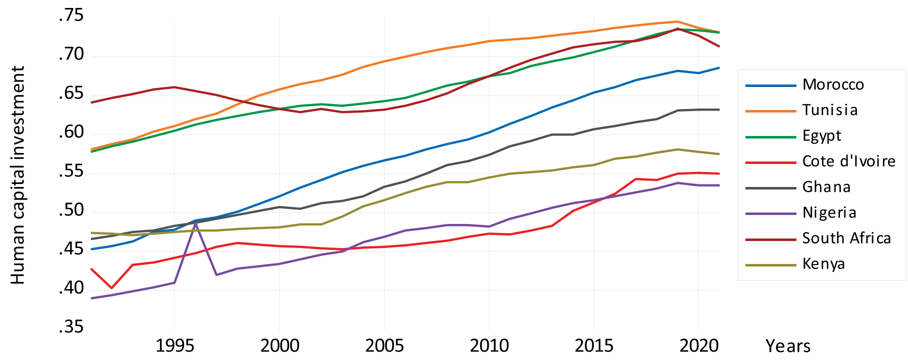

FIGURE 10
Human capital investment levels from 1991 to 2021.

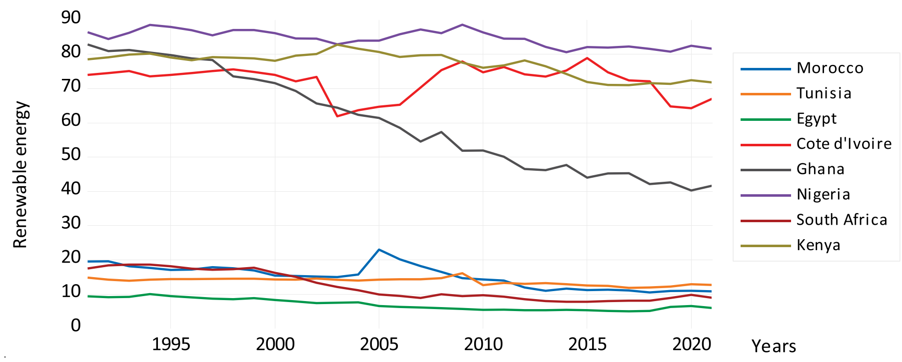

FIGURE 11
Renewable energy levels from 1991 to 2021.

significant contribution to the existing body of research by delving into the intricate relationship between GDP, RE, and CO2 emissions, utilizing comprehensive global panel data. Employing a diverse set of econometric methodologies, their study demonstrates that GDP plays a pivotal role in moderating the association between RE usage and CO2 emissions. Concurrently, the study reveals that GDP exerts an influence on NRE consumption, consequently leading to an increase in CO2 emissions. In West Africa, Radoine et al. (2024) analysed annual data from 1991 to 2018 of urban population growth, gross domestic product, energy consumption, and greenhouse gas emissions. The study revealed variation across the selected countries in terms of rate of urbanization, productivity, and energy consumption. In the realm of the HCD-CO2 emissions link, there is a paucity of studies. Desha et al. (2015) posit that HCD, nurtured through education, not only enhances RE consumption but also facilitates the production of environmentally less polluting goods, as suggested by Hartman and Kwon (2005). This notion has been further been substantiated by Bano et al. (2018), contending that an improvement in HCD can effectively reduce CO2 without compromising GDP. In the corporate sphere, highly educated employees tend to leverage innovative technologies for cleaner production processes and actively engage in environmental management and compliance efforts, a point also underscored by Dasgupta et al. (2000). In MENA region, Bajja et al. (2024) assert that HCD significantly contributes to environmental degradation.

Exploring 11 European Union countries, they uncover, in Bayar et al. (2022), a negative association between HCD and carbon dioxide emissions in Croatia, Hungary, the Czech Republic, and Slovenia. In contrast, this relationship exhibits a positive impact in Lithuania and Latvia. Yao et al. (2020) emphasize that advanced HCD, tied to years of schooling, exerts a negative influence on CO2 emissions. Interestingly, they discern a shift in this relationship from positive to negative after the 1950s. Li and colleagues (2022), in their analysis of the HCD -CO2 emissions nexus, ascertain that an increase in education levels leads to a reduction in CO2 emissions, while conversely, a decrease in education levels is associated with an increase in CO2 emissions.

