International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(1), 276-285.

Dynamic Causality between CO_2 Emissions, Urbanization and Economic Growth in India and South Africa

Gopal Ji Singh[1], Pawan Kumar Singh[2], Rakesh Kumar[3], Arfia Aman[4], Imran Alam[1], Ramla Fatma[5], Shoaib Ansari[6]*

[1]Department of Economics, Magadh University, Bodh Gaya, Bihar, India, [2]Department of Economics, Lakshmibai College, Delhi University, New Delhi, India, [3]Department of Geography, Magadh University, Bodh Gaya, Bihar, India, [4]Department of Finance, College of Administrative and Financial Sciences, Saudi Electronic University, Riyadh, KSA, Saudi Arabia, [5]Department of Management, Magadh University, Bodh Gaya, Bihar, India, [6]Department of Economics AKI's Poona College, Arts Science and Commerce, Savitribai Phule Pune University Pune, Maharashtra, India. *Email: sansari83@myamu.ac.in

Received: 26 June 2025 **Accepted:** 17 October 2025 **DOI:** https://doi.org/10.32479/ijeep.21757

ABSTRACT

This study investigates the interplay between urbanization, economic growth, and carbon dioxide emissions in South Africa and India, highlighting its significance for sustainable environmental management. Using autoregressive distributed lag (ARDL) bound testing and drawing on ecological modernization and urban environmental transition theories, the analysis covers the period 1971-2019. The results reveal a long-term relationship among urbanization, economic growth, and emissions in both countries. In South Africa, urbanization contributes to a reduction in carbon dioxide emissions, whereas in India, it negatively affects environmental quality and does not significantly mitigate pollution. Economic growth, however, consistently increases emissions over time in both nations. The study further finds that urban expansion predominantly drives emissions in South Africa, while economic growth has a stronger influence in India. These findings underscore the need for integrated urban and environmental planning, along with stable environmental regulations, to achieve long-term ecological benefits and align development with sustainable environmental objectives.

Keywords: Urbanization, ARDL Model, Cointegration, Variance Decomposition, Impulse Response Function
JEL Classifications: C32, Q43, Q54

1. INTRODUCTION

The sustainability of life on Earth is increasingly threatened by climate change and global warming, posing one of the greatest challenges to humanity. These environmental issues manifest across various magnitudes and spatiotemporal scales, largely driven by human activities such as unsustainable resource exploitation, rapid urbanization, industrialization, and population growth. A broad scientific consensus identifies greenhouse gas (GHG) emissions as the primary driver of global warming, with carbon dioxide (CO_2) accounting for nearly 73% of total emissions (Zhang et al., 2017). Since the pre-industrial era (1850-1900), anthropogenic activities have raised global surface temperatures by an estimated 1.07°C, representing an unprecedented change over the last two millennia (Legg, 2021). The consequences of this warming are evident across the atmosphere, hydrosphere, and biosphere, manifested through shifting precipitation patterns, floods, droughts, glacier retreat, sea-level rise, and increased frequency of extreme weather events such as cyclones and tornadoes. Urbanization and economic growth further exacerbate energy demand and CO_2 emissions, particularly in developing countries where urban populations are expanding faster than in developed nations (Sadorsky, 2014; Khan et al., 2023).

India, with the world's second-largest urban population after China, contributes approximately 60% of its GDP through urban centers (Outridge et al., 2018), and its urban population grew nearly fourfold from 109 million in 1970 to 493 million in 2021. Similarly, South Africa, one of Africa's most urbanized countries, had 67.35% of its population residing in urban areas by 2020 (Mingst et al., 2022). Combined, India and South Africa account for 487.34 million urban dwellers, exceeding the population of Oceania and the European Union (Mingst et al., 2022). Both nations are also major contributors to global CO_2 emissions: South Africa, the largest emitter in Africa, and India, the second-largest in Asia after China, collectively account for 8.4% of global emissions, surpassing the European Union's 7.9% share (Holechek et al., 2022). South Africa alone contributes 35% of Africa's emissions, while economically, South Africa ranks as the continent's second-largest economy and India as the world's fifth-largest (World Bank, 2017). These statistics underscore the importance of analyzing the nexus of urbanization, economic growth, and environmental impact in these countries. Decoupling economic expansion and urbanization from CO_2 emissions is therefore critical for sustainable development. Ecological Modernization Theory posits that economic growth often degrades the environment, and sustainability requires a shift from carbon-intensive industrial economies to service-oriented, low-carbon structures (Poumanyvong and Kaneko, 2010). Similarly, Urban Environmental Transition Theory suggests that urban populations tend to consume more carbon than rural ones, meaning early industrialization-driven urbanization can initially worsen environmental quality (Salahuddin et al., 2019).

Empirical evidence supports the linkages between economic growth and CO_2 emissions (Anser et al., 2020), as well as between urbanization and emissions (Kasman and Duman, 2015; Zi et al., 2016), though results often vary due to methodological differences. Despite their global importance, comparative studies exploring the dynamic interactions among urbanization, economic growth, and CO_2 emissions in South Africa and India remain limited. This study addresses this gap by systematically investigating both short- and long-term effects of urbanization and economic growth on CO_2 emissions in the two countries. Specifically, the study applies the ARDL approach to assess symmetric effects, employs the Toda-Yamamoto test to examine causal relationships, and uses Impulse Response Functions (IRF) and Variance Decomposition (VDC) to evaluate the relative exogeneity and endogeneity of variables. By comparing findings across South Africa and India, the study provides evidence-based insights for policymakers to develop targeted strategies for sustainable urban and economic planning. The paper is organized into five sections: introduction, literature review, research methodology, results and discussion, and conclusion with policy recommendations.

2. REVIEW OF LITERATURE

Over the past few decades, extensive empirical research has explored the causal links between urbanization, economic growth, and CO_2 emissions across diverse temporal and spatial contexts. Nonetheless, findings remain inconsistent across countries and periods, often due to methodological variations. Many studies examining the environmental impacts of urbanization have relied on frameworks such as Ecological Modernization Theory and Urban Environmental Transition Theory. For example, Wang et al. (2022), using a geographically weighted regression (GWR) model, analyzed regional and temporal differences in urbanization quality and CO_2 emissions across 30 Chinese provinces from 2000 to 2015, concluding that improvements in urban quality consistently reduce emissions. Similarly, Poumanyvong and Kaneko (2010) found that the relationship between urbanization and energy consumption varies with a country's development level, showing a positive association in middle- and high-income nations and a negative one in low-income settings.

