

How effective are transport energy consumption, trade openness, and financial development in achieving the sustainable development goals (SDGs)? What are the realities and myths for selected African countries?

Salwa Bajja^{a,*}, Ali Celik^{b,c}, Michael Provide Fumey^d

^a School of Architecture, Planning and Design SAP+D, Mohammed VI Polytechnic University, UM6P, Ben Guerir, Morocco

^b Department of Electronic Commerce and Management, Istanbul Gelisim University, Istanbul, Turkey

^c Western Caspian University, Baku, Azerbaijan

^d School of Public Policy and Administration, Northwestern Polytechnical University, Xi'an, Shaanxi Province, China

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ABSTRACT

This research paper explores the nexus of urban development in some selected African economies, urban transport energy consumption, and their combined effects on environmental quality in four African countries. Using data from 1990 to 2021 on transport energy consumption and environmental quality with insights into urban policies, the research sheds light on the challenges and prospects within the region's urbanization. The findings, by using the Augmented Mean Group (AMG) method, show that the relationship between openness to trade and CO₂ emissions differs significantly between countries. In highly industrialized economies like South Africa, trade openness increases emissions because it is associated with the growth of carbon-intensive industries. Conversely, in lowly developed nations like Kenya, the link between trade openness and emissions is weak, implying that industrial composition is crucial in controlling the environmental impacts of trade. The findings for economic growth show varied outcomes, and trade openness depends on the countries involved. The empirical analysis also supports the first hypothesis, which indicates a statistically significant positive association between transport energy utilization and CO₂ emissions. They highlight escalating energy demands in transportation and associated environmental impacts, underscoring the need for policy interventions to promote sustainable alternatives. This research provides essential insights for policymakers and urban planners, offering a nuanced understanding of the complex relationships between urban development and sustainable urban transport and their implications for energy consumption and environmental sustainability in Africa, thus emphasizing the urgency of adopting sustainable practices to effectively guide the region's urbanization.

1. Introduction

In an age of increasing global environmental crises, the knowledge of the likely effects of economic development on sustainability outcomes becomes crucial for countries struggling to attain Sustainable Development Goals while balancing growth with ecological integrity (Bekun et al., 2024; Yeboah et al., 2024). Urbanization in Africa is rapidly evolving, driven by population growth, rural-urban migration, and economic development (Radoine et al., 2022; Bajja et al., 2024). As cities expand and populations concentrate, the challenges of sustainable urban development become increasingly pertinent (Radoine et al., 2024). Among these challenges, transportation energy consumption is a critical factor influencing urban development trajectories and

environmental sustainability (Salah-Uddin et al., 2016; Isik et al., 2018; Leal et al., 2018). Understanding the complex nexus between urbanization, transportation, and energy consumption is paramount for policymakers and urban planners to navigate the path toward sustainable development. Africa's urban population is projected to double by 2050, with the continent experiencing one of the fastest urbanization rates globally (Faye et al., 2022). This unprecedented urban growth presents opportunities for economic development and improved living standards.

However, it poses significant challenges, including inadequate infrastructure, environmental degradation, and social inequalities (Celik et al., 2024). Sustainable urban development in Africa requires addressing these challenges while promoting economic prosperity, social equity, and ecological conservation. Transportation is central to

* Corresponding author.

E-mail address: salwa.bajja@um6p.ma (S. Bajja).

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urban development, connecting people to jobs, services, and opportunities. The reliance on fossil fuels for transportation in many African cities contributes to air pollution, greenhouse gas emissions, and energy insecurity (Ghaffarpasand et al., 2024). Moreover, inefficient transportation systems can exacerbate congestion, road accidents, and social exclusion, undermining the quality of urban life and economic productivity (Sharif et al., 2019; Meersman and Nazemzadeh, 2017; Zhang et al., 2022). In the context of African countries, there are often assumptions within policy circles and academic discourse regarding the uniformly positive roles of trade openness, financial development, and energy consumption in advancing sustainable development (Salah-Uddin et al., 2016). This study unpacks these dynamics by distinguishing between what holds across the selected countries and what constitutes a commonly held but unsubstantiated belief, thereby shedding light on the realities and myths surrounding the effectiveness of these variables in achieving the SDGs (Bekun et al., 2025). The main reason for exploring the realities and myths about the impact of economic and social variables on environmental degradation for selected African countries is that the impact of economic activities on environmental degradation is less effective, especially since the countries in question are underdeveloped and developing countries. For instance, it is within this framework that the pollution haven hypothesis was developed. Contrary to this myth, the realities revealed by the research findings indicate that economic and social activities that generate pollution are risk factors for environmental degradation in selected African countries.

Consequently, this research focuses on four diverse African countries: Morocco, Egypt, South Africa, and Kenya. These countries represent a range of socio-economic contexts, urbanization patterns, and policy landscapes, offering valuable insights into the complexities of sustainable urban development in Africa. With its ambitious infrastructure projects and growing urban centers like Casablanca and Marrakech, Morocco exemplifies the challenges and opportunities of urbanization in North Africa (Bajja et al., 2023, 2024). Egypt, home to megacities like Cairo and Alexandria, grapples with congestion, pollution, and inadequate public transportation systems amidst rapid population growth (Moussa, 2023; Abdel Wahed Ahmed et al., 2020). South Africa, with its history of apartheid spatial planning and ongoing urbanization trends, confronts issues of social inequality and spatial segregation in cities like Johannesburg, Cape Town, and Durban. Kenya, characterized by vibrant urban hubs like Nairobi and Mombasa, faces informal settlements, traffic congestion, and air pollution challenges (Manshur et al., 2023; Desouza, 2020; Arioli et al., 2020). This research article examines the interrelationships between urban development, transportation energy consumption, and environmental sustainability in the context of selected African countries. Specifically, it assesses urbanization and transportation energy consumption patterns and trends in Morocco, Egypt, South Africa, and Kenya. Finally, it offers policy interventions and strategies that should be identified to promote energy-efficient and environmentally sustainable transportation systems in African cities.

This research contributes to the existing literature on urban sustainability by comprehensively analyzing the complex interactions between urban development, transportation energy consumption, and environmental quality in selected African countries. The study aims to inform decision-makers and practitioners involved in Africa's urban planning, transportation management, and environmental policy by identifying key challenges, opportunities, and policy implications. Furthermore, the findings of this research have broader implications for global efforts to address urbanization challenges and achieve sustainable development goals. As urbanization accelerates worldwide, particularly in developing regions like Africa, understanding the dynamics of transportation energy consumption and its implications for environmental sustainability becomes increasingly crucial. In the subsequent sections of this paper, we delve into the empirical analysis, presenting key findings and discussing their impact on policy and

practice. Through this comprehensive examination, we aim to advance knowledge and promote sustainable urban development in Africa and beyond.

2. Literature review

The primary focus of the initial research group is to explore the connection between economic development and the transport sector. Rodrigue and Notteboom (2013) has proposed that an efficient transport infrastructure will stimulate economic growth. Put differently, enhancing transportation infrastructure can yield various benefits, such as increased job opportunities, value generation, broader market access, and improved efficiency in terms of time and cost. The advancement of transport infrastructure can also encourage urban agglomeration, leading to knowledge spillover, pooling of labor markets, and specialized suppliers, thereby bolstering economic development.

Liddle and Lung (2013) delved into the long-term causal relationship between GDP and transport energy consumption (TEC). Their empirical findings show that TEC has a causal impact on GDP. Sharif et al. (2019) discovered a correlation between economic growth and transportation activities. In Belgium, Meersman and Nazemzadeh (2017) employed VECM models to analyze the significant impact of transportation enhancement on economic growth. The findings also suggest that investing in highways and railways positively affects long-term economic growth. Gherghina et al. (2018) discovered that within the EU-28 nations, different forms of transportation infrastructure positively affect economic progress, except for railways. Meanwhile, Zhang et al. (2022) examined the correlation between economic growth and transportation in China, covering 63 countries using the generalized method of moments from 2005 to 2019. Their results suggest that enhancing sufficient transportation infrastructure can notably foster eco-friendly and sustainable economic development.

Transportation infrastructure's impact on energy use and environmental quality becomes apparent through its impacts on economic sectors. A robust transportation infrastructure is essential for fostering economic enhancement by decreasing geographical distances and travel costs and improving aggregate demand. Consequently, Xie et al. (2017) show that regional and international markets may witness heightened energy use and carbon emissions levels. Transportation infrastructure can contribute to higher energy use and carbon emissions due to traffic congestion (Chen et al., 2020). In the article by Saidi and Hammam (2018), it's observed that transport infrastructure can exacerbate environmental quality. However, others argue that infrastructure development should be a priority instead of strict environmental legislation. This could lead, in the end, to patterns of pernicious growth. That's why some have advocated for a balanced policy where infrastructure and the

Table 1
The definition of variables.

Variable	Definition	Unit	Data source
CO ₂	Per capita CO ₂ emissions	Kiloton (kt)	https://ourworldindata.org/
GDP	Gross Domestic Product (constant 2015 US\$)	USA dollar	https://data.worldbank.org/
TOP	Trade openness, Trade (% of GDP), trade is the sum of exports and imports of goods and services measured as a share of gross domestic product	% of GDP	
URB	Urban population growth	Annual %	
TEC	Transport energy consumption, consumption in transport covers all transport activity (in mobile engines) regardless of the economic sector to which it is contributing	Petajoule (PJ)	www.iea.org
FDI	Financial development index	Index	https://www.imf.org/en/Data

Table 2

The statistical definition of panel time series data.