3 Material and methods

In this article, we examine on the impacts of specific factors including GDP as a measure of economic growth, manufacturing value-added (MVA), urbanization rate (UB), financial development

TABLE 1 Descriptive Statistics of selected variables.

	CO2	*GDP*	*MVA*	*UB*	*HCD*	*FD*	*RE*	*ENC*	*TR*
Mean	1.806,734	4,118.038	16.04448	47.25757	0.57477	41.80765	42.82509	813.7187	59.07147
Median	0.915,831	2914.511	15.50657	47.145	0.5735	26.48584	31.625	585.1536	55.46557
Maximum	8.44665	11,566	53.18669	69.89	0.745	142.422	88.68	2904.276	116.0484
Minimum	0.142,469	226.5212	5.660,586	17.043	0.39	3.65734	4.93	257.7809	16.35219
Std. Dev	2.175,438	3427.748	7.032675	13.39905	0.09513	34.88031	32.13464	675.276	19.99893

TABLE 2 Correlation analysis results.

	LNCO2	*LNGDP*	*LNMVA*	*LNUB*	*LNHCD*	*LNFD*	*LNRE*	*LNENC*	*LNTR*
LNCO2	1.000								

LNGDP	0.787***	1.000							
	(0.000)	-----							
LNMVA	0.357***	0.156**	1.000						
	(0.000)	(0.013)	-----						
LNUB	0.643***	0.700***	0.147**	1.000					
	(0.000)	(0.000)	(0.020)	-----					
LNHCD	0.739***	0.833	−0.162**	0.589***	1.000				
	(0.000)	(0.000)	(0.010)	(0.000)	-----				
LNFD	0.819***	0.737***	−0.014	0.485***	0.77***	1.000			
	(0.000)	(0.000)	(0.824)	(0.000)	(0.000)	-----			
LNRE	−0.84***	−0.88***	−0.132**	−0.58***	−0.81***	−0.75***	1.000		
	(0.000)	(0.000)	(0.036)	(0.000)	(0.000)	(0.000)	-----		
LNENC	0.824***	0.479***	0.325***	0.387***	0.530***	0.648***	−0.4***	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	-----	
LNTR	0.035	0.132**	−0.33***	0.338***	0.245***	0.24***	−0.1***	−0.2***	1.000
	(0.583)	(0.035)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	-----

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

(FD), renewable energy use (RE), energy consumption (ENC), international trade (TR), human capital (HCD) on CO2 emissions. The conceptual framework illustrating these factors is shown in Figure 1, while the research steps followed in this study are detailed in Figure 2. The focus of our work was on 8 african countries including Morocco, Egypt, Tunisia, Cote d'lvoire, Ghana, Nigeria, South Africa, and Kenya. We collected annual data spanning from 1991 to 2021 for our analysis. Although we aimed to utilize more recent and extensive data, we faced limitations as comprehensive and consistent data on CO2 emissions were only available until 2021.

Figure 3 through 11 provide trends in each of the main factors affecting CO_2 emissions across the study period, including urbanization rates (Figure 3), financial development (Figure 4), CO_2 emissions (Figure 5), GDP levels (Figure 6), energy consumption (Figure 7), manufacturing value-added (Figure 8), international trade (Figure 9), human capital development (Figure 10), and renewable energy use (Figure 11). The data utilized in this study were sourced from the World Development Indicators (WDI), provided by the World Bank. Information specifically pertaining to RE was gathered from the IEA website. To estimate carbon emissions, the study will employ the following functions.

$$CO2 = f\ (MVA;\ UB;\ FD;\ RE, ENC, TR) \tag{1}$$

$$CO2 = f\ (GDP;\ HCD;\ UB, TR) \tag{2}$$

In Equations 1, 2, the variable CO2 represents carbon emissions measured in metric tons. GDP represents the *per capita* gross domestic product in current US dollars, which serves as a proxy for economic growth. MVA denotes manufacturing value-added as a percentage of total GDP. UB