Further studies have examined the role of economic growth in shaping environmental outcomes. Chen et al. (2014) reported no direct link between urbanization rates and global economic growth, though urbanization was significantly associated with GDP per capita. Supporting the Environmental Kuznets Curve (EKC) hypothesis, Liu (2009) identified unidirectional causality from urbanization to total energy consumption in China in both the short and long term. Panel studies suggest that CO_2 emissions are influenced by energy consumption, trade openness, and urbanization in the short term, while long-term models demonstrate strong cointegration among these variables. Country-specific evidence reveals substantial heterogeneity. Using ARDL modeling, Salahuddin et al. (2019) found that urbanization in South Africa positively affects CO_2 emissions in both the short and long term. Alhashim et al. (2024) analysed E-7 countries, and Anser et al. (2020) examined SAARC nations, reporting a U-shaped relationship between household CO_2 emissions and urbanization, with GDP as a key positive driver. Anwar et al. (2020), using panel fixed-effects models, confirmed that trade openness, urbanization, and economic growth significantly increase emissions, advocating renewable energy, green urbanization, and industrial restructuring.

In India, cointegration and Vector Error Correction Model analyses (Phillips and Perron, 1988; Gregory and Hansen, 1996) highlighted feedback effects, showing short-term causality from energy consumption and trade to CO_2 emissions and from emissions to growth. Evidence from Africa and other emerging economies further demonstrates these dynamics. Ali et al. (2016) employed the ARDL approach on Nigerian data covering 1971-2011. More recent studies have utilized advanced ARDL techniques in BRICS countries: Chishty et al. (2025) implemented the PMG ARDL model, Khan et al. (2025) applied the CS-ARDL method, and Shareef et al. (2025) also used CS-ARDL for their analysis. Alam et al. (2016) found that income, energy use, and emissions were strongly positively correlated across Brazil, China, India, and Indonesia, though population growth effects varied. Ali et al. (2020) also confirmed a positive long-term relationship between Nigeria's economic growth and energy consumption but cautioned that urbanization might impede sustainable growth over time. Recent studies on BRICS economies (Chen et al., 2022; Khan et al., 2025) and analyses of financial development impacts (Kwakwa, 2020; Rafindadi, 2016a) further emphasize the intertwined effects of urbanization, economic growth, and emissions, stressing the importance of structural reforms and green investments.

Despite the growing literature, significant gaps remain. Comparative studies that systematically examine the short- and long-term interactions between urbanization, economic growth, and CO_2 emissions in large emerging economies like South Africa and India are still limited. Moreover, the relative contributions of urbanization, economic expansion, trade, and energy consumption to emissions remain insufficiently quantified in these contexts, and there is a lack of integrated analyses combining ARDL, causality tests, and dynamic decomposition techniques. Addressing these gaps is crucial to inform targeted policies for sustainable urban and economic development while mitigating environmental degradation in major carbon-emitting nations.

3. DATA AND METHODOLOGY

3.1. Data Source and Econometric Model

This study utilizes data from the World Data Bank (2022) for the period 1971-2014, with values for 2015-2019 projected using the Sutte ARIMA model (Ahmar, 2018). It investigates the impact of urbanization on CO_2 emissions while accounting for the mediating role of economic growth. Urbanization, measured as the growth of urban population due to rural-to-urban migration, follows the approach outlined by Sadorsky (2014). Environmental degradation is proxied by per capita CO_2 emissions (Brown and McDonough, 2016). To address issues of dimensional inconsistency, ensure stationarity (Lau et al., 2014), and reduce the risks of heteroskedasticity and autocorrelation, all variables are transformed into their natural logarithms, a method validated in prior studies (Bekhet and Othman, 2017; Shahbaz et al., 2014). This logarithmic transformation enhances the stability and reliability of the empirical results by minimizing data volatility.

Following Miao (2017), the study evaluates the relationship between CO_2 emissions and urbanization, assuming a linear association where economic growth contributes to emissions. The framework of Ecological Modernization (EM) theory is applied to conceptualize the interrelations among CO_2 emissions, urbanization, and GDP. Urbanization affects household energy consumption patterns by influencing social behavior and increasing urban density (Kaneko, 2010). The study employs a specified functional form and econometric model to empirically analyze these relationships and address the research objectives.

$$CO_{2t} = f\,(URt,\ GDPt) \tag{1}$$

In addition, the following econometric model has been utilised in the analysis:

$$CO_{2tj} = \alpha_j + \beta_{1j}\, UR_{tj} + \beta_{2j}\, GDP_{tj} + U_{tj} \tag{2}$$

CO_2tj, URtj, and GDPtj denote carbon dioxide emissions, urbanization rate, and economic growth, respectively, for India and South Africa. Before conducting the analysis, it is essential to test the data for stationarity to ensure reliability. Stationary data help prevent spurious regressions and enable more accurate estimations. To verify the stationarity properties of the datasets for both countries, the KPSS test (Kwiatkowski et al., 1992) and the PP test (Perron, 1988) were applied. Additionally, the Zivot-Andrews (ZA) unit root test (Zivot and Andrews, 2002) was utilized to detect stationarity in the presence of a single structural break.

After confirming the order of integration, the autoregressive distributed lag (ARDL) model developed by Pesaran et al. (2001) was employed to examine the cointegration relationship among the variables. This model, which has been applied in previous studies (Johansen and Juselius, 1990; Lee and Lee, 2015) is preferred due to its flexibility and superiority over traditional cointegration approaches such as the Engle-Granger and Johansen-Juselius tests. The ARDL framework used in this study helps identify long-run relationships among the selected variables.

$$\begin{aligned}\Delta CO_{2(t)j} &= a_0 + \sum\nolimits_{i=0}^{n} a_{1ij}\, \Delta CO_{2(t-i)j} \\ &\quad + \sum\nolimits_{i=0}^{n} a_{2ij}\, \Delta UR_{(t-i)j} + \sum\nolimits_{i=0}^{n} a_{3ij}\, \Delta GDP_{(t-i)j} + \\ &\quad \alpha_{1j} CO_{2(t-1)j} + \alpha_{2j} UR_{(t-1)j} + \alpha_{3j}\, GDP_{(t-1)j} + U_{1j}\end{aligned} \tag{3}$$

j = 1 for India and j =2 for South Africa.