Variable	Obs	Mean	Std. Dev.	Min	Max
ln CO ₂	128	0.47	1.20	−1.62	2.28
lnGDP	128	25.51	0.80	24.14	26.78
lnTOP	128	3.93	0.23	3.30	4.36
URB	128	2.73	1.05	1.16	4.98
lnTEC	128	5.38	1.05	3.47	6.69
FDI	128	0.29	0.13	0.10	0.59

environment should be given equal attention.

Li et al. (2021) found that TOP exacerbates emissions in China, delaying the achievement of carbon neutrality. Ibrahim and Ajide (2021) suggested that TOP increased emissions in G-7 economies from 1990 to 2019. In China, Pata & Caglar (2021) examined data between 1980 and 2016 and discovered that TOP boosts emissions levels in the country. Udeagha and Ngepah (2022) investigated the TOP effects on CO₂ emissions in South Africa and concluded that increased TOP drives up emissions in the country. Wang and Wang (2021) studied the TOP's impact on emissions in 104 economies from 2000 to 2014, finding an inverted U-shaped relationship between TOP and emissions, indicating a reversal of the positive correlation in the long term. In contrast, Kim (2022) established that TOP mitigates carbon emissions in OECD economies from 1990 to 2018. Hossain et al. (2021) examined the TOP effect on emissions in Bangladesh from 1980 to 2016 and found that TOP reduces emissions in the country. Weili et al. (2022) studied 176 economies and found that TOP reduced emissions from 2000 to 2019. Liguio et al. (2022) concluded that TOP exacerbates environmental degradation in the USA. Wang et al. (2022) found that global trade increases global CO₂ emissions by 25 %. In the article of Wang and Zhang (2021), they analyzed data from 182 nations between 1990 and 2015, confirming that TOP increases CO₂ emissions in wealthy economies but mitigates them in poorer countries. Can et al. (2022) analyzed data from 31 OECD nations from 2007 to 2017 and concluded that TOP reduces CO₂ emissions. Can et al. (2021) also confirmed the same effect in OECD economies. While trade may harm the environment, it also offers chances for doing good. For instance, reducing trade barriers concerning environmental goods and promoting access to green technologies may lessen some of the harm done. Governments should allow trade liberalization and strict ecological regulation to effect sustainable development.

The environmental Kuznets curve hypothesis is premised mainly on an inverted U-shape between economic growth and ecological degradation (Dinda, S., 2004). Therefore, it asserts that pollution levels increase during the initial phases of economic development, reach a maximum at a middle income level, and decline with economic maturity based on technological innovation, changes in consumer preferences toward environmental quality, changes in economic structures, and improvements in regulatory capacity (Wang and Zhang, 2021). This somewhat nonlinear relationship implies that, once again, environmental degradation cannot be said to result directly from economic development. As analyzed by Kotroni et al. (2020), the EKC curve presents mixed results regarding the relationship between environmental degradation and economic growth, which has sparked unexpected interest among scholars. This research posits that as countries undergo industrialization, transitioning from agriculture to urban-based economies, it creates an inequality situation where industrial owners hold a significant portion of their income. At the same time, employees experience a decrease in their income. Additionally, Kuznets suggested that inequality follows an inverted "U" shape, initially increasing and then decreasing with higher income per capita. Initially, GDP growth is positively correlated with environmental pollution, causing pollution to

rise until reaching a tipping point where it begins to decrease due to shifts toward cleaner industrialization and investments in pollution-free economies. CO₂ emissions often increase with economic activity. Nasir and Rehman (2011) found a positive long-run relationship between TOP and CO₂ emissions in Pakistan. Salah-Uddin et al. (2016) examined the long-run relationship between TOP, economic growth, energy consumption, and carbon emissions in Sri Lanka from 1971 to 2006, confirming a causal relationship between economic growth and CO₂ emissions. Isik et al. (2018) investigated linear and nonlinear relationships between tourism demand and GDP growth across 126 countries from 1995 to 2012. Their findings indicate bidirectional causal relationships between renewable energy and GDP growth in selected countries, with Spain exhibiting a unidirectional causal relationship from renewable energy consumption to GDP growth and China, Turkey, and Germany showing a causal relationship from GDP growth to renewable energy. Furthermore, there is a causal relationship between tourist arrivals and GDP growth in the T-7 countries.

Moreover, this study delves into the efforts of scientists and policy-makers who have consistently worked on developing renewable energy consumption (REC) alternatives and other sources to mitigate reliance on traditional energy sources, thereby reducing negative environmental impacts. Heydari et al. (2019) examined the relationship between energy consumption generation and CO₂ emissions, utilizing data from Canada, Italy, and Iran from 1980 to 2015. Their study, employing cointegration, regression, and causality tests, confirmed that increased utilization reduces fossil fuel dependency, consequently lowering carbon emissions. Their findings provide empirical evidence supporting the expansion of renewable energy usage to mitigate CO₂ emissions. Leal et al. (2018) empirically analyzed the dynamics of energy growth, CO₂ emissions, and their impact on the Australian environment due to energy consumption. Focusing on variables such as coal, the oil energy sector, and CO₂, the study examined data from 1965 to 2015. Results indicated that adopting renewable energy reduces fossil fuel consumption, decreasing CO₂ emissions. The study suggests that Australia should prioritize increasing the proportion of renewable energy while reducing reliance on fossil fuels. Kwakwa and Alhassan (2018) conducted a study in Ghana, finding that hydro energy, waste energy, and combustible renewables decrease CO₂ emissions, whereas electricity generation from fossil fuels contributes to increased CO₂ emissions. Wang and Dong (2019) discovered in 14 sub-Saharan African countries that renewable energy can reduce environmental pollution, contrasting with the adverse effects of Non-renewable energy sources. Based on the arguments mentioned earlier and empirical evidence, the current study proposed the following hypothesis.

H1. Transport energy consumption brings about an increase in CO₂ emissions in some African countries.

H2. Trade openness makes the situation worse for the environment because more CO₂ is released into the atmosphere.

H3. The effect of urbanization on CO₂ emissions in African countries differs according to their economic fortune.

H4. Promoting cleaner technologies by financial development leads to diminished CO₂ emissions.

H5. Short-run economic growth positively correlates with increasing CO₂ emissions levels and reduces them in the long run, known as the EKC hypothesis.

H6. Investing in sustainable transportation infrastructure reduces urbanization's negative environmental impact.

3. Data, model specification, econometric methodology

3.1. Data

In this study, we examine the nexus between CO₂ emission, gross domestic product (GDP), trade openness (TOP), urbanization (URB),

transport energy consumption (TEC), and financial development index (FDI) for the period from 1990 to 2021. Additionally, we employed the novel panel econometric methods. Before the econometric model, we indicate the definition of variables in Table 1. We also present the statistical definition of panel time series data in Table 2. Accordingly, we used a logarithmic transformation for some variables. Fig. 1 also depicts

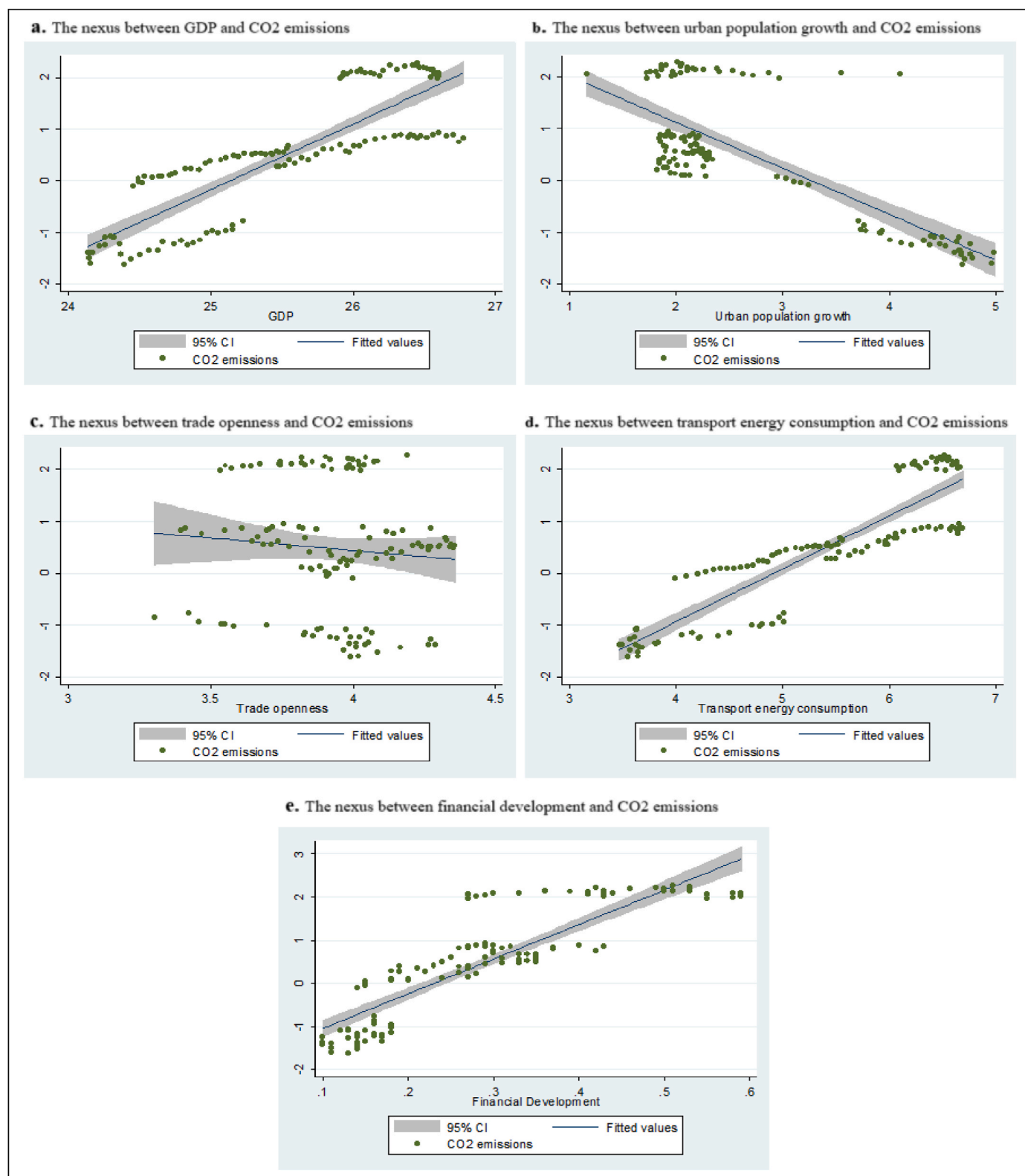


Fig. 1. Regression links between variables.