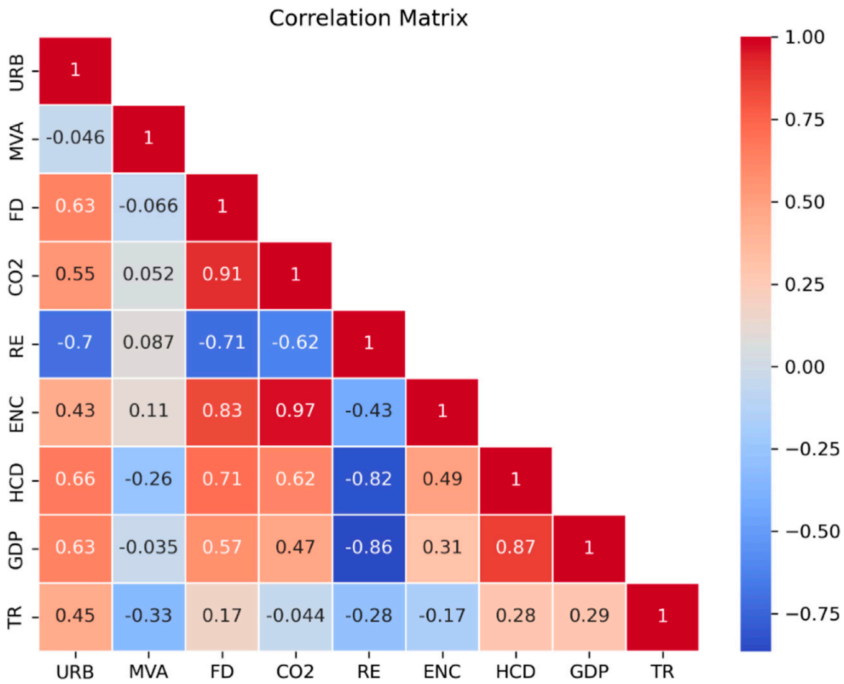

FIGURE 12
Graphical visualization of the correlation matrix.

represents the urbanization rate, expressed as a percentage of the total population. HCD, measures the development of a country in terms of income, education, and health. FD refers to financial development, measured as a percentage of GDP and is represented by the proxy domestic credit issued to the Private sector (see Appendix 1 for more detail).

All the variables used in this model are transformed into logarithmic form, as shown in Equations 3, 4, to mitigate the influence of extreme values in the data and to observe the elasticity of variables. This transformation helps to ensure a more stable and balanced analysis.

$$LNCO_{it} = \beta_0 + \beta_{1t}LNMVA_{it} + \beta_{2t}LNURB_{it} + \beta_{3t}LNFD_{it} + \beta_{4t}LNRE_{it} + \beta_{5t}LNENC_{it} + \beta_{6t}LNTR_{it} + \varepsilon_{it} \quad (3)$$

$$LNCO_{it} = \alpha_0 + \alpha_{1t}\,LN\,GDP_{it} + \alpha_{2t}LNURB_{it} + \alpha_{3t}LNHCD_{it} + \alpha_{4t}LNTR_{it} + u_{it} \quad (4)$$

whereas i represents the number of countries; t indicates the time period; ε and u represent the error term; and $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6,$ and $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are the parameters of manufacturing value-added, UB, FD, economic growth, RE use, ENC, HCD, and international trade, respectively.

4 Results and discussion

After the models are defined, Table 1 indicates the descriptive statistics for the eight countries over the 31-year time periods (1990–2021). Accordingly, the mean values of the series in Table 1 are 1.80 for CO2, $4,118.03 for GDP, 16.04% for MVA, 47.7% for UB, 0.57 for HCD, 41.80% for FD, 42.82% for RE, 813.71 for ENC and 59.07% for TR while the median values of the series are 0.91 for CO2, $2914.51 for GDP, 15.50% for MVA, 47.14% for UB, 0.57 for HCD, 26.48% for FD, 31.62% for RE, 585.15 for ENC and 55.46% for TR. It is seen that there are high differences between the maximum and minimum values of the series, except for HCD and UB. For this reason, logarithmic transformation of all variables was made in order to avoid the problem of heteroscedasticity and to measure the elasticity values of the variables. Figure 3 presents the scatterplot matrix representation of the data.

TABLE 3 Variance inflation factor (VIF) test results.

Model 1			Model 2		
Variable	VIF	1/VIF	Variable	VIF	1/VIF
LNFD	4.00	0.25	LNGDP	4.61	0.21
LNRE	2.88	0.34	LNHCD	3.51	0.28
LNENC	2.72	0.36	LNUB	2.25	0.44
LNUB	1.84	0.54	LNTR	1.24	0.80
LNTR	1.72	0.58			
LNMVA	1.38	0.72			
Mean VIF	2.42		Mean VIF	2.90	

Table 2 presents the correlation analysis results, while Figure 12 provides a visual representation of the findings. Correlation analysis results indicate the direction of the relationship between variables. If

TABLE 4 Cross-section dependence and slope homogeneity tests results.