α_{1j}, α_{2j}, and α_{3j} indicate estimates of long-run effect and α_{1ij}, α_{2ij}, and α_{3ij} indicate estimates of short-run effect in the model. Null hypothesis, H_0: $\alpha_{1j} = \alpha_{2j} = \alpha_{3j} = 0$ is tested against the alternative hypothesis, H_1: $\alpha_{1j} \neq \alpha_{2j} \neq \alpha_{3j} \neq 0$. Pesaran et al. (2001) state that if the estimated F-statistic surpasses the upper critical value, the null hypothesis of no cointegration is rejected, signifying a long-run relationship among the variables. If the F-statistic is below the upper critical value, the null hypothesis cannot be rejected, indicating a lack of cointegration. Upon establishing cointegration, long-run coefficients are estimated, and short-run dynamics are analyzed using the Error Correction Model (ECM). The Error Correction Term (ECT) indicates both significance and negativity, reflecting the rate at which short-run disequilibrium converges to long-run equilibrium, thus affirming the model's stability. This paper used the following error correction model:

$$\begin{aligned}\Delta CO_{2(t)j} &= a_{0j} + \sum\nolimits_{i=0}^{n} a_{1ij} \Delta CO_{2(t-i)j} \\ &+ \sum\nolimits_{i=0}^{n} a_{2ij}\, \Delta UR_{(t-i)j} + \sum\nolimits_{i=0}^{n} a_{3ij}\, \Delta GDP_{(t-i)j} + \eta_1\, ECT_{(t-1)j}\end{aligned} \tag{4}$$

Finally, Breusch-Godfrey Serial Correlation test, ARCH test, and CUSUM tests for stability of the estimated model have been performed.

3.2. Toda-Yamamoto Causality Test

The Granger causality test, proposed (Granger, 1969), is widely used to examine causal relationships between variables. However, it has certain limitations, including issues related to model specification, lag length selection, and the possibility of spurious regressions (Gujarati, 1995). To overcome these shortcomings, the Toda Yamamoto (T-Y) causality approach developed by Toda and Yamamoto (1995) is applied. This method remains valid regardless of whether the variables are integrated of order I(0), I(1), or I(2), and whether they are cointegrated or not (Wolde-Rufael, 2005). Accordingly, this study employs the following functional specification to conduct the causality analysis:

$$\begin{aligned}CO_{2(t)j} &= b_0 + \sum\nolimits_{i=1}^{m} b_{1ij}\, CO_{2(t-i)j} + \sum\nolimits_{i=m+1}^{m+dmax} b_{2ij}\, CO_{2(t-i)j} \\ &+ \sum\nolimits_{i=1}^{m} b_{3ij}\, UR_{(t-i)j} + \sum\nolimits_{i=m+1}^{m+dmax} b_{4ij}\, UR_{(t-i)j} + V_{1j}\end{aligned} \tag{5}$$

$$UR_{(t)j} = c_0 + \sum_{i=1}^{m} c_{1ij} UR_{(t-i)j} + \sum_{i=m+1}^{m+dmax} c_{2ij} UR_{(t-i)j} + \sum_{i=1}^{m} c_{3ij} CO_{2(t-i)j} + \sum_{i=m+1}^{m+dmax} c_{4ij} CO_{2(t-i)j} + V_{2j} \quad (6)$$

$$CO_{2(t)j} = d_0 + \sum_{i=1}^{m} d_{1ij} CO_{2(t-i)j} + \sum_{i=m+1}^{m+dmax} d_{2ij} CO_{2(t-i)j} + \sum_{i=1}^{m} d_{3ij} GDP_{(t-i)j} + \sum_{i=m+1}^{m+dmax} d_{4ij} GDP_{(t-i)j} + V_{3j} \quad (7)$$

$$GDP_{(t)j} = f_0 + \sum_{i=1}^{m} f_{1ij} GDP_{(t-i)j} + \sum_{i=m+1}^{m+dmax} f_{2ij} GDP_{(t-i)j} + \sum_{i=1}^{m} f_{3ij} CO_{2(t-i)j} + \sum_{i=m+1}^{m+dmax} f_{4ij} CO_{2(t-i)j} + V_{4j} \quad (8)$$

$$UR_{(t)j} = g_0 + \sum_{i=1}^{m} g_{1ij} UR_{(t-i)j} + \sum_{i=m+1}^{m+dmax} g_{2ij} UR_{(t-i)j} + \sum_{i=1}^{m} g_{3ij} GDP_{(t-i)j} + \sum_{i=m+1}^{m+dmax} g_{4ij} GDP_{(t-i)j} + V_{5j} \quad (9)$$

$$GDP_{(t)j} = k_0 + \sum_{i=1}^{m} k_{1ij} GDP_{(t-i)j} + \sum_{i=m+1}^{m+dmax} k_{2ij} GDP_{(t-i)j} + \sum_{i=1}^{m} k_{3ij} UR_{(t-i)j} + \sum_{i=m+1}^{m+dmax} k_{4ij} UR_{(t-i)j} + V_{6j} \quad (10)$$

3.3. Variance Decomposition and Impulse Response Function

The Variance Decomposition (VDC) framework measures relative homogeneity and endogeneity, while the Error Correction Model (ECM) provides insights into absolute homogeneity and endogeneity within the system. VDC helps determine the extent to which external shocks contribute to variations over time by quantifying the percentage of forecast error variance in each endogenous variable attributable to exogenous influences. Moreover, the Impulse Response Functions (IRFs) illustrate both the magnitude and direction of the system's reactions, capturing the dynamic effects of shocks in one variable on the others throughout the adjustment process.

4. EMPIRICAL FINDINGS AND ANALYSIS

4.1. Descriptive Statistics

Table 1, revealed that the analysis explores the balanced influence of urban development and economic expansion on CO_2 emissions in India and South Africa from 1971 to 2019. The descriptive statistics summarize the behavior of CO_2 emissions, urbanization (UR), and GDP for India and South Africa. In India, all three variables show moderate variation, with positive skewness indicating slightly right-tailed distributions. South Africa's data display lower variability and are closer to normal distribution, as shown by low skewness and kurtosis values near three. The Jarque-Bera test probabilities for both countries exceed 0.05, confirming that the data are approximately normally distributed.

4.2. Unit Root Tests

Table 2 displays the outcomes of the KPSS test (Kwiatkowski, et al., 1992) and the PP test (Perron, 1988), revealing that CO_2 emissions, urbanization rate, and economic growth are non-stationary at level I(0) but become stationary after taking the first difference I(1) for both India and South Africa. The KPSS results further suggest that the datasets for both nations achieve stationarity at level I(0). However, in the presence of structural breaks, these conventional unit root tests may produce misleading or unreliable results, as highlighted by Adebayo (2021).

The Zivot-Andrews (ZA) unit root test was employed to examine the stationarity of the data while accounting for a single structural break in each series. Table 3 summarizes the results in accordance with Zivot and Andrews (2002). The findings indicate that, except for GDP growth, all variables achieve stationarity at their first difference, confirming the presence of structural breaks in both countries. In India, CO_2 emissions, urbanization, and economic growth exhibit structural breaks in 2001, 1981, and 2002, respectively. Similarly, for South Africa, structural breaks are identified in 1990 for CO_2 emissions, 1994 for urbanization, and 2003 for economic growth, suggesting significant economic and environmental shifts during these periods.