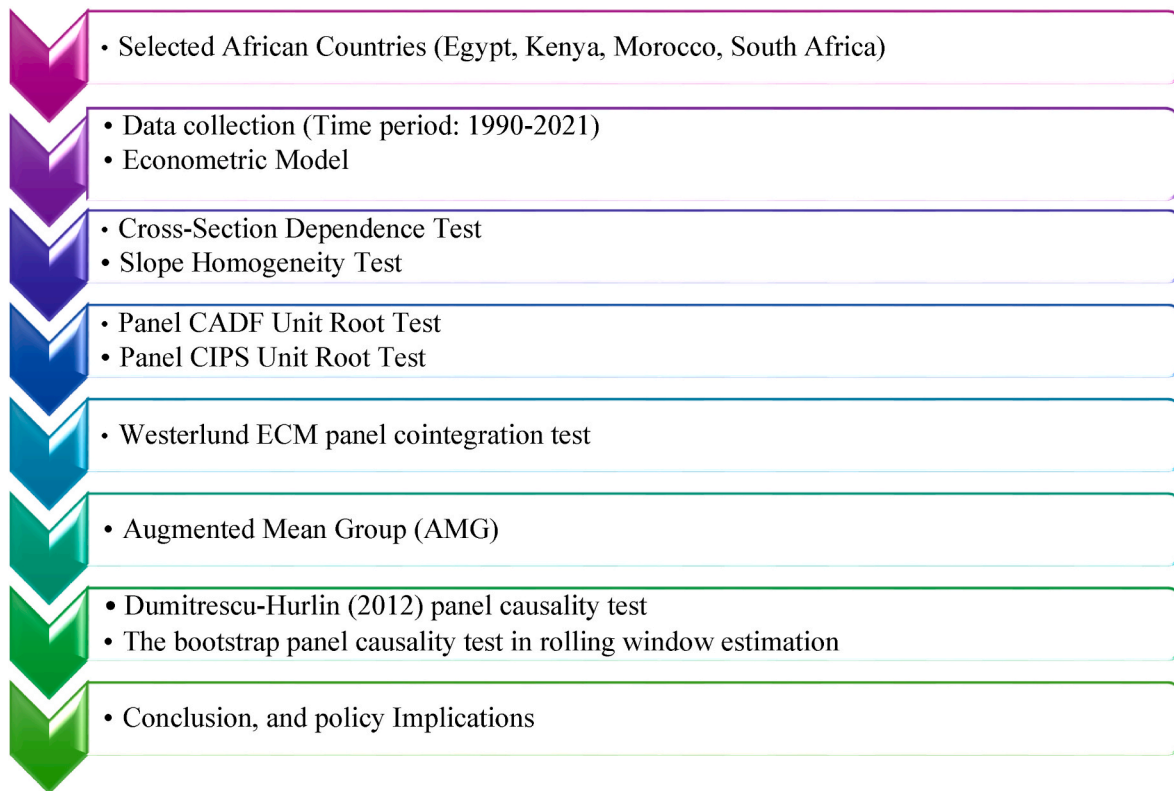


Fig. 2. Methodological framework. Source: constructed by authors.

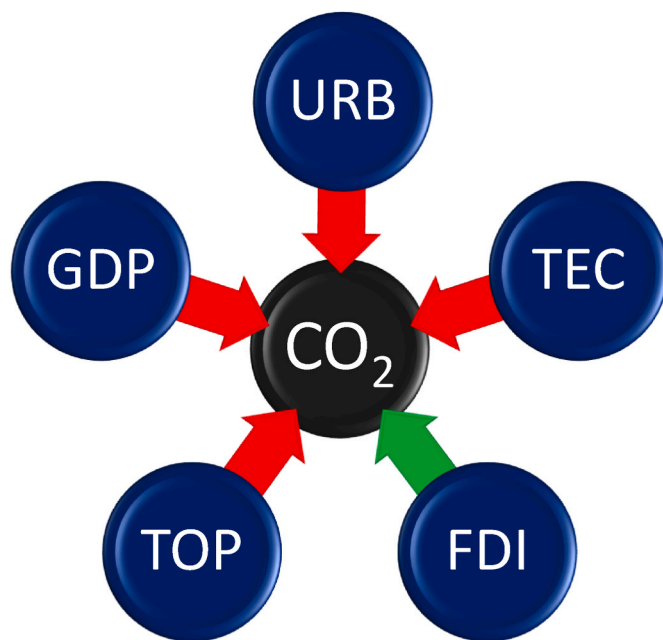


Fig. 3. Schematic presentation of analysis results.

Note. The red arrow indicates that the independent variable increases CO₂, while the green arrow indicates that the independent variable decreases CO₂.

the regression graphs between the variables. A positive relationship was observed between GDP, transport energy consumption, financial development, and CO₂ emissions, while a negative relationship was identified between urban population growth, trade openness, and CO₂ emissions.

Table 3

The results of the cross-section dependence and the Delta tests.

Panel A. Cross-section dependence test for variables				
	LM (Breusch-Pagan, 1980)	Pesaran scaled LM (Pesaran, 2004)	Bias-adjusted scaled LM (Pesaran et al., 2008)	Pesaran CD (Pesaran, 2004)
LNCO ₂	55.94*** (0.000)	14.41*** (0.000)	14.35*** (0.000)	5.46*** (0.000)
LNGDP	185.60*** (0.000)	51.84*** (0.000)	51.78*** (0.000)	13.62*** (0.000)
LNTEC	156.91*** (0.000)	43.56*** (0.000)	43.50*** (0.000)	12.48*** (0.000)
LNTOP	58.92*** (0.000)	15.27*** (0.000)	15.21*** (0.000)	−0.191 (0.957)
URB	114.71*** (0.000)	31.38*** (0.000)	31.31*** (0.000)	3.82*** (0.000)
FDI	88.58*** (0.000)	23.84*** (0.000)	23.77*** (0.000)	8.92*** (0.000)

Panel B. Cross-section dependence test for the model		
Test	Statistic	p-value
LM	10.49	0.105
LM adj.	2.992***	0.002
LM CD	2.367**	0.017

Panel C. Delta test		
	Delta	p-value
	3.008***	0.003
adj.	3.337***	0.001

Note. *** p-value<0.01, ** p-value<0.05, and * p-value<0.10.

Table 4

The results of the panel CADF and CIPS unit root test.

Variables	CADF		CIPS			
	t-statistic	p-value	t-statistic	10 %	5 %	1 %
lnCO ₂	−0.319	0.999	−1.269	−2.21	−2.33	−2.55
lnGDP	−1.494	0.728	−1.394	−2.21	−2.33	−2.55
URB	−1.782	0.498	−0.986	−2.21	−2.33	−2.55
lnTOP	−1.106	0.924	−0.603	−2.21	−2.33	−2.55
lnTEC	−1.551	0.687	−1.607	−2.21	−2.33	−2.55
FDI	−1.962	0.349	−2.430**	−2.21	−2.33	−2.55
ΔlnCO ₂	−3.664***	0.000	−6.130***	−2.21	−2.33	−2.55
ΔlnGDP	−2.994***	0.000	−4.688***	−2.21	−2.33	−2.55
ΔURB	3.730***	0.000	−3.550***	−2.21	−2.33	−2.55
ΔlnTOP	−3.274***	0.000	−5.489***	−2.21	−2.33	−2.55
ΔlnTEC	−2.844**	0.012	−4.421***	−2.21	−2.33	−2.55
ΔFDI	−3.629***	0.000	−5.510***	−2.21	−2.33	−2.55

Note. *** p-value<0.01, ** p-value<0.05, and * p-value<0.10.

Table 5

Westerlund ECM panel cointegration tests.

Statistic	Value	Z-value	p-value	Robust p-value
Gt	−3.599***	−2.752	0.003	0.050
Ga	−4.207	1.958	0.975	0.600
Pt	−6.09**	−1.904	0.028	0.105
Pa	−9.859	−0.46	0.323	0.185

Note. *** p-value<0.01, ** p-value<0.05, and * p-value<0.10.

Table 6

Results of AMG estimation.