Panel A. Cross-section dependence test results for variables								
Test	Breusch-Pagan LM		Pesaran scaled LM		Bias-corrected scaled LM		Pesaran CD	
	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
LNCO2	470.1***	0.00	58.0***	0.00	57.8***	0.00	7.7***	0.00
LNGDP	699.7***	0.00	88.6***	0.00	88.5***	0.00	26.3***	0.00
LNMVA	194.3***	0.00	21.1***	0.00	21.0***	0.00	7.9***	0.00
LNUB	670.4***	0.00	84.7***	0.00	84.6***	0.00	19.4***	0.00
LNHCD	715.7***	0.00	90.8***	0.00	90.7***	0.00	26.6***	0.00
LNFD	242.9***	0.00	27.6***	0.00	27.5***	0.00	6.5***	0.00
LNRE	370.6***	0.00	44.7***	0.00	44.5***	0.00	17.1***	0.00
LNENC	483.5***	0.00	59.8***	0.00	59.6***	0.00	14.2***	0.00
LNTR	151.2***	0.00	15.4***	0.00	15.2***	0.00	5.5***	0.00

Panel B. Cross-section dependence test results for models				
Test	Model 1		Model 2	
	Statistic	p-value	Statistic	p-value
LM	42.09**	0.04	25.34	0.60
*LM adj**	3.57***	0.00	−2.04**	0.04
*LM CD**	0.52	0.60	1.96*	0.05

Panel C. Slope homogeneity test results				
	Model 1		Model 2	
	Delta	p-value	Delta	p-value
	12.482***	0.00	14.316***	0.00
adj	14.491***	0.00	15.942***	0.00

Note: ***p < 0.01, **p< 0.05, *p < 0.10.

there is a high correlation between variables, this also indicates that a multicollinearity problem may arise. As with the VIF test results in Table 3, correlation analysis results proved that there was no multicollinearity problem. According to the VIF test results in Table 3, it is determined that the use of Models 1 and 2 is appropriate because the variables and Mean VIF values are less than 5. Moreover, the correlation analysis results showed that there was a positive relationship between GDP, MVA, UB, HCD, FD, ENC and CO2, while there was a negative relationship between RE and CO2.

Technological developments after the Second World War and the end of the bipolar world with the collapse of the Soviet Union after 1989 were two fundamental facts that accelerated globalization. Although protectionism came to the fore for some countries from time to time after this period, the integration process of countries with each other has reached an advanced stage with globalization. The results of the cross-sectional dependence (Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, Pesaran CD) test in

TABLE 5 Panel CADF unit root test results.

Variable	Level		First difference	
	t-bar	p-value	t-bar	p-value
$LNCO_2$	−1.609 [1]	0.696	−3.953 [1]***	0.000
LNGDP	−2.045 [1]	0.213	−3.964 [1]***	0.000
LNMVA	−2.264 [1]	0.597	−3.619 [1]***	0.000
LNUB	−1.167 [2]	0.347	−2.265 [2]*	0.071
LNHCD	−1.374 [1]	0.889	−3.652 [0]***	0.000
LNFD	−1.967 [1]	0.287	−2.703 [1]***	0.003
LNTR	−1.750 [1]	0.535	−4.280 [1]***	0.000
LNRE	−1.795 [1]	0.482	−3.839 [1]***	0.000
LNENC	−1.671 [1]	0.629	−3.672 [1]***	0.000

Note: ***pm < 0.01, **p < 0.05, *p < 0.10. Numbers in [ ] state lag length.

TABLE 6 Durbin-Hausman cointegration test results.

	Model 1 with constant term		*Model 2 with constant term*	
	Statistic	p-value	Statistic	p-value
Dh_g	11.878	1.00	7.607	1.00
Dh_p	−1.675**	0.04	−1.714**	0.04
	Model 1 with constant term and trend		*Model 2 with constant term and trend*	
	Statistic	p-value	Statistic	p-value
Dh_g	−0.043	0.48	1.808	1.00
Dh_p	−1.482*	0.07	−1.569*	0.06

Note: ***p < 0.01, **p < 0.05, *p < 0.10.

