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ARTICLE

The role of tourism development in improving environmental quality in South Africa: Insights from novel dynamic ARDL simulations approach

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Abstract

One approach to tackling environmental problems and achieving environmental sustainability goals is to boost the tourism industry, but this paradigm is also contested. Using the recently developed novel dynamic autoregressive distributed lag (DARDL) simulations framework, this study evaluates the influence of tourism development in promoting environmental quality in South Africa from 1960 to 2020. The results demonstrate that: (i) the growth of the tourism industry reduces CO_2 emissions over the short and long terms; (ii) the scale effect worsens ecological environment while the technique effect is ecologically friendly, supporting the environmental Kuznets curve (EKC) theory; (iii) trade openness strengthens ecological integrity in the short term but considerably intensifies environmental degradation over the long term; (iv) industrial production, foreign direct investment, economic complexity, and energy use increase CO_2 emissions while composition effect reduces it; (v) tourism development, industrial growth, trade openness, foreign direct investment, energy use, economic complexity index, composition effect, technique effect and scale effect Granger-cause CO_2 emissions in the short, long and medium term. These findings raise important policy questions.

Keywords: tourism development, trade openness, CO2 emissions, dynamic ARDL simulations, energy consumption, industrial value-added, South Africa

JEL classification: Z30; Z32; Z38; Z39; F18; F13; Q56; O13; F1; F41

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1. Introduction

Greenhouse gas (GHG) emissions are widely acknowledged as the primary drivers of global warming (Udeagha and Ngepah, 2022a; Udeagha and Breitenbach, 2023b). The once-prevailing notion that environmental degradation predominantly imperils industrialized nations, leaving less industrialized ones unaffected, no longer holds true (Uche et al., 2023). Irrespective of the region responsible for carbon pollution, the accumulation of GHGs in the Earth's atmosphere has significant repercussions worldwide. Recent ecological repercussions include the Japan tsunami, Haiti earthquake, Australia and Pakistan floods, and Russia's wildfires (Jena et al., 2022). These calamities have led to infrastructure losses, environmental asset depletion and, most crucially, the loss of human lives.

Given the vulnerability of every nation to such hazards, climate change has evolved into a global predicament. Countries like China, India, Russia, Brazil, USA, and countries in the OECD—recognized as major GHG emitters—bear a substantial responsibility to protect the planet from these perils (Udeagha and Ngepah, 2022b). Furthermore, the collaboration among these major polluters is pivotal to the success of global initiatives aimed at reducing CO_2 emissions. However, challenges arise for nations due to the intertwined relationship between CO_2 emissions and energy generation, crucial for economic advancement. Lowering CO_2 emissions in this context may seemingly lead to output reduction, hampering economic growth and industrial prosperity. Consequently, these economies may be hesitant to adhere to global regulations or commit to programs that lower pollution levels. This underscores the necessity for innovative approaches that harmonize sustainable economic progress and improved environmental quality (Udeagha and Breitenbach, 2021). In this context, promoting tourism emerges as a strategic avenue for nations to enhance environmental quality while fostering substantial economic growth.

Tourism's pivotal role in economic growth and environmental sustainability is acknowledged (Udeagha and Breitenbach, 2023c). Wangzhou et al. (2022) highlight its contributions: income generation, socio-economic progress, reducing inequality, food security, ecological integrity, cultural harmony, and knowledge exchange. Despite a smaller GDP share compared to mining and construction, tourism significantly boosts national GDP, even surpassing agriculture (Udeagha and Breitenbach, 2023d). Empirical studies, like Wang et al. (2012), underscore tourism's positive impact on accommodation, food, trade, and technology. South Africa's tourism began in 1947 with SATOUR's establishment (Udeagha and Breitenbach, 2023e). Despite apartheid-era challenges, post-apartheid, it thrived, becoming a key economic driver. Hosting global events like FIFA World Cup 2010, it attracted millions of visitors, making it a compelling focus for researching the tourism-CO_2 emissions link (Udeagha and Muchapondwa, 2022).

South Africa holds Africa's top emitter status, emitting around 390 million tonnes of CO_2 in 2020, ranking 15th globally (World Bank, 2021). Coal combustion is the chief driver of rising emissions (Udeagha and Ngepah, 2019, 2020). Coal dominates electricity generation, contributing 77% and fuelling industries, homes, and cooking (Udeagha and Ngepah, 2021a). With vast coal reserves, South Africa heavily depends on this sector. This makes it an apt focus for a study investigating the dynamic role of tourism in enhancing environmental quality. However, research on the ecological impact of tourism expansion has yielded inconsistent findings, fuelling debate (Tang et al., 2011). Some studies argue tourism improves environmental quality (Tang et al., 2011), while others contend it worsens conditions (Al-Mulali et al., 2015; Udeagha and Muchapondwa, 2023b). This underscores the complexity of the relationship between tourism growth and environmental outcomes, warranting comprehensive analysis.

This study contributes significantly to the literature on the interplay between the tourist industry and CO_2 emissions by addressing five key gaps: (i) While existing studies have explored various factors influencing South Africa's CO_2 emissions, the role of tourist development in enhancing ecological integrity has been underexplored. This study aims to bridge this gap. (ii) Instead of conventional approaches, the study employs the novel dynamic ARDL simulations methodology introduced by Jordan and Philips (2018), which provides a more accurate and versatile analysis of the long- and short-run relationships between tourism development and CO_2 emissions. (iii) By adopting the Squalli and Wilson (2011) trade openness metric, the study offers a distinct perspective on how trade openness influences the relationship between tourism growth and CO_2 emissions. (iv) The frequency domain causality (FDC) technique proposed by Breitung and Candelon (2006) is employed to assess permanent causation across different timeframes, enhancing the robustness of the findings. (v) Incorporating second-generation econometric methods, the study accounts for overlooked structural breaks. Narayan and Popp's structural break unit root test is used to address their impact on CO_2 emissions, trade openness, and tourism growth. Overall, this research enriches the understanding of the complex interactions between the tourist industry and CO_2 emissions, particularly within the context of South Africa.