4.3. Long Run Effect

Table 4 presents the findings of the limits test (Pesaran et al., 2001). The F-statistic in India and South Africa is 14.54 and 5.55, respectively, exceeding the upper critical value of 5.00 at the 1% significance level, so affirming the existence of a cointegration relationship among CO_2, UR, and GDP.

Table 5 presents the long-run cointegration estimates, revealing distinct patterns between India and South Africa. In South Africa, urbanization exerts a positive influence on CO_2 emissions, whereas in India, it has a mitigating effect. This suggests that while urban growth in South Africa has contributed to higher emissions, in

Table 1: Results of descriptive statistics

Statistics	India			South Africa		
	CO_2	UR	GDP	CO_2	UR	GDP
Mean	6.7054	1.0736	6.619	9.0261	0.9704	8.7814
Median	6.7229	1.0178	6.5141	9.0332	0.965	8.7628
Maximum	7.5484	1.375	7.674	9.1737	1.2651	8.9336
Minimum	6.0029	0.8345	5.9442	8.9139	0.7268	8.6157
Standard Deviation	0.4991	0.18	0.5392	0.0609	0.1671	0.0972
Skewness	0.1734	0.4283	0.4597	−0.0565	0.277	0.123
Kurtosis	1.7959	1.932	1.9369	2.3922	1.7255	1.8975
Jarque-Bera	3.2055	3.8268	4.03351	0.7803	3.9429	2.6052
Probability	0.2013	0.1476	0.1331	0.677	0.1393	0.2718

Table 2: Results of unit root test

Tests type	Variables	India		South Africa	
		At level	At first difference	At level	At first difference
KPSS	CO_2	0.9088***	0.225	0.2176	0.0648
	UR	0.8454***	0.1299	0.5103**	0.1580
	GDP	0.9042***	0.8999***	0.3853*	0.2084
PP	CO_2	0.824	−6.3035***	−2.2	−5.9500***
	UR	−0.2976	−7.4878***	−0.8015	−3.2291**
	GDP	5.5174	−6.4068***	−0.7551	−4.2413***

***P<0.001 (1%), **P<0.005 (5%), *P<0.1 (10%)

Table 3: ZA unit root test (Intercept and trend structural break)

Country	Variables	ZA test statistic	Zivot-Andrew breakpoints (Year)
India	CO_2	−3.2378**	2001
	UR	−4.5648**	1981
	GDP	−0.05722	2002
South Africa	CO_2	−4.3043***	2003
	UR	−3.7334**	1994
	GDP	−3.5264	1990

***P<0.001 (1%), **P<0.005 (5%), *P<0.1 (10%)

Table 4: Results of bounds test

Country	Periods	Models	F-statistic
India	1971-2019	(1,0,0)	14.5438***
South Africa	1971-2019	(4,0,1)	5.5527***
Critical value		**I (0)**	**I (I)**
1%		4.13	5
5%		3.1	3.87
10%		2.63	3.35

***P<0.001 (1%), **P<0.005 (5%), *P<0.1 (10%)

Table 5: Estimated coefficients of ARDL models (Long-run elasticity)

Regressors	India	South Africa
UR	−1.0090***	0.1210***
GDP	0.6163***	0.5476***
C	3.7691***	4.0987***

***P<0.001 (1%), **P<0.005 (5%), *P<0.1 (10%)

India it has supported emission reduction efforts. These findings are consistent with those of Poumanyvong and Kaneko (2010) and Al-Mulali and Tang (2013), while the Indian results align with Sadorsky (2014). Drawing on ecological modernization and urban-environmental transition theories, the results imply that CO_2 emissions typically rise during the early phases of urbanization but decline as cities progress toward sustainable development. India's effective environmental policies and energy reforms explain the negative long-term relationship, while South Africa's absence of sustainable urban planning contributes to the continued positive association.

Elasticity estimates further demonstrate the sensitivity of CO_2 emissions to changes in urbanization. In India, a 1% increase in the urbanization rate leads to a 1.01% decline in emissions, reflecting the country's transition toward cleaner energy and efficient urban infrastructure. Conversely, in South Africa, a 1% rise in urbanization results in a 0.12% increase in emissions, indicating continued reliance on fossil fuels.

Additionally, economic growth significantly drives CO_2 emissions in both nations. A 1% expansion in GDP leads to a 0.62% increase in emissions in India and a 0.55% increase in South Africa, confirming the positive and robust relationship between economic activity and environmental degradation. These findings are in line with Anser et al. (2020).

4.4. Short Run Effect

Table 6 summarizes the short-run estimation results, showing that urbanization has a significant impact on CO_2 emissions in both India and South Africa. The coefficients for India are negative, while those for South Africa are positive. This implies that urbanization contributes to higher emissions in South Africa in both the short and long run, whereas in India, it consistently helps lower emissions over time. Economic growth, on the other hand, has a strong and immediate positive effect on CO_2 emissions in both nations, reaffirming its role as a key driver of environmental degradation. The error correction term (ECT) is negative and statistically significant for both countries, confirming the long-run stability of their respective systems. The adjustment coefficients indicate that short-term disequilibria are corrected at rates of 35.8% per year in India and 16.08% in South Africa. Hence, India's economy tends to restore equilibrium faster than South Africa's, reflecting stronger adjustment mechanisms in response to short-term shocks.

4.5. Diagnostic Tests

Following the approach proposed by Brown et al. (1975), diagnostic tests were conducted to verify the short- and long-term stability of the estimated model coefficients. These included the Cumulative Sum (CUSUM) tests based on recursive residuals, illustrated in Figures 1 and 2 for India and South Africa. The results show that both plots remain within the 5% significance boundaries, confirming the model's structural stability over time. Furthermore, as presented in Table 7, no evidence of serial correlation or heteroskedasticity is detected in either country's model, reinforcing the robustness and reliability of the estimated results.