Table 4 revealed that the countries examined are related to each other. At the same time, the cross-sectional dependence test results in Table 4 (Panel A and B) proved that the the existence of cross-sectional dependence for models and variables was detected. In other words, we found that there is cross-section dependence for each models and variables. In this regard, we should use second generation test methods that can be used under cross-section dependence. Additionally, Table 4 (Panel C) revealed that the heterogeneous panel models are valid for Model 1 and Model 2.

In the continuation of the analysis, the cross-sectional ADF (CADF) unit root test developed by Pesaran (2007) was used. This unit root test, which can be applied under cross-section dependence and heterogeneity, is considered among the second-generation unit root tests. Table 5 presents the results obtained considering the constant model. Accordingly, the variables became stationary by taking their first difference. A parallel result was also obtained for the model with trend and constant. For this reason, it could not be added to the table separately.

After reporting the panel unit root test results, we used the second-generation panel cointegration tests proposed by Westerlund (2008) to determine whether there is a long-term cointegration relationship between the variables. The cointegration results in Table 6 revealed that there is a long-term relationship between the variables.

For long-term parameter estimates, we applied the mean group dynamic least squares (DOLSMG) developed by Pedroni (2001). As Models 1 and 2 are established in full logarithmic form, the coefficients can be interpreted as percentage changes. For Model 1, the DOLSMG estimator showed that a 1% increase in LNMVA would reduce LNCO2 by 1.4%, while a 1% increase in LNUB raises LNCO2 by 1.3%. Additionally, a 1% increase in LNRE reduces LNCO2 by 0.5%, while a 1% increase in LNTR decreases LNCO2 by 1.4%. However, a 1% increase in LNENC rises LNCO2 by 2.7%. On the other hand, DOLSMG results for Model 2 prove that a 1% increase in LNUB raises LNCO2 by 3.1%, while a 1% increase in LNHCD raises LNCO2 by 2.86% (see Table 7). The results are visually displayed in Figure 13.

Long-term country results include differences in all panel results presented in Table 8. For example, a 1% increase in LNMVA in Morocco reduces LNCO2 by 1.22%. In parallel with this result, a 1% increase in LNMVA reduces LNCO2 in Tunisia by 0.44%, LNCO2 in Egypt by 2.48%, LNCO2 in Cote

TABLE 7 The results of the mean group dynamic least squares (DOLSMG).

	Model 1		Model 2	
Variables	Beta	t-Stat	Beta	t-Stat
LNMVA	−1.428***	−26.9	-	-
LNFD	−0.174	−1.273	-	-
LNRE	−0.549***	−23.8	-	-
LNENC	2.799***	24.06	-	-
LNUB	1.381***	4.69	2.18*	3.18
LNTR	−1.428***	−23.35	−0.09	−0.37
LNGDP	-	-	0.01	0.43
LNHCD	-	-	2.86*	3.47

Note: ***p < 0.01, **p < 0.05, *p < 0.10.

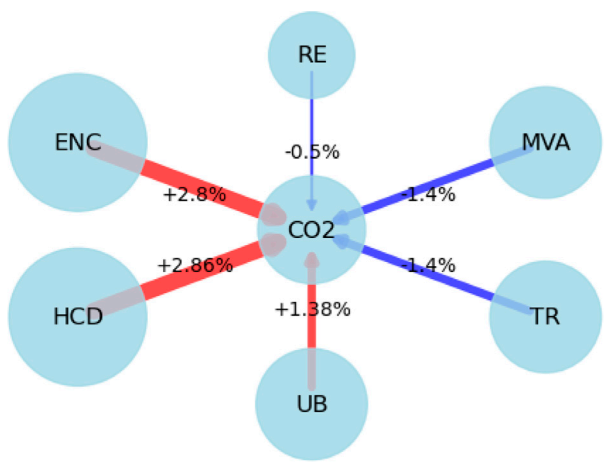

FIGURE 13
Long-run coefficient results for entire panel.

d'lvoire by 6.35%, LNCO2 in GHANA by 0.40%, LNCO2 in Nigeria by 1.18% and LNCO2 in South Africa by 0.40%. Contrary to these results, it was found that a 1% increase in LNMVA in

TABLE 8 Country-specific long run coefficients results.