Variables	Coef.	Std.err.	z	P> z	[95 % Conf. Interval]	
lnGDP	0.38***	0.13	3.03	0.00	0.13	0.63
URB	−0.02	0.09	−0.20	0.85	−0.20	0.16
lnTOP	0.11	0.08	1.38	0.17	−0.05	0.26
lnTEC	0.37***	0.06	6.09	0.00	0.25	0.49
FDI	−0.60*	0.36	−1.67	0.09	−1.30	0.10

Note. *** p-value<0.01, ** p-value<0.05, and * p-value<0.10.

3.2. Model

Given the aim, this study examines the effect of transport energy consumption alongside economic growth, trade openness, urbanization, and financial development on CO₂ emissions. Our econometric model is given by Eq. (1). Following that, the models for time-varying panel causality analysis are presented in Eq. (1).

Table 7

Results of AMG estimation for country-specific coefficients.

Panel A. Egypt				Panel B. Kenya			
Variable	Coef.	Std. Err.	P-value	Variable	Coef.	Std. Err.	P-value
lnGDP	0.166	0.140	0.236	lnGDP	0.367***	0.127	0.004
lnTOP	0.217***	0.043	0.000	lnTOP	−0.069	0.098	0.480
URB	0.160**	0.062	0.010	URB	−0.280***	0.075	0.000
FDI	0.193	0.186	0.301	FDI	−1.440	0.757	0.057
lnTEC	0.534***	0.107	0.000	lnTEC	0.374***	0.110	0.001
Constant	−8.081**	3.166	0.011	Constant	−9.804***	2.938	0.001
Panel C. Morocco				Panel D. South Africa			
Variable	Coef.	Std. Err.	P-value	Variable	Coef.	Std. Err.	P-value
lnGDP	0.254	0.221	0.249	lnGDP	0.736***	0.300	0.014
lnTOP	0.265**	0.107	0.014	lnTOP	0.024	0.129	0.852
URB	0.018	0.037	0.631	URB	0.030	0.022	0.174
FDI	−0.253	0.483	0.600	FDI	−0.894**	0.359	0.013
lnTEC	0.314*	0.180	0.081	lnTEC	0.252	0.210	0.231
Constant	−8.607*	4.646	0.064	Constant	−18.512***	6.639	0.005

Note. *** p-value<0.01, ** p-value<0.05, and * p-value<0.10.

Table 8

Results of panel causality test (Dumitrescu–Hurlin (2012) Granger causality).

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
DLNGDP does not homogeneously cause DLNCO2	3.55436***	3.0623	0.002
DLNCO2 does not homogeneously cause DLNGDP	3.00756**	2.38621	0.017
DLNTEC does not homogeneously cause DLNCO2	5.21524***	5.11591	0.000
DLNCO2 does not homogeneously cause DLNTEC	2.0249	1.17118	0.242
DLNTOPT does not homogeneously cause DLNCO2	2.7851**	2.11114	0.035
DLNCO2 does not homogeneously cause DLNTOPT	2.97944**	2.35143	0.019
DURB does not homogeneously cause DLNCO2	2.05878	1.21307	0.225
DLNCO2 does not homogeneously cause DURB	1.0445	−0.04104	0.967
DFDI does not homogeneously cause DLNCO2	0.31048	−0.94863	0.343
DLNCO2 does not homogeneously cause DFDI	0.12389	−1.17934	0.238

Note. ***p < 0.01, **p < 0.05, *p < 0.10. Lags to include = 1.

$$\ln\text{CO}_{2it} = \alpha_0 + \alpha_1 \ln\text{GDP}_{it} + \alpha_2 \ln\text{TOP}_{it} + \alpha_3 \text{URB}_{it} + \alpha_4 \ln\text{TEC}_{it} + \alpha_5 \text{FDI}_{it} + \varepsilon_{it} \quad (1)$$

Where i subscript stands for cross-section units, whereas t subscript denotes time period. α_0 is the constant term, while $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are the coefficients of economic growth, trade openness, urbanization, transport energy consumption, and financial development, respectively. ε_{it} indicates the error term.

3.3. Econometric methodology

After testing the cross-sectional dependence and heterogeneity in the analysis stage, the unit root test of the variables was carried out. Then, according to the obtained result, the cointegration test was performed, and a long-run relationship between variables was revealed. Then, the long-run coefficients were examined using the AMG estimator for the panel and the countries in particular. Next, the Granger causality test of Dumitrescu–Hurlin (2012) was used to test the general causality results. This causality test is suitable for this study, as it is applied under cross-sectional dependence and heterogeneity. Finally, the bootstrap panel causality test in rolling windows, a current technique, was implemented. In this regard, before analysis, we should formulate the following equations based on the Zellner (1962) Seemingly Unrelated

Regressions (SUR) model:

$$\begin{aligned} \ln CO2_{1,t} &= \alpha_{1,1} + \sum_{l=1}^{llnCO2} \phi_{1,1,l} \ln CO2_{1,t-1} + \sum_{l=1}^{llnGDP} \beta_{1,1,l} \ln GDP_{1,t-1} + \sum_{l=1}^{IZ} \gamma_{1,1,l} Z_{1,t-1} + \varepsilon_{1,1,t} \\ \ln CO2_{N,t} &= \alpha_{1,N} + \sum_{l=1}^{llnCO2} \phi_{1,N,l} \ln CO2_{N,t-1} + \sum_{l=1}^{llnGDP} \beta_{1,N,l} \ln GDP_{N,t-1} + \sum_{l=1}^{IZ} \gamma_{1,N,l} Z_{N,t-1} + \varepsilon_{1,N,t} \end{aligned} \quad (2)$$

$$\begin{aligned} \ln GDP_{1,t} &= \alpha_{2,1} + \sum_{l=1}^{llnCO2} \phi_{2,1,l} \ln CO2_{1,t-1} + \sum_{l=1}^{llnGDP} \beta_{2,1,l} \ln GDP_{1,t-1} + \sum_{l=1}^{IZ} \gamma_{2,1,l} Z_{1,t-1} + \varepsilon_{2,1,t} \\ \ln GDP_{N,t} &= \alpha_{2,N} + \sum_{l=1}^{llnCO2} \phi_{2,N,l} \ln CO2_{N,t-1} + \sum_{l=1}^{llnGDP} \beta_{2,N,l} \ln GDP_{N,t-1} + \sum_{l=1}^{IZ} \gamma_{2,N,l} Z_{N,t-1} + \varepsilon_{2,N,t} \end{aligned} \quad (3)$$

$$\begin{aligned} \ln TOP_{1,t} &= \alpha_{3,1} + \sum_{l=1}^{llnCO2} \phi_{3,1,l} \ln CO2_{1,t-1} + \sum_{l=1}^{llnTOP} \beta_{3,1,l} \ln TOP_{1,t-1} + \sum_{l=1}^{IZ} \gamma_{3,1,l} Z_{1,t-1} + \varepsilon_{3,1,t} \\ \ln TOP_{N,t} &= \alpha_{3,N} + \sum_{l=1}^{llnCO2} \phi_{3,N,l} \ln CO2_{N,t-1} + \sum_{l=1}^{llnTOP} \beta_{3,N,l} \ln TOP_{N,t-1} + \sum_{l=1}^{IZ} \gamma_{3,N,l} Z_{N,t-1} + \varepsilon_{3,N,t} \end{aligned} \quad (4)$$

$$\begin{aligned} \ln URB_{1,t} &= \alpha_{4,1} + \sum_{l=1}^{llnCO2} \phi_{4,1,l} \ln CO2_{1,t-1} + \sum_{l=1}^{llnURB} \beta_{4,1,l} \ln URB_{1,t-1} + \sum_{l=1}^{IZ} \gamma_{4,1,l} Z_{1,t-1} + \varepsilon_{4,1,t} \\ \ln URB_{N,t} &= \alpha_{4,N} + \sum_{l=1}^{llnCO2} \phi_{4,N,l} \ln CO2_{N,t-1} + \sum_{l=1}^{llnURB} \beta_{4,N,l} \ln URB_{N,t-1} + \sum_{l=1}^{IZ} \gamma_{4,N,l} Z_{N,t-1} + \varepsilon_{4,N,t} \end{aligned} \quad (5)$$

$$\begin{aligned} \ln TEC_{1,t} &= \alpha_{5,1} + \sum_{l=1}^{llnCO2} \phi_{5,1,l} \ln CO2_{1,t-1} + \sum_{l=1}^{llnTEC} \beta_{5,1,l} \ln TEC_{1,t-1} + \sum_{l=1}^{IZ} \gamma_{5,1,l} Z_{1,t-1} + \varepsilon_{5,1,t} \\ \ln TEC_{N,t} &= \alpha_{5,N} + \sum_{l=1}^{llnCO2} \phi_{5,N,l} \ln CO2_{N,t-1} + \sum_{l=1}^{llnTEC} \beta_{5,N,l} \ln TEC_{N,t-1} + \sum_{l=1}^{IZ} \gamma_{5,N,l} Z_{N,t-1} + \varepsilon_{5,N,t} \end{aligned} \quad (6)$$

$$\begin{aligned} \ln FDI_{1,t} &= \alpha_{6,1} + \sum_{l=1}^{llnCO2} \phi_{6,1,l} \ln CO2_{1,t-1} + \sum_{l=1}^{llnFDI} \beta_{6,1,l} \ln FDI_{1,t-1} + \sum_{l=1}^{IZ} \gamma_{6,1,l} Z_{1,t-1} + \varepsilon_{6,1,t} \\ \ln FDI_{N,t} &= \alpha_{6,N} + \sum_{l=1}^{llnCO2} \phi_{6,N,l} \ln CO2_{N,t-1} + \sum_{l=1}^{llnFDI} \beta_{6,N,l} \ln FDI_{N,t-1} + \sum_{l=1}^{IZ} \gamma_{6,N,l} Z_{N,t-1} + \varepsilon_{6,N,t} \end{aligned} \quad (7)$$