4.6. Toda-Yamamoto Causality Test

Understanding causality is essential for policymakers, as it reveals the direction of influence among variables and supports the formulation of effective development strategies. Table 8 presents

Table 6: Estimated coefficients of ARDL models (Short run elasticity)

Regressors	India	South Africa
ΔCO_2 (−1)	0.6420***	0.6646***
ΔCO_2 (−2)	-----	−0.1141
ΔCO_2 (−3)	-----	−0.0542
ΔCO_2 (−4)	-----	−0.2844*
ΔUR	−0.3612***	0.0954**
ΔGDP	0.220633**	0.8563***
ΔGDP(-1)	-----	−0.4248
C	1.3493***	3.2301***
ECT (-1)	−0.3580***	−0.1608***

***P<0.001 (1%), **P<0.005 (5%), *P<0.1 (10%)

Table 7: Estimated coefficients of diagnostic tests

Tests	F-statistic	
	India	South Africa
Breusch-Godfrey Serial Correlation Test	0.0502	1.4004
Heteroskedasticity Test: ARCH	1.8427	0.0003

Table 8: Toda-Yamamoto causality test

Causality direction	Chi-square test	
	India	South Africa
$\Delta CO_2 \rightarrow \Delta UR$	7.479416***	6.205500
$\Delta UR \rightarrow \Delta CO_2$	5.614253**	18.14880**
$\Delta CO_2 \rightarrow \Delta GDP$	16.72202***	6.952489
$\Delta GDP \rightarrow \Delta CO_2$	1.201264	15.45268**
$\Delta UR \rightarrow \Delta GDP$	0.184661	13.56745
$\Delta GDP \rightarrow \Delta UR$	1.099151	2.863729

***P<0.001 (1%), **P<0.005 (5%), *P<0.1 (10%)

the results of the causality analysis based on the Toda-Yamamoto approach (Yamamoto and Kurozumi, 2006). The findings show a bidirectional causal link between CO_2 emissions and urbanization in India, while a unidirectional causality runs from economic growth to CO_2 emissions (Figure 3). This mutual interaction between urbanization and emissions is consistent with the results of Al-Mulali and Tang (2013). In contrast, for South Africa, the analysis identifies a one-way causality from urbanization to CO_2 emissions and from economic growth to CO_2 emissions (Figure 3), suggesting that emissions are primarily driven by urban growth and economic activity without feedback effects. Rafindadi, (2016) further note that globalization and energy consumption significantly aggravate environmental degradation in South Africa, as supported by the Toda-Yamamoto causality findings.

4.7. Variance Decomposition

Variance decomposition graph shows the contribution of exogenous variables in the variation of endogenous variables whereas historical decomposition model is used to interpret the historical variations in the estimated model from the angle of known structural shocks. Figures 4 and 5 show the results of variance decomposition and historical decomposition analysis for India while Figures 6 and 7 show the results for South Africa, demonstrating that the contribution of urbanization and economic growth in the variation of CO_2 emissions is

Figure 1: CUSUM Tests (India)

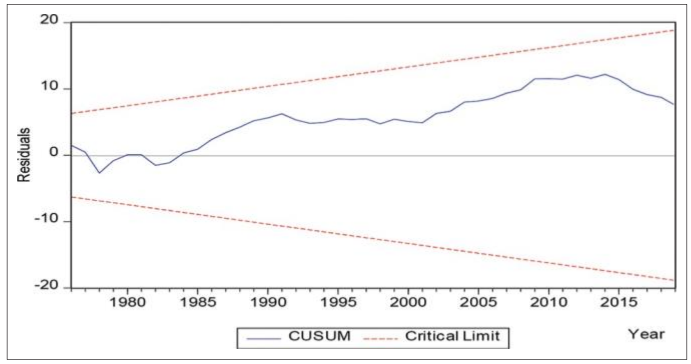


Figure 2: CUSUM (South Africa)

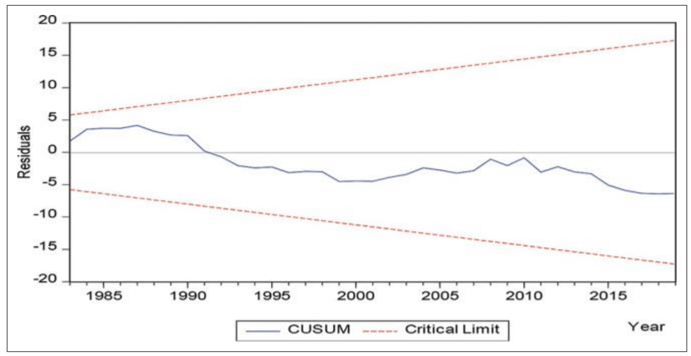
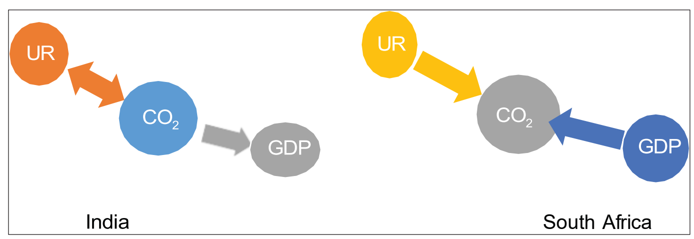


Figure 3: Causal relationship among variables in India and South Africa



continuously increasing in India but begins to decline after 2001. While urbanization and economic growth continue to increase their contributions to CO_2 emissions variation, the contribution of economic growth in South Africa begins to decline after 1983.

4.8. Impulse Response Function

Figures 8 and 9 illustrate the carbon dioxide emission impulse response function (IRF) to the standard deviation of urbanization and economic growth in India and South Africa, respectively. CO_2 emissions in India demonstrate a negative reaction to a one standard deviation shock in urbanization, as per the Impulse Response Function (IRF). Nonetheless, there has been a favorable response to the adverse effects of urbanization on CO_2 emissions since 1976. Nonetheless, South Africa experienced a beneficial impact of urbanization shock on CO_2 emissions until 1975. Despite the adverse impact of urbanization on CO_2 emissions, this negative effect has shown a positive response since 1981

Figure 4: Variance Decomposition of CO_2 using Cholesky Factors (India)

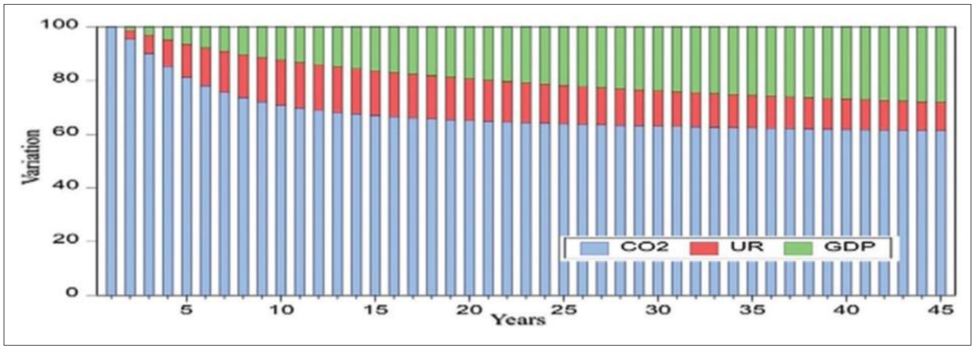


Figure 5: Historical Decomposition using Cholesky Weights (India)