Panel A: Country-specific long run coefficients results for Model 1								
	Morrocco		Tunisia		Egypt		Cote d'lvoire	
	Beta	t-stat	Beta	t-stat	Beta	t-stat	Beta	t-stat
LNMVA	−1.22***	−4.39	−0.44***	−2.70	−2.48***	−39.87	−6.35***	−13.21
LNFD	−0.11	−1.65	−0.31	−0.79	−0.02	−1.24	−1.69***	−13.37
LNRE	−0.11	−1.93	0.93**	2.10	−1.43***	−43.89	−0.90***	−7.97
LNENC	3.62***	10.99	−0.93	−1.20	0.39***	8.65	8.98***	15.62
LNUB	14.67***	7.31	3.05	1.34	−1.01***	−14.49	−35.81***	−14.51
LNTR	−0.06	−0.66	0.41	0.77	−0.61	−39.82	0.28	1.20
	Ghana		Nigeria		South Africa		Kenya	
	Beta	t-stat	Beta	t-stat	Beta	t-stat	Beta	t-stat
LNMVA	−0.40***	−10.27	−1.18***	−9.89	−0.40***	−3.71	1.03***	7.97
LNFD	1.05***	15.82	0.40***	5.33	−0.31***	−3.55	−0.42***	−4.15
LNRE	3.94***	12.18	−3.95***	−3.46	−0.32***	−13.74	−2.55***	−10.62
LNENC	3.66***	20.70	2.99***	5.27	−0.09	−0.70	3.78***	8.72
LNUB	18.92***	16.88	−0.57	−0.36	1.79***	2.90	10.01***	14.20
LNTR	−1.66***	−16.38	0.22***	2.75	−1.05***	−26.42	1.08***	12.51
Panel B: Country-specific long run coefficients results for Model 2								
	Morrocco		Tunisia		Egypt		Cote d'lvoire	
	Beta	t-stat	Beta	t-stat	Beta	t-stat	Beta	t-stat
LNUB	9.52***	5.25	2.11***	6.76	1.24**	2.35	−3.98	−1.42
LNGDP	−0.56***	−7.58	−0.01	−0.13	−0.27	−0.8	0.1	0.78
LNHCD	2.99***	4.08	0.01	0.04	−4.49	−0.99	−0.03	−0.04
LNTR	−0.01	−0.06	0.02	0.16	−0.02	−0.14	−1.76***	−5.56
	Ghana		Nigeria		South Africa		Kenya	
	Beta	t-stat	Beta	t-stat	Beta	t-stat	Beta	t-stat
LNUB	7.15***	3.2	−3.42***	−8.77	7.8***	4.52	−2.95***	−2.9
LNGDP	0.13	1.29	−0.09	−1.15	0.35***	4.65	0.39	1.75
LNHCD	6.93***	4.31	9.66***	4.15	−1.03***	−4.43	8.84***	2.71
LNTR	0.46***	2.71	0.29	1.93	0.5***	2.66	−0.19	−0.65

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Kenya leads to a 1.02% rise in LNCO2. Another result was that an increase in LNFD decreased LNCO2 in Cote d'lvoire, South Africa and Kenya, while an increase in LNFD was found to raise LNCO2 in Ghana and Nigeria. While increasing the use of LNRE was found to reduce CO2 emissions in countries other than Ghana and Kenya, increasing LNENC was found to rise CO2 emissions in all countries. Looking at the results by level of urbanization, increases in LNUB were found to raise LNCO2 in countries other than Egypt and Côte d'lvoire. In addition, increases in LNTR reduce LNCO2 in Ghana and South Africa, but increase LNCO2 in Nigeria and Kenya. Finally, increases in LNHCD were found to raise LNCO2 in Morocco, Ghana, Nigeria and Kenya, while lowering LNCO2 in South Africa.

The results of the MMQR tests are shown in Table 9. First, contradictions were found between the MMQR results and the DOLMG results for MVA. Accordingly, according to the MMQR results, it was concluded that the increase in LNMVA leads to an increment in LNCO2 based on different quantiles (0.10, 0.25, 0.50,

TABLE 9 MMQR test results.