In Eqs. (2)–(6), 7), I states the optimal lag length, while Z denotes the other independent variables. For this study, Akaike's information criterion was utilized in the analysis process. It also focuses on the significance of the slope coefficients in the equations using the Wald test, with cross-section specific bootstrap critical values (Yilanci and Ozgur, 2019), to investigate the causality between variables. In the SUR model, the only possible connection between individual regressions is the contemporaneous correlation within the systems. This feature distinguishes the SUR model from the VAR model. It is also stated that, as bootstrap critical values are used for country/cross-section units in the SUR-based causality analysis, the variables do not need to be stationary, unlike the VAR model. With this, the nexus between residuals is crucial for the SUR-based approach, whereas the VAR model focuses on the lagged values of variables. In addition, in the presence of contemporaneous correlation for countries, Ordinary Least Squares (OLS) estimators are inefficient in accessing more information. Regarding contemporaneous correlation, in the system, the SUR are more successful estimators than the OLS estimators (Kónya, 2006). For this reason, a new panel data approach was applied by Kónya (2006). This approach is based on SUR

systems and Wald tests with country-specific bootstrap critical values. However, the causal relationships between variables may change over time. Yilanci and Özgür (2019) modified the causality test developed by Kónya (2006) and proposed the dimension of causality that changes over time. Therefore, we preferred to use this test to analyze the time change of causality. Fig. 2 presents the methodological steps used in the empirical analysis (see Fig. 3).

4. Empirical findings

The results of the analysis are as follows. First, we obtained the test results for the variables' cross-sectional dependence in Table 3. The test's null hypothesis is that the variables have no cross-sectional dependence. According to the test results, the null hypothesis can be rejected. In other words, there is evidence of cross-sectional dependence between the variables. Therefore, it seems appropriate to apply second-generation unit root tests. Similarly, the existence of cross-sectional dependence is shown in the model. The delta test provides information on whether the slope coefficients are homogeneous. In this context, the null hypothesis states that the slope coefficients are homogeneous.

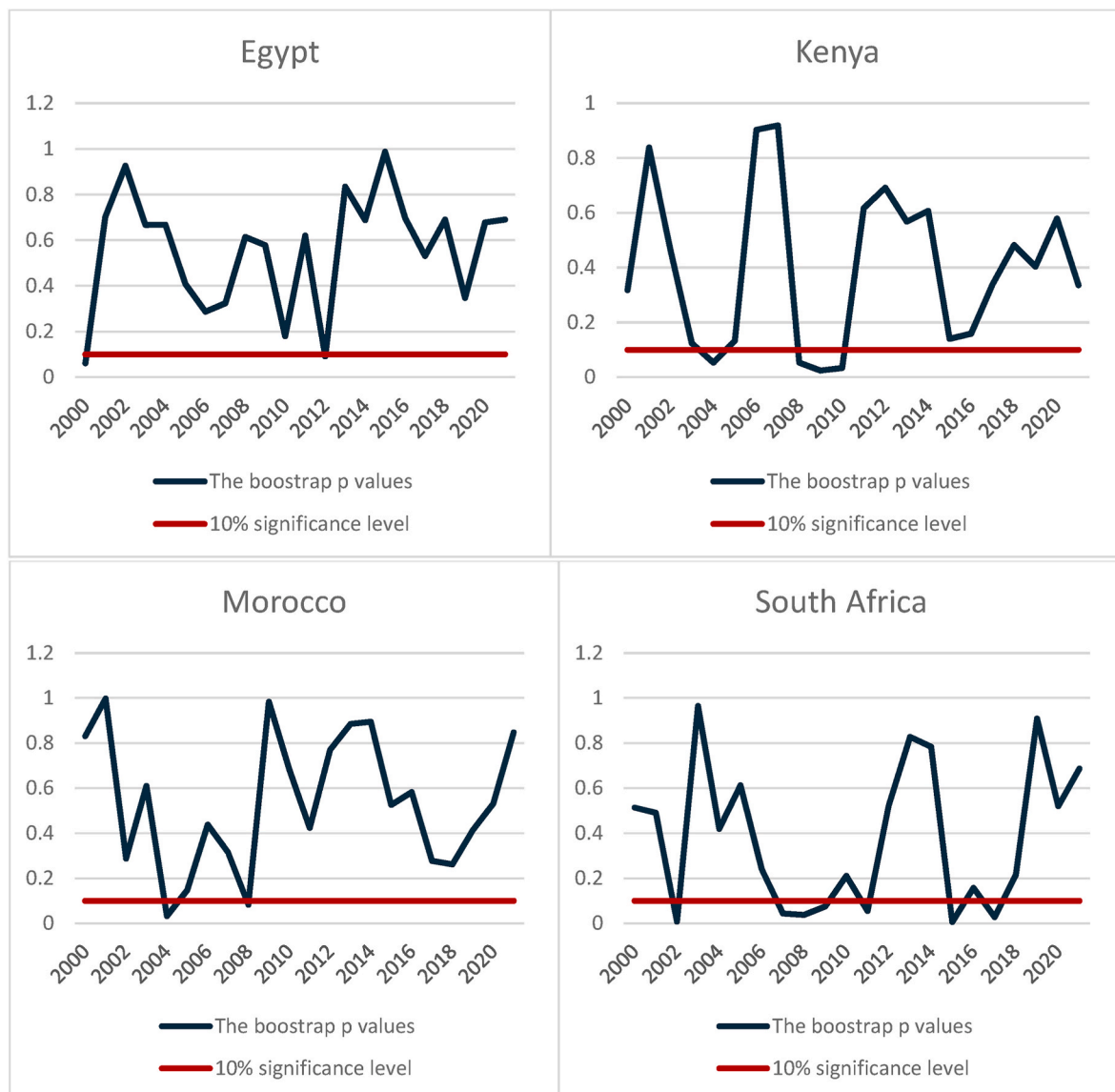


Fig. 4. Time-varying panel causality test results from $\ln\text{GDP}$ to $\ln\text{CO}_2$ for Egypt, Kenya, Morocco, and South Africa. The subsample window was selected as 11 using the $[T(0.01 + 1.8/\sqrt{T})]$ formula. In this formula, T denotes the period.

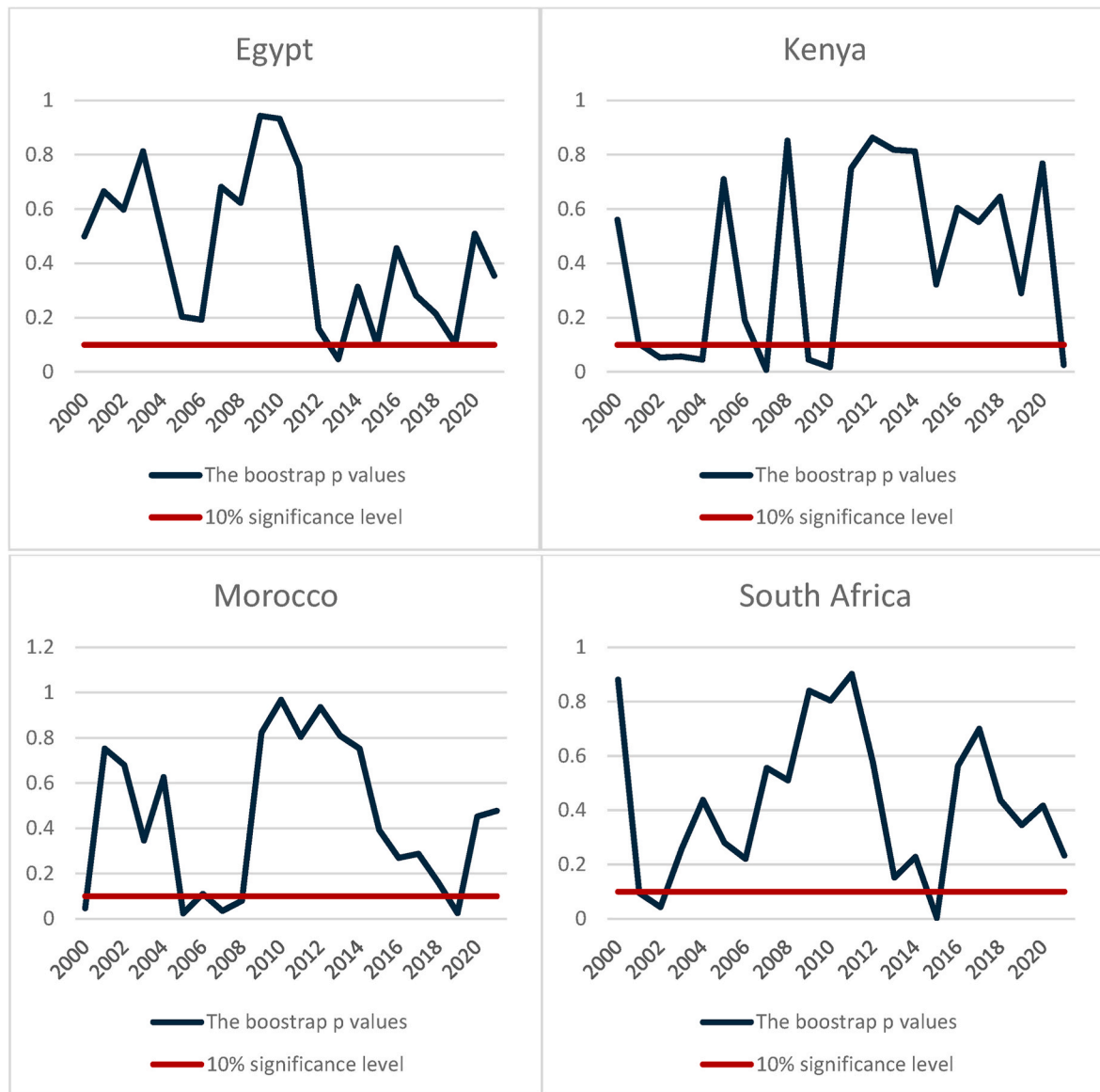


Fig. 5. Time-varying panel causality test results from URB to $\ln\text{CO}_2$ for Egypt, Kenya, Morocco, and South Africa. The subsample window was selected as 11 using the $[T(0.01 + 1.8/\sqrt{T})]$ formula. In this formula, T denotes the period.