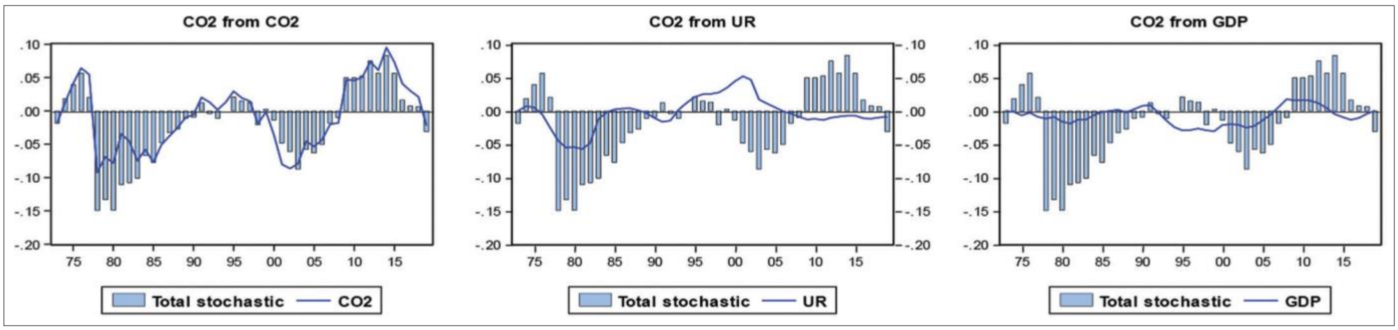


Figure 6: Variance Decomposition of CO_2 using Cholesky Factor (South Africa)

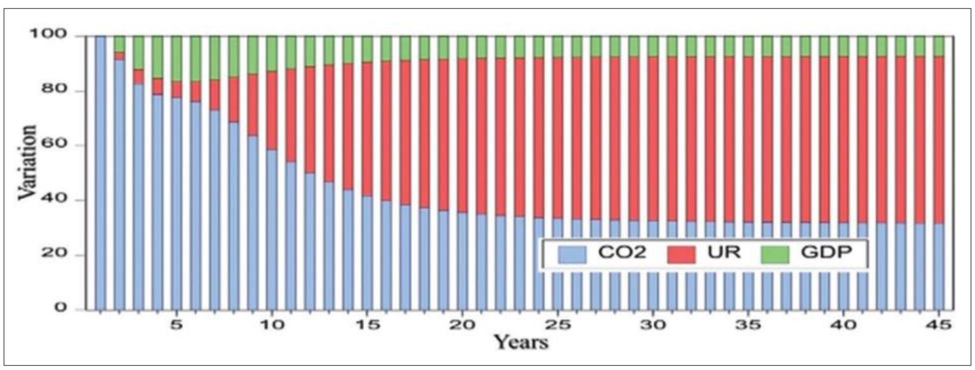
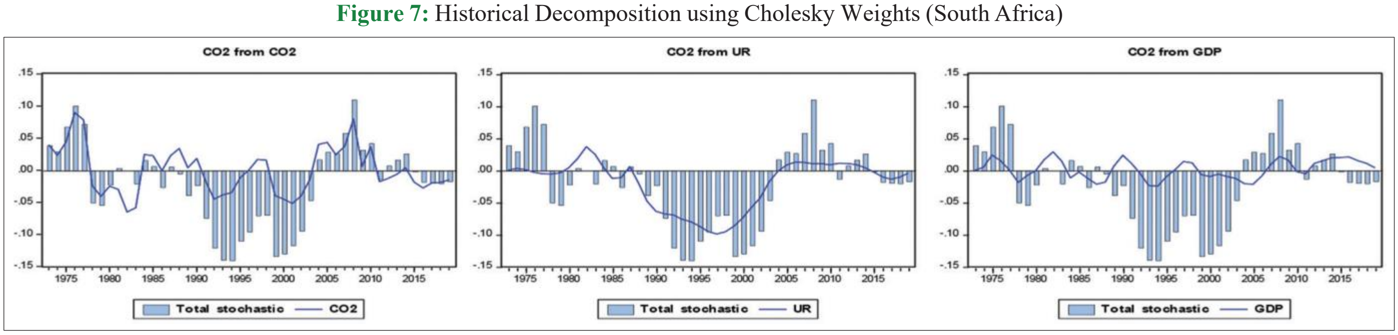


Figure 7: Historical Decomposition using Cholesky Weights (South Africa)



and is swiftly approaching a stable positive equilibrium. The IRF indicates that urbanization exerts an uneven impact on CO_2 emissions in South Africa. A one standard deviation shock to economic growth in India positively influences CO_2 emissions. In South Africa, the economic growth shock exerts an unbalanced impact on CO_2 emissions. Initially, economic expansion exerted a beneficial impact; however, post-1976, a one standard deviation perturbation in economic growth resulted in an adverse effect on CO_2 emissions. Subsequent to 1996, it re-establishes its positive steady-state trajectory.

Figure 8: Response to Cholesky One S.D. Innovations ± 2 S.E. (India)

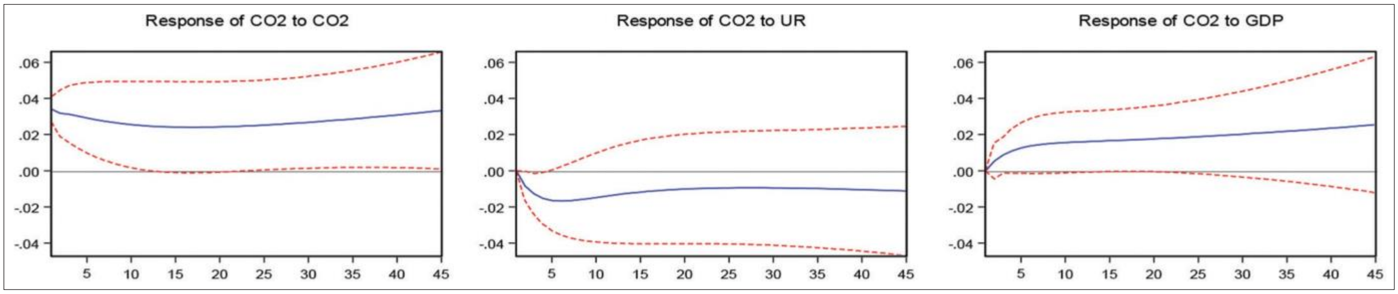
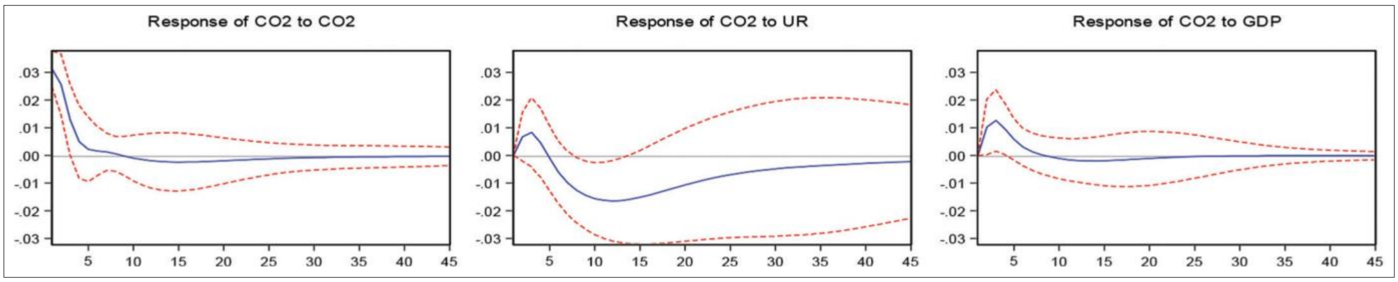