Panel A. MMQR results for Model 1							
Variable	location	scale	qtile_10	qtile_25	qtile_50	qtile_75	qtile_90
LNMVA	0.48*** (0.00)	0.02 (0.51)	0.44*** (0.00)	0.46*** (0.00)	0.48*** (0.00)	0.50*** (0.00)	0.52*** (0.00)
LNFD	0.27*** (0.00)	−0.01 (0.61)	0.29*** (0.00)	0.28*** (0.00)	0.27*** (0.00)	0.26*** (0.00)	0.26*** (0.00)
LNRE	−0.43*** (0.00)	0.06*** (0.00)	−0.54*** (0.00)	−0.48*** (0.00)	−0.43*** (0.00)	−0.37*** (0.00)	−0.33*** (0.00)
LNENC	0.69*** (0.00)	−0.04* (0.09)	0.76*** (0.00)	0.72*** (0.00)	0.69*** (0.00)	0.65*** (0.00)	0.63*** (0.00)
LNUB	0.49*** (0.00)	0.14*** (0.00)	0.25** (0.02)	0.38*** (0.00)	0.48*** (0.00)	0.61*** (0.00)	0.71*** (0.00)
LNTR	−0.05 (0.47)	−0.04 (0.37)	0.02 (0.86)	−0.02 (0.84)	−0.05 (0.50)	−0.08 (0.22)	−0.11 (0.18)
_cons	−6.94*** (0.00)	−0.19*** (0.00)	−6.59*** (0.00)	−6.78*** (0.00)	−6.93*** (0.00)	−7.12*** (0.00)	−7.24*** (0.00)
Panel B. MMQR results for Model 2							
Variable	location	scale	qtile_10	qtile_25	qtile_50	qtile_75	qtile_90
LNUB	0.88*** (0.00)	0.73*** (0.00)	−0.05 (0.87)	0.22 (0.40)	0.66** (0.01)	1.57*** (0.00)	2.22*** (0.00)
LNGDP	0.33** (0.01)	−0.35*** (0.00)	0.77*** (0.00)	0.64*** (0.00)	0.43*** (0.00)	−0.01 (0.96)	−0.33 (0.19)
LNHCD	2.30*** (0.00)	1.23*** (0.00)	0.75 (0.30)	1.19* (0.06)	1.93*** (0.00)	3.45*** (0.00)	4.55*** (0.00)
LNTR	−0.59** (0.03)	−0.76** (0.02)	0.37 (0.18)	0.10 (0.69)	−0.36 (0.16)	−1.30*** (0.00)	−1.98*** (0.00)
_cons	−2.24 (0.11)	4.22*** (0.00)	−7.56*** (0.00)	−6.04*** (0.00)	−3.51*** (0.00)	1.72 (0.41)	5.50** (0.04)

Note: ***p < 0.01, **p < 0.05, *p < 0.10.

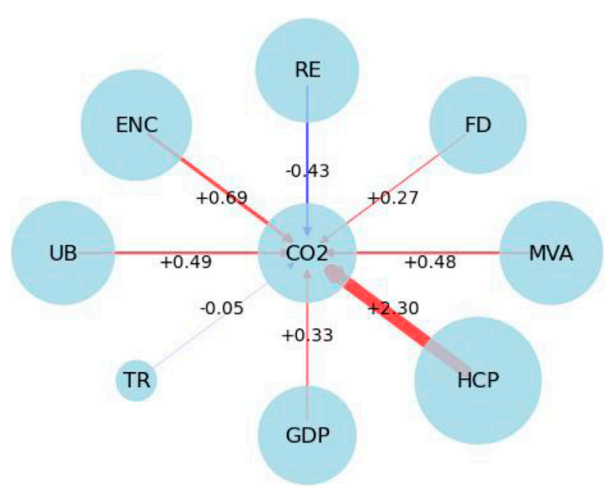

FIGURE 14
MMQR test results.

TABLE 10 Dumitrescu Hurlin causality tests results.

	W-Stat	Zbar-Stat	Prob
LNGDP to $LNCO_2$	1.587	−0.708	0.478
$LNCO_2$ to LNGDP	5.455***	3.83199	0.000
LNMVA to $LNCO_2$	2.367	0.20808	0.835
$LNCO_2$ to LNMVA	1.717	−0.55458	0.579
LNUB to $LNCO_2$	16.6994***	17.0276	0.000
$LNCO_2$ to LNUB	2.875	0.80389	0.421
LNFD to $LNCO_2$	2.256	0.07699	0.938
$LNCO_2$ to LNFD	1.677	−0.60212	0.547
LNHCD to $LNCO_2$	12.697***	12.3311	0.000
$LNCO_2$ to LNHCD	1.874	−0.37092	0.710
LNTR to $LNCO_2$	2.286	0.11241	0.910
$LNCO_2$ to LNTR	3.266	1.26235	0.206
LNENC to $LNCO_2$	1.490	−0.82105	0.411
$LNCO_2$ to LNENC	5.533***	3.92384	0.000
LNRE to $LNCO_2$	4.22747**	2.39061	0.016
$LNCO_2$ to LNRE	1.047	−1.34188	0.1796

Note: ***p < 0.01, **p < 0.05, *p < 0.10.