The results of the delta test in Table 3 prove that the null hypothesis can be rejected. In other words, we conclude that the slope coefficients are heterogeneous.

In the remainder of the analysis, the panel Cross-Sectionally Augmented Dickey–Fuller (CADF) and Cross-Sectionally Augmented IPS (CIPS) unit root tests introduced by Pesaran (2007), which are the second generation unit root tests, are discussed. We present the results of the Panel CADF and the CIPS unit root test in Table 4. The null hypothesis of these tests states that a series has a unit root. According to the Panel CADF test result, the null hypothesis can be rejected for all variables at their level values. This means that the variables have unit roots at the level values. For this reason, the first differences in the variables were taken, and the application was repeated. Accordingly, the variables are stationary $I(1)$ after their first differences. The panel CIPS unit root test results are similar to those of the CADF unit root test, except for the FDI variable. The FDI variable is stationary at level values in the panel CIPS test.

In line with the results of the panel CADF test, we found that the

variables are stationary at $I(1)$. Therefore, we used the Westerlund ECM panel cointegration test proposed by Westerlund (2007), which considers cross-sectional dependence and is suitable for heterogeneous panels. The results of the Westerlund ECM panel cointegration test are presented in Table 5. The test's null hypothesis is that the variables have no cointegration relationship. The test results show that the null hypothesis is rejected for Gt and Pt . In other words, there is a long-run cointegration relationship between the variables (see Table 6).

Following the existence of the cointegration relationship, we employed the Augmented Mean Group (AMG) proposed by Bond and Eberhart (2009) and Eberhardt and Teal (2010) estimators for parameter estimates according to the suitability of the preliminary tests. The AMG estimation results indicate that a 1 % increase in $\ln\text{GDP}$ raises $\ln\text{CO}_2$ by 0.38 %, while a 1 % increase in $\ln\text{TEC}$ raises $\ln\text{CO}_2$ by 0.37 %. Additionally, a 1 unit increase in FDI has been proven to reduce $\ln\text{CO}_2$ by nearly 60 %. Afterwards, Table 7 presents the AMG estimation results for each country. Hence, in ceteris paribus, in Egypt, a 1 % increase in $\ln\text{TOP}$ raises $\ln\text{CO}_2$ by 0.21 %, while a 1 % increase in $\ln\text{TEC}$ increases

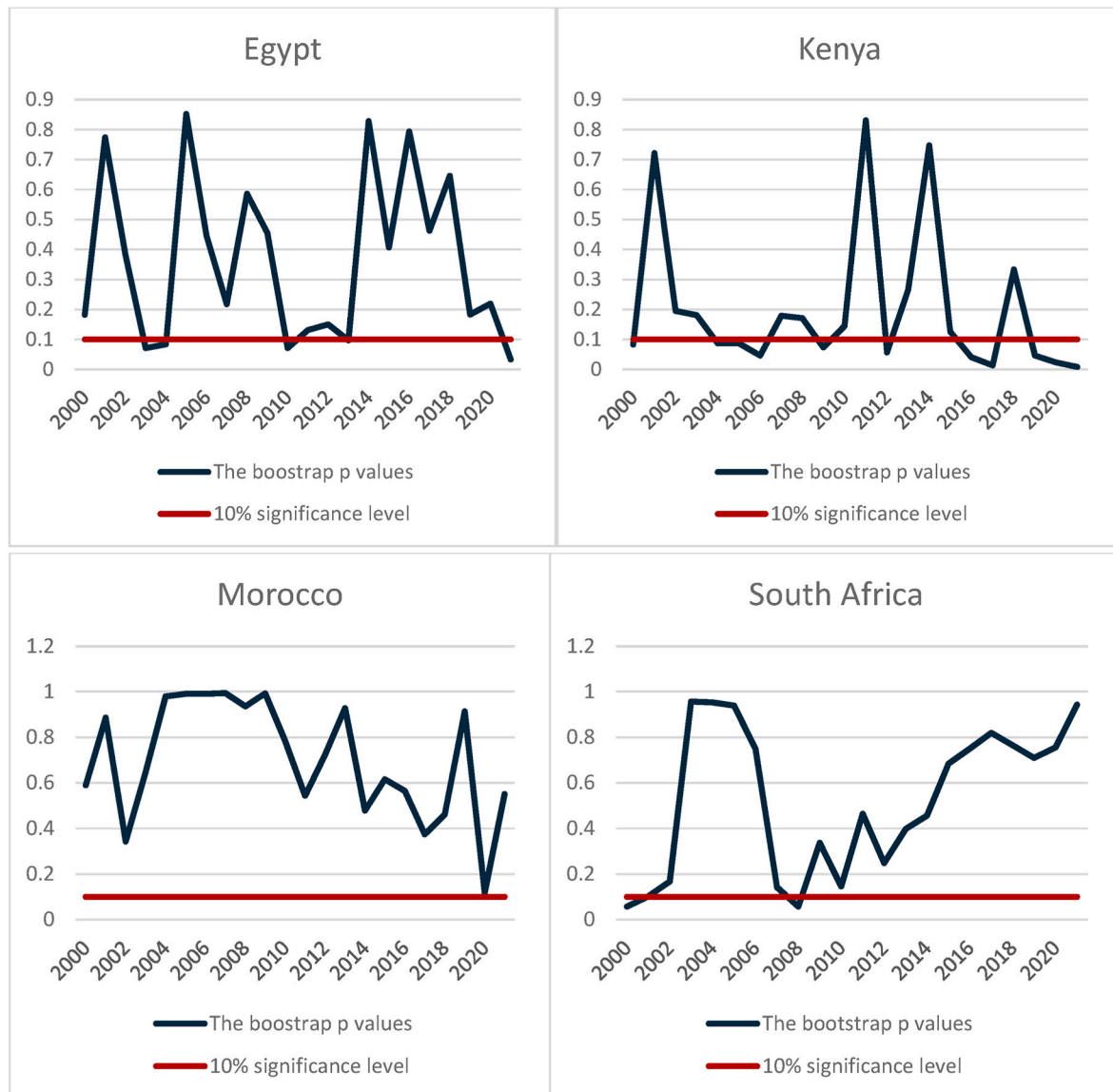


Fig. 6. Time-varying panel causality test results from $\ln\text{TOP}$ to $\ln\text{CO}_2$ for Egypt, Kenya, Morocco, and South Africa. The subsample window was selected as 11 using the $[T(0.01 + 1.8/\sqrt{T})]$ formula. In this formula, T denotes the period.

$\ln\text{CO}_2$ by 0.53 %. Also, on average, a 1 unit increase in URB boosts $\ln\text{CO}_2$ by 16 % (log-linear model). Moreover, *ceteris paribus*, in Kenya, a 1 % increase in $\ln\text{GDP}$ increases $\ln\text{CO}_2$ by 0.36 %, while a 1 % increase in $\ln\text{TEC}$ increases $\ln\text{CO}_2$ by 0.37 %. Also, in contrast to Egypt, on average, a 1 unit increase in URB decreases $\ln\text{CO}_2$ by 28 % (log-linear model). This result is due to Kenya's relatively low population growth rate, which has declined over the years. Furthermore, in Morocco, *ceteris paribus*, a 1 % increase in $\ln\text{TOP}$ raises $\ln\text{CO}_2$ by 0.26 %, while a 1 % increase in $\ln\text{TEC}$ raises $\ln\text{CO}_2$ by 0.31 %. Finally, a 1 % increase in $\ln\text{GDP}$ in South Africa boosts $\ln\text{CO}_2$ by 0.74 %, while a unit increase in FDI reduces $\ln\text{CO}_2$ by 89 % (log-linear model). It is an important finding that financial development significantly reduces environmental degradation in South Africa. As is well known, South Africa is the most economically developed of the countries studied. This result may be due to a shift from polluting sectors to financial sectors, which can have a positive impact on the environment.

Causality is a vital tool for understanding the origin of the relationship between variables. Here, as can be seen in Table 8, bidirectional causality was found between GDP and CO_2 , while unidirectional causality link was found from TEC to CO_2 . Finally, a bidirectional causality

link was found between the TOP and the CO_2 .