Figure 9: Response to Cholesky One S.D. Innovations ± 2 S.E. (South Africa)



5. CONCLUSION AND POLICY FRAMEWORK

Both South Africa and India are among the most urbanized countries on the planet. In spite of substantial economic growth, the twin nations are still grappling with the catastrophic threat of climate change. In this work, we use time-series data from 2014 to 2019 to examine how urbanization and economic development affected CO_2 emissions. Following the detection of unit roots and structural breaks, the long-run cointegration among the variables was investigated using the ARDL bounds testing methodology. Then, the short-run and long-run coefficients were estimated.

The findings show that CO_2 emissions are negatively impacted by urbanization in India. While this negative effect is severe at the outset, the impulse response function shows that it shifts to a positive steady state over time, most likely as a result of the fast development of both public and private infrastructure. Rapid urbanization, on the other hand, increases CO_2 emissions in South Africa, suggesting that the two are positively correlated. An imbalanced impact of urbanization on emissions in South Africa is brought to light by the impulse response function. Wang, et al., (2016) came to the same conclusions as these results. The use of energy-intensive resources in building, maintaining, and operating the infrastructure linked to urban expansion is mainly responsible for the beneficial effects in South Africa.

These results suggest that growing economies like South Africa and India will not be able to reduce environmental deterioration by merely reducing the pace of urbanization. A more practical approach to lowering CO_2 emissions is strategic urbanization, which can be bolstered by a shift to renewable energy sources (Kaneko, 2016). Emissions associated with urbanization may start to decrease after a certain point, hence it's crucial to set a firm urbanization threshold. Therefore, in order to keep up with the demands of expanding cities, governments should put renewable energy infrastructure development, sustainable technology deployment, and energy conservation at the top of their list of priorities.

The study also shows that both nations' CO_2 emissions are positively and significantly impacted by economic growth, which has a negative impact on environmental quality in the short and long run. Therefore, the link between growth and emissions needs to be addressed head-on in environmental policy. Nevertheless, poverty, inequality, corruption, and underfunded healthcare systems are some of the complicated issues that South Africa and India, two rapidly developing middle-income nations, confront. Neither nation can afford to put carbon reduction ahead of pro-growth policies. Rather, they should take supplementary actions including reorganizing industrial infrastructure, shifting consumption patterns toward renewable energy in both households and businesses, and encouraging a shift from manufacturing-based to service-oriented economies.

Energy efficiency and low-carbon technology should be aggressively promoted by policymakers with the help of financial sector actions. Crucial roles can be played by financial institutions, which can encourage clean businesses with accommodating loan terms and discourage polluting sectors with more stringent financing requirements. With these plans in place, the two countries would be better able to balance their development needs with environmental sustainability.

REFERENCES

Adebayo, T.S. (2021), Do CO_2 emissions, energy consumption and globalization promote economic growth? Empirical evidence from Japan. Environmental Science and Pollution Research, 2021, 34714-34729.