0.75, 0.90) for model 1. In addition, the increase in LNFD was found to contribute to the increment in LNCO2 based on different quantile levels. Considering the results in which DOLMG and MMQR are compatible, it was observed that the increase in the use of LNRE decreased LNCO2, while the increase in LNUB raised LNCO2. It was also found that increase in LNENC leds to rise in LNCO2. MMQR results for model 2 observed that increases in LNUB and LNGDP raised LNCO2 based on different quantile levels. On the other hand, an increase in LNHCD was found to raise LNCO2, while an increase in LNTR was found to lower LNCO2 at different quantile levels. The MMQR results are visually presented in Figure 14. These results are in line with the DOLSMG results.

In the final stage of the analysis, we applied the causality analysis developed by Dumitrescu-Hurlin (2012), which can be used for heterogeneous panels. The null hypothesis assumes no causal relationship between two variables, and results where the null hypothesis was rejected are reported in Table 10. According to our results (see Table 10), while a unidirectional causality relationship was detected from LNUB, LNHCD and LNRE to LNCO2, a unidirectional causality relationship was found from LNCO2 to LNGDP and LNENC.

5 Conclusion

In conclusion, this research sheds light on the complex interplay of human capital development, international trade, financial development, renewable energy consumption, and urbanization in the context of environmental degradation in emerging-market economies in Africa. The findings emphasize the nuanced nature of these relationships, with financial development and renewable energy consumption revealing both positive and negative impacts on environmental degradation.

The empirical results conclude that urbanization, energy consumption, economic growth and human capital development have significant and positive effects on environmental degradation, while financial development, renewable energy consumption, manufacturing activities and international trade have a significant negative effect on environmental degradation. As the African continent continues to experience economic growth and urbanization, it is paramount for policymakers to recognize the dual nature of these forces and their environmental consequences. Encouraging financial development and promoting renewable energy consumption can serve as positive steps towards mitigating environmental degradation. Simultaneously, addressing the adverse effects of urbanization on the environment is vital to ensure a sustainable path for economic growth in these emerging-market economies.

This study underscores the necessity for a comprehensive and well-balanced approach in shaping environmental policies in African emerging-market economies, one that harnesses the potential of human capital, international trade, and financial development, while also acknowledging the vital role of renewable energy and urbanization management in achieving a sustainable and environmentally friendly economic future for the continent. The study makes a valuable contribution to the discussion on environmental degradation in Africa, particularly by exploring the interplay between human capital development, international trade, renewable energy consumption, and urbanization. However, it has certain limitations, mainly due to its focus on only eight parameters. Future research could expand by incorporating additional variables and exploring their impact on various environmental indicators, leading to a more comprehensive understanding of urban sustainability in Africa. Additionally, analyzing the data within the context of the Environmental Kuznets Curve could shed light on the link between economic development and environmental quality. That said, the lack of some necessary datasets poses a challenge that future studies should address.

Data availability statement

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author.

Author contributions

SB: Investigation, Methodology, Supervision, Writing–original draft, Writing–review and editing. RE-B: Methodology, Writing–review and editing. AÇ: Conceptualization, Methodology, Software, Writing–review and editing. ZA: Supervision, Validation, Writing–review and editing. HR: Funding acquisition, Project administration, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix 1

TABLE A1 Definition and Data source of variables.

Variable	Definition	Data source
Carbon Emissions	CO_2 Emissions *per capita*	WDI database
Economic growth	Gross Domestic Product *per capita*	WDI database
Manufacturing Value-added	Manufacturing value-added (% of total GDP)	WDI database
Urbanization rate	Urbanization rate	WDI database
Human Capital	The HDI measures the development of a country in terms of income, education, and health	United Nations Development Program
Financial Development	Domestic credit issued to the Private sector (% of total GDP)	WDI database
Renewable energy	Renewable energy consumption (% of total energy consumption)	EIA website "https://www.eia.gov/"
Energy consumption	Energy Consumption in kg of oil equivalent *per capita*	WDI database
International Trade	International Trade in percentage of GDP	WDI database

Note: Period of the data is from 1991 to 2021. WDI, states World Development Indicators.