In the final step of the analysis, we interpreted the results of the time-varying panel causality tests. Accordingly, first, the unidirectional causality relationship from $\ln\text{GDP}$ to $\ln\text{CO}_2$ (Fig. 4) was observed in 2000 and 2012 for Egypt, in 2004 and 2008–2010 for Kenya, in 2004 and 2008 for Morocco, in 2002, 2007–2009, 2011, 2015, 2017 for South Africa. Moreover, the unidirectional causality relationship from URB to $\ln\text{CO}_2$ (Fig. 5) was determined in 2013 for Egypt, in 2001–2004, 2007, 2009–2010, and 2021 for Kenya, in 2000, 2005–2006, 2007–2008, and 2019 for Morocco, in 2001–2003, and 2015 for South Africa. Furthermore, the unidirectional causality relationship from $\ln\text{TOP}$ to $\ln\text{CO}_2$ (Fig. 6) was detected in 2003, 2010, and 2021 for Egypt, in 2000, 2004–2006, 2009, 2012, and 2016–2017, 2019–2021 for Kenya, and in 2000 and 2008 for South Africa. Additionally, the unidirectional causality relationship from $\ln\text{TEC}$ to $\ln\text{CO}_2$ (Fig. 7) was obtained in 2005 and 2021 for Egypt, in 2005, 2007, and 2013 for Kenya, and in 2007 and 2010 for Morocco. Finally, the unidirectional causality relationship from FDI to $\ln\text{CO}_2$ (Fig. 8) was observed in 2000, 2004, 2006, 2009, 2012, 2016–2017, 2019–2021 for Kenya, in 2001–2003, 2008, 2010, 2013, 2016–2017 for Morocco, in 2002, 2010–2011, and 2015–2017 for South

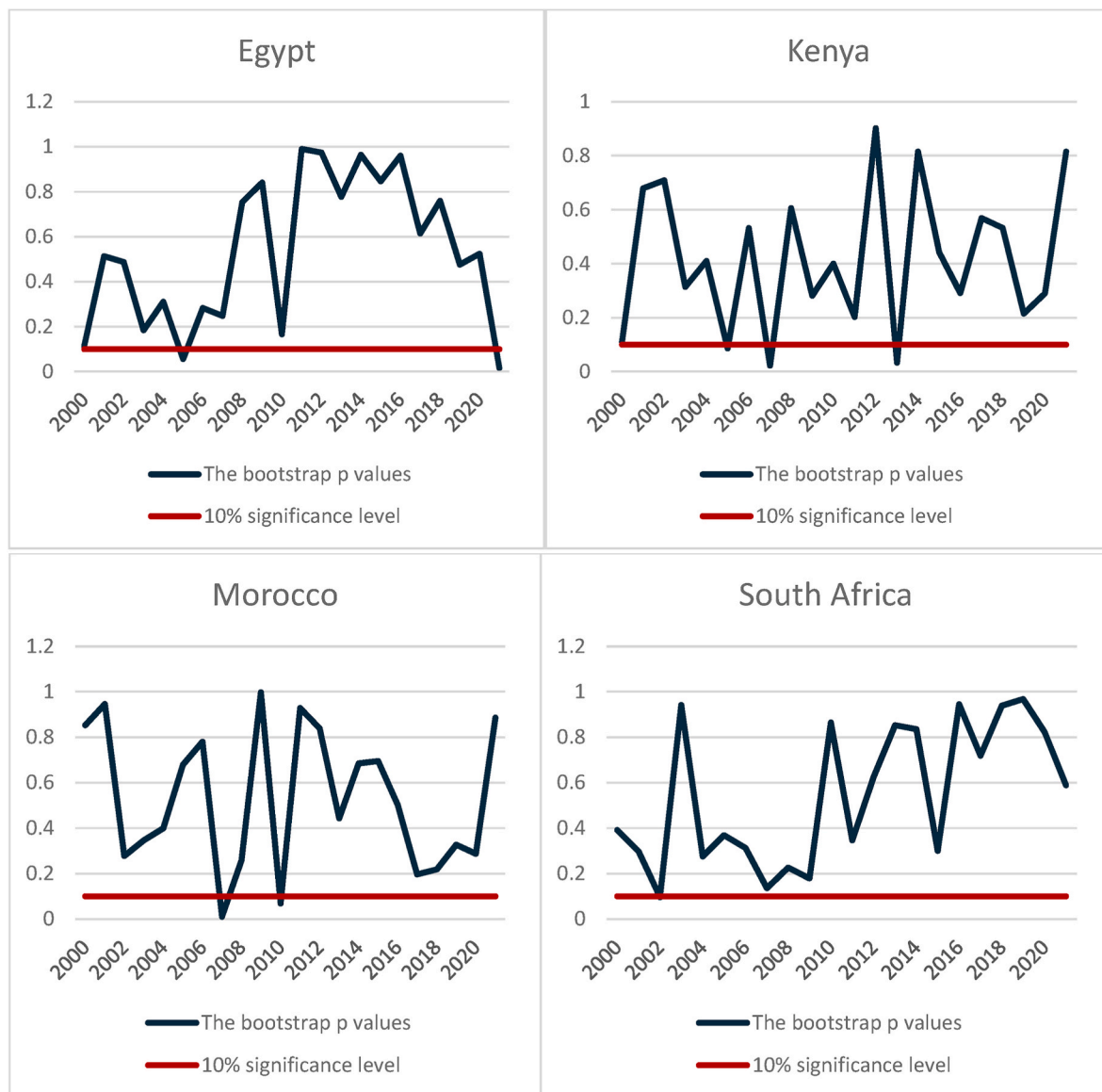


Fig. 7. Time-varying panel causality test results from $\ln\text{TEC}$ to $\ln\text{CO}_2$ for Egypt, Kenya, Morocco, and South Africa. The subsample window was selected as 11 using the $[T(0.01 + 1.8/\sqrt{T})]$ formula. In this formula, T denotes the period.

Africa. [Table 9](#) illustrates an overview of all results of the time-varying causality relationship.

5. Discussion

This paper examines the relationship between transport energy consumption, economic growth, trade openness, financial development, and urbanization with CO_2 emissions in specific African countries. The outcomes are important because they show the causes of environmental sustainability and the effectiveness of policies in addressing it. The results provide empirical support for the nine research hypotheses outlined. The analysis supported the first hypothesis, which indicated a statistically significant positive association between transport energy utilization and CO_2 emissions. For instance, [Saidi and Hammam \(2018\)](#) have shown that Egypt and South Africa, among others, are highly urbanized and motorized, hence focusing much more on fuel-based motorized transport systems, which have resulted in higher emissions of CO_2 according to former investigations ([Chen et al., 2020](#)). They also pointed out that transport infrastructure could lead to increased energy use and emission of carbon dioxide due to traffic jams. Therefore, there

is an urgent need to shift towards more energy-efficient modes of transport while giving prominence to public transit as a policy priority.

The findings for economic growth show varied outcomes, and trade openness (TOP) depends on the countries involved. As stipulated in hypothesis two, the rise in emissions due to trade openness has been witnessed in countries such as South Africa and Egypt because of increased trade in carbon-intensive goods and services. However, in other nations like Kenya, the influence is either non-existent or negative, signifying that the effects of TOPs on environmental degradation depend on the economy's structural aspect and existing regulatory policies. Similarly, [Pata and Caglar \(2021\)](#) found that TOP increases emissions in China, supporting the study's second hypothesis. On the contrary, in OECD economies between 199 and 2018, [Kim \(2022\)](#) ascertained that TOP reduces carbon emissions. On these grounds, it is evident that international trade policies must consider ecological objectives.

It can be noted from the study that the connection between urbanization and CO_2 emissions does not affect all countries uniformly, further aligning with hypothesis three, which states that the effect of urbanization on CO_2 emissions in African countries differs according to their economic fortune. For instance, in Egypt, there was a great deal of urban