Ahmar, A.S. (2018), RcmdrPlugin. SutteForecastR: An RcmdrPlugin for

forecasting data. Journal of Physics Conference Series, 1028, 012224.
Alam, M.M., Murad, M.W., Noman, A.H.M., Ozturk, I. (2016), Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia. Ecological Indicators, 70, 466-479.
Alhashim, M., Rehman, M.Z., Ansari, S., Ahmed, P. (2024), Examining the influence of renewable energy consumption, technological innovation, and export diversification on economic growth: Empirical insights from E-7 Nations. Sustainability, 16(21), 9159.
Ali, H.S., Law, S.H., Zannah, T.I. (2016), Dynamic impact of urbanization, economic growth, energy consumption, and trade openness on CO_2 emissions in Nigeria. Environmental Science and Pollution Research, 23(12), 12435-12443.
Ali, H.S., Nathaniel, S.P., Uzuner, G., Bekun, F.V., Sarkodie, S.A. (2020), Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria: Fresh insights from Maki Cointegration and causality tests. Heliyon, 6(2), e03400.
Al-Mulali, U., Tang, C.F. (2013), Investigating the validity of pollution haven hypothesis in the gulf cooperation council (GCC) countries. Energy Policy, 60, 813-819.
Anser, M.K., Alharthi, M., Aziz, B., Wasim, S. (2020), Impact of urbanization, economic growth, and population size on residential carbon emissions in the SAARC countries. Clean Technologies and Environmental Policy, 22(4), 923-936.
Anwar, A., Younis, M., Ullah, I. (2020), Impact of urbanization and economic growth on CO_2 emission: A case of far East Asian countries. International Journal of Environmental Research and Public Health, 17(7), 2531.
Bekhet, H.A., Othman, N.S. (2017), Impact of urbanization growth on Malaysia CO_2 emissions: Evidence from the dynamic relationship. Journal of Cleaner Production, 154, 374-388.
Brown, R.L., Durbin, J., Evans, J.M. (1975), Techniques for testing the constancy of regression relationships over time. Journal of the Royal Statistical Society Series B Statistical Methodology, 37(2), 149-163.
Brown, S.P., McDonough, I.K. (2016), Using the environmental Kuznets curve to evaluate energy policy: Some practical considerations. Energy Policy, 98, 453-458.
Chen, H., Tackie, E.A., Ahakwa, I., Musah, M., Salakpi, A., Alfred, M., Atingabili, S. (2022), RETRACTED ARTICLE: Does energy consumption, economic growth, urbanization, and population growth influence carbon emissions in the BRICS? Evidence from panel models robust to cross-sectional dependence and slope heterogeneity. Environmental Science and Pollution Research, 29(25), 37598-37616.
Chen, M., Zhang, H., Liu, W., Zhang, W. (2014), The global pattern of urbanization and economic growth: Evidence from the last three decades. PLoS One, 9(8), e103799.
Chishty, S.K., Rashid, M., Ansari, S., Ahmad, F.R., Mallick, M.F., Khan, N. (2025), The impact of green technological innovation and management improvement on environmental quality in the BRICS economies. International Journal of Energy Economics and Policy, 15(2), 429.
Granger, C.W. (1969), Investigating causal relations by econometric models and cross-spectral methods. Econometrica Journal of the Econometric Society, 37, 424-438.
Gregory, A.W., Hansen, B.E. (1996), Residual-based tests for cointegration in models with regime shifts. Journal of Econometrics, 70(1), 99-126.
Gujarati, D.N. (1995), Basic Econometrics. New York: McGraw-Hill Inc.
Holechek, J.L., Geli, H.M.E., Sawalhah, M.N., Valdez, R. (2022), A global assessment: Can renewable energy replace fossil fuels by 2050? Sustainability, 14, 4792.
Johansen, S., Juselius, K. (1990), Maximum likelihood estimation and inference on cointegration-with applications to the demand for money. Oxford Bulletin of Economics and Statistics, 52(2), 169-210.
Kaneko, S. (2016), Integrated coal gasification combined cycle: a reality, not a dream. Journal of Energy Engineering, 142(2), E4015018.
Kasman, A., Duman, Y.S. (2015), CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. Economic Modelling, 44, 97-103.
Khan, A., Ansari, A., Khan, M.S., Ansari, S. (2023), The impact of financial sector, renewable energy consumption, technological innovation, economic growth, industrialization, forest area and urbanization on carbon emission: New insight from India. Korea Review of International Studies, 17(54), 60-77.
Khan, S., Fatma, R., Sinha, G.K., Alam, I., Dilawar, M., Hussain, D.M.S. (2025), Natural resource management and forest area dynamics: A Panel-ARDL assessment of environmental quality in BRICS nations. International Journal of Environmental Sciences, 11(22s), 2627-2641.
Kwakwa, P.A. (2020), The long-run effects of energy use, urbanization and financial development on carbon dioxide emissions. International Journal of Energy Sector Management, 14(6), 1405-1424.
Kwiatkowski, D., Phillips, P.C., Schmidt, P., Shin, Y. (1992), Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? Journal of Econometrics, 54(1-3), 159-178.
Lau, L.S., Choong, C.K., Eng, Y.K. (2014), Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do Foreign direct investment and trade matter? Energy Policy, 68, 490-497.
Lee, H., Lee, J. (2015), More powerful Engle-Granger cointegration tests. Journal of Statistical computation and Simulation, 85(15), 3154-3171.
Legg, S. (2021), IPCC, 2021: Climate change 2021-the physical science basis. Interaction, 49(4), 44-45.
Liu, Y. (2009), Exploring the relationship between urbanization and energy consumption in China using ARDL (autoregressive distributed lag) and FDM (factor decomposition model). Energy, 34(11), 1846-1854.
Miao, L. (2017), Examining the impact factors of urban residential energy consumption and CO2 emissions in China–Evidence from city-level data. Ecological indicators, 73, 29-37.
Mingst, K.A., Karns, M.P., Lyon, A.J. (2022), The United Nations in the 21st Century. London: Routledge.
Outridge, P.M., Mason, R.P., Wang, F., Guerrero, S., Heimburger-Boavida, L.E. (2018), Updated global and oceanic mercury budgets for the United Nations global mercury assessment 2018. Environmental Science Technology, 52(20), 11466-11477.
Perron, P.C. (1988), Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.
Pesaran, M.H., Shin, Y., Smith, R.J. (2001), Bounds testing approaches to the analysis of level relationships. Journal of applied econometrics, 16(3), 289-326.
Phillips, P.C., Perron, P. (1988), Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.
Poumanyvong, P., Kaneko, S. (2010), Does urbanization lead to less energy use and lower CO_2 emissions? A cross-country analysis. Ecological Economics, 70(2), 434-444.
Rafindadi, A.A. (2016), Revisiting the concept of environmental Kuznets curve in period of energy disaster and deteriorating income: Empirical evidence from Japan. Energy Policy, 94, 274-284.
Rafindadi, A.A. (2016a), Does the need for economic growth influence energy consumption and CO_2 emissions in Nigeria? Evidence from the innovation accounting test. Renewable and Sustainable Energy Reviews, 62, 1209-1225.

Sadorsky, P. (2014), The effect of urbanization on CO_2 emissions in emerging economies. Energy Economics, 41, 147-153.

Salahuddin, M., Ali, M.I., Vink, N., Gow, J. (2019), The effects of urbanization and globalization on CO_2 emissions: Evidence from the Sub-Saharan Africa (SSA) countries. Environmental Science and Pollution Research, 26(3), 2699-2709.

Shahbaz, M., Sbia, R., Hamdi, H., Ozturk, I. (2014), Economic growth, electricity consumption, urbanization and environmental degradation relationship in United Arab Emirates. Ecological Indicators, 45, 622-631.

Shareef, M., Ahmad, M.W., Ansari, S. (2025), Assessing financial development's and green technological innovation impact on environmental quality in India: A model-based approach. International Journal of Management (IJM), 16(1), 1-19.

Toda, H.Y., Yamamoto, T. (1995), Statistical inference in vector autoregressions with possibly integrated processes. Journal of Econometrics, 66(1-2), 225-250.

Wang, Y., Liu, Y., Li, Y., Li, T. (2016), The spatio-temporal patterns of urban–rural development transformation in China since 1990. Habitat International, 53, 178-187.

Wang, J., Werner, D., Manning, D.A. (2022), A framework for integrating the terrestrial carbon stock of estates in institutional carbon management plans. Soil Use and Management, 38(2), 1172-1188.

Wolde-Rufael, Y. (2005), Energy demand and economic growth: The African experience. Journal of Policy Modeling, 27(8), 891-903.

World Bank. (2017), International Economics Department. Development Data Group. United States: World Bank.

Yamamoto, T., Kurozumi, E. (2006), Tests for long-run Granger non-causality in cointegrated systems. Journal of Time Series Analysis, 27(5), 703-723.

Zhang, S., Liu, X., Bae, J. (2017), Does trade openness affect CO_2 emissions: Evidence from ten newly industrialized countries? Environmental Science and Pollution Research, 24(21), 17616-17625.

Zi, C., Jie, W., Hong-Bo, C. (2016), CO_2 emissions and urbanization correlation in China based on threshold analysis. Ecological Indicators, 61, 193-201.

Zivot, E., Andrews, D.W.K. (2002), Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. Journal of Business Economic Statistics, 20(1), 25-44.