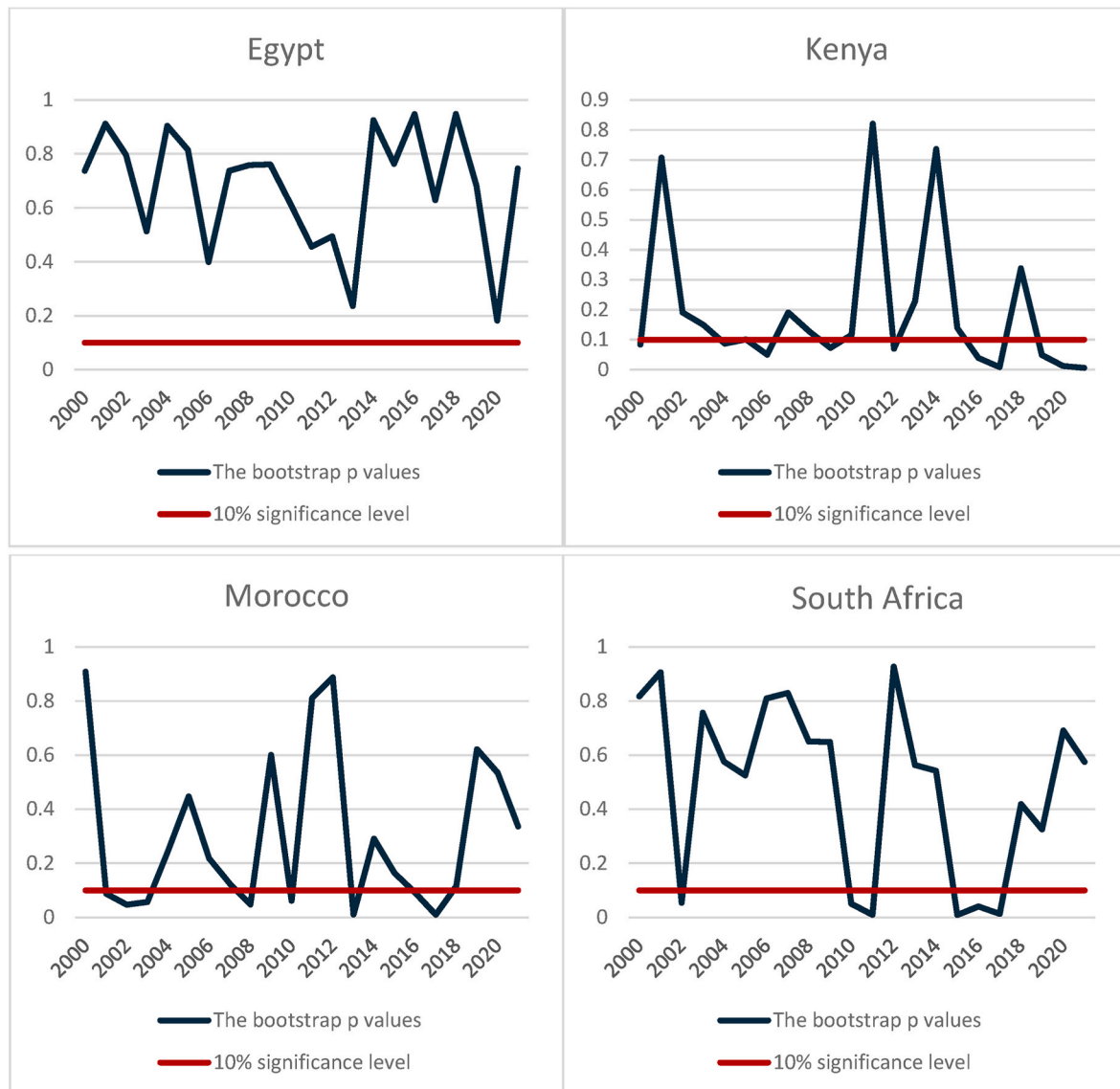


Fig. 8. Time-varying panel causality test results from FDI to $\ln\text{CO}_2$ for Egypt, Kenya, Morocco, and South Africa. The subsample window was selected as 11 using the $[T(0.01 + 1.8/\sqrt{T})]$ formula. In this formula, T denotes the period.

growth during the last decade, leading to more greenhouse gas emissions owing to inadequate infrastructural facilities based on fossil fuels. However, it is decreasing in Kenya due to lower population growth rates and deliberate attempts to make towns environmentally viable. Heydari et al. (2019) imply that urbanization depends on the level of infrastructure development and government policies that affect emissions.

According to this study, financial development is also instrumental in reducing CO₂ emissions, as stipulated in the study's hypothesis four, showing that promoting cleaner technologies by financial development leads to diminished CO₂ emissions. Consequently, decreasing volumes of these gases in the South African economy may be ascribed directly to increased industrial output. This, in turn, implies a need to invest in clean technologies owing to easy access to capital for such projects (Sharif et al., 2019). This stresses the need for stable financial markets to encourage more investment in eco-friendly projects as they promote sustainable development practices in African economies.

The findings lend credence to the argument that economic growth contributes to some extent to increasing greenhouse gas emissions through the EKC hypothesis, thus validating hypothesis five. Such increases in greenhouse gas emissions during the initial industrialization period and GDP levels are registered in countries like South Africa, thus

further showing that CO₂ emissions increase with GDP growth in selected African countries, especially in South Africa, support the early part of the Environmental Kuznets Curve hypothesis, whereby countries experience rising environmental degradation during early stages of growth until the income level is reached when improvement sets in. However, it may not hold in the long run as countries shift towards cleaner technologies and focus on safeguarding the environment; such it comes with contrary results in Kotroni et al. (2020), who refers to a new perspective on the relationship between economic indicators and environment damage which is gaining unexpected popularity among researchers. This is evident in the context of South Africa where economic prospects have led to a short-term rise in emission rates. However, this trend could change if leaders seek policies to move toward green growth over time.

Evidence from this paper reveals that nations such as Morocco, with more robust urban governance structures, have been able to mitigate the adverse consequences of transport energy consumption on the environment. Sustainable urban planning policies, stakeholder engagement, and institutional capacity are necessary for promoting energy-efficient mobility systems, as advocated for in the works of Rodrigue and Notteboom (2013). Such moves may involve infrastructure development

Table 9
General overview of time-varying panel causality test results.

Causality	Egypt	Kenya	Morocco	South Africa
GDP→CO ₂	2000–2002	2004, 2008–2010	2004–2008	2002, 2007–2009, 2011, 2015, 2017
URB→CO ₂	2013	2001–2004, 2007, 2009–2010, 2021	2000, 2005–2006, 2007–2008, 2019	2001–2003, 2015
TOP→CO ₂	2003, 2010, 2021	2000, 2004–2006, 2009, 2012, 2016–2017, 2019–2021	–	2000, 2008
TEC→CO ₂	2005, 2021	2005, 2007, 2013	2007, 2010	–
FDI→CO ₂	–	2000, 2004, 2006, 2009, 2012, 2016–2017, 2019–2021	2001–2003, 2008, 2010, 2013, 2016–2017	2002, 2010–2011, 2015–2017

Note. The dates given in the table are the dates for which there is a statistically significant causal relationship according to bootstrap critical values.

needed for transport and spatial concentration that would lead to the diffusion of ideas among people working together from similar firms, therefore working towards economic expansion by creating knowledge hubs based on shared suppliers and labor markets. However, in Egypt, vulnerable states often find it challenging to solve these problems concerning the environmental impact of using energy in transportation.

The study found that investment in sustainable transport infrastructure, such as public transport systems and electric cars, could significantly reduce the environmental footprint of urbanization. The outcomes align with the propositions of hypothesis six, stating that investing in sustainable transportation infrastructure reduces urbanization's negative ecological impact. By adopting a long-term perspective, [Liddle and Lung \(2013\)](#) aimed to investigate the causal relationship between GDP and transport energy consumption (TEC). Their findings showed that TEC has a causal relationship with GDP. Despite ongoing urban growth, expanding public transportation networks in Morocco have helped reduce CO₂ emissions. This shows the need for enhancing infrastructure investments that ensure sustainability while decreasing reliance on private cars.

The relationship between openness to trade and CO₂ emissions differs significantly between countries. In highly industrialized economies like South Africa, trade openness increases emissions because it is associated with the growth of carbon-intensive industries ([Xie et al., 2017](#)). Conversely, in lowly developed nations like Kenya, the link between trade openness and emissions is weak, implying that industrial composition is crucial in controlling the environmental impacts of trade.

6. Conclusion & policies

6.1. Conclusion

The findings of this research underscore the pressing need for concerted efforts to address the intertwined challenges of urban development, transport energy consumption, and environmental sustainability in African countries. The study highlights the urgency of adopting sustainable practices and implementing effective policies to mitigate the adverse impacts of escalating energy demands in transportation. By emphasizing the critical role of urban governance, policy frameworks, and stakeholder engagement, this research provides valuable insights for policymakers and urban planners seeking to navigate the region's urbanization complexities. The recommendations outlined herein offer a roadmap for fostering inclusive, environmentally conscious urban

development strategies to drive positive social, economic, and environmental outcomes for African cities. Through collaborative action, proactive policy interventions, and international cooperation, the vision of sustainable urban development in Africa can be realized, ensuring a resilient and prosperous future for future generations.

6.2. Policy recommendation

To address the challenges identified in the research and promote sustainable urban development in African countries, policymakers should prioritize promoting sustainable transport solutions, strengthening urban governance mechanisms, and developing and enforcing regulations that promote energy-efficient transport systems and reduce emissions. Additionally, capacity-building programs for urban planners, policymakers, and stakeholders should be implemented, fostering collaboration between government agencies, civil society, academia, and the private sector. Integrating environmental considerations into urban planning processes, establishing long-term sustainable urban development strategies, and supporting knowledge sharing and international cooperation are essential. Finally, seeking international cooperation and financial assistance from multilateral organizations, development banks, and donor agencies can help mobilize resources for infrastructure investments and capacity-building efforts, facilitating the transition towards sustainable urban development in Africa.

6.3. Limitations and future research suggestions

This research has its main limitations. First, it analyzed four African nations with limited data for generalizations for the whole continent. It is recommended that future studies incorporate various countries; thus, it will provide a chance for more profound research. Secondly, relying on only national-level data might ignore significant differences at the regional or city level. This calls for more research on city-based data to capture the localized effects of urbanization and transport energy. Moreover, the data is unavailable; hence, recent developments like post-pandemic transportation patterns may not be captured. Using newer information will give a clearer understanding of what is happening now. Finally, new technologies like electric vehicles could affect our cities. To this end, it is recommended that future researchers investigate the way forward regarding such inventions to reduce CO₂ emissions in cities. Consequently, there is a need for future researchers to direct their work to these areas as this would provide more comprehensive and practical solutions for achieving sustainable urban development.

CRedit authorship contribution statement

Salwa Bajja: Writing – original draft, Methodology, Investigation, Data curation. **Ali Celik:** Writing – review & editing, Software, Methodology, Data curation. **Michael Provide Fumey:** Writing – review & editing, Methodology.

Data availability statement

The article cites public sources where the raw data that underpins the conclusions can be accessed.

Statement

During the preparation of this work, the author(s) used ChatGPT to improve language and readability. After using this tool, the author(s) reviewed and edited the content as needed and took full responsibility for the publication's content.

Declaration of competing interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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