The remaining sections of the work are arranged as follows. The key research on the relationship between tourism growth and CO_2 emissions is reviewed in Section 2. The material and procedures are presented in Section 3; the findings are covered in Section 4. Section 5 concludes with policy implications.

2. Tourism Development in South Africa: Stylized facts

South Africa stands out as a popular tourism destination with 3.8 million foreign visitors in 2020, hosting UNESCO World Heritage sites and boasting diverse landscapes. Its multicultural identity, with 11 official languages, adds to the allure. International visitors to South Africa increased by over 10% from 2011 to 2012, double the global average. The tourism sector directly contributed 5% to the GDP and employment rose from 4.3% to 4.5% (Udeagha and Muchapondwa, 2023d) Former President Zuma highlighted the nation's success in differentiating itself globally. Exploring how South Africa's appealing tourism programs and local community involvement contribute to this growth is crucial, as the nation continues to flourish as an inviting and unique destination. South Africa's tourism sector is a significant economic contributor, accounting for 10.3% of employment and ZAR 102 billion of GDP in 2012. South Africa Tourism, the official marketing authority, promotes the nation's diverse attractions, including natural landscapes, wildlife reserves, cultural heritage, and renowned wines. Iconic sites like Kruger National Park, coastal regions, and major cities such as Cape Town and Johannesburg are highly popular. The Tourism and Migration Survey revealed around 3.5 million visitors arrived in August 2017, with top sources being the United States, the United Kingdom, Germany, the Netherlands, and France. South African Development Community (SADC) nations like Lesotho, Mozambique, Eswatini, Botswana, and Nigeria also contribute significantly.

South Africa ranks sixth among the world's seventeen megadiverse nations, boasting a rich variety of wildlife. The northern bushveld houses numerous large mammals such as lions, leopards, rhinoceroses, and giraffes. Iconic game reserves like Sabi Sand and Kruger National Park are in the north-east, attracting 1,659,793 visitors in 2014-2015. The nation's diverse biomes include the endemic fynbos biome, the Highveld grasslands, and the saline Karoo (Udeagha and Muchapondwa, 2023c). Table Mountain National Park, protecting Table Mountain's unique flat-topped peak and vegetation, attracted 2,677,767 visitors during the same period. South Africa's cultural wealth is also notable, with monuments in Cape Town and Johannesburg, significant fossil-bearing caves, and remnants of the Mapungubwe Kingdom. Ten UNESCO World Heritage Sites, both cultural and natural, contribute to its allure.

The COVID-19 pandemic severely impacted South Africa's economy, including its travel and tourism industry. The sector's GDP contribution dropped to 3.7% in 2020, the lowest since 2005, down from 6.9% in the previous year. Employment in the industry also fell by 32.4% to around 987,000 jobs. The pandemic-triggered lockdowns led to a sharp decline in foreign arrivals, with visitors plummeting from 863,232 in March to 29,341 in April 2020. Even though recovering, foreign visitor numbers remained below pre-pandemic levels. Domestic spending outweighed foreign expenditure in both 2019 and 2020, with corporate spending showing a three-percentage-point increase in 2020 (Udeagha and Muchapondwa, 2023e). The lodging and non-tourism sectors were the main contributors to tourism direct gross value added (TDGVA) in 2019, with around 69,600 available rooms in 2020, but only 19.2% occupancy. Despite some recovery, visitor lodging revenue in 2021 still lagged behind 2019 levels. But, overall, the contribution of tourism to growth and, hence, to sustainable develop seems quite straightforward.

However, there are sustained criticisms, too. A fundamental one, developed is that unsustainability is driven by inequality or that, regardless of how much growth there is in the short-term, even if this leads to sustainability, over the long-term, a divided society cannot be sustainable (Obeng-Odoom, 2020a, 2020b, 2021). In the case of South Africa, one of the world's most unequal countries, these observations are particularly serious. South Africa's thriving tourism industry is a double-edged sword for its environment (Rogerson et a., 2020; Rogerson and Hoogendoorn, 2014). On one hand, it injects much-needed revenue into conservation efforts, aiding in the preservation of the country's rich biodiversity and natural wonders. Tourist dollars fund national parks and wildlife sanctuaries, helping combat habitat loss and poaching. On the flip side, the environmental impact of tourism cannot be ignored. The carbon footprint from travel, habitat disruption, and water resource depletion are growing concerns (Rogerson and Baum, 2020; Rogerson and Rogerson, 2020). Striking a balance between reaping the economic rewards of tourism and ensuring the long-term health of South Africa's environment is an ongoing and complex debate.

This study looks at the following research questions:

1. How does tourism development in South Africa contribute to improvements in environmental quality, as assessed by the key indicator such as CO_2 emissions, when analysed using the novel dynamic ARDL simulations approach?
2. To what extent do different aspects of tourism development, such as international tourist arrivals, economic complexity index, and trade openness, influence the relationship between economic growth and environmental quality in South Africa, as investigated through the novel dynamic ARDL simulations approach?

3. Material and methods

The study employs a novel dynamic ARDL simulations framework to analyse the relationship between tourism development and CO_2 emissions in South Africa from 1960 to 2020. Stationarity tests are conducted using classic unit root tests to determine variable integration orders. Structural break impacts are considered using the Narayan and Popp's structural break unit root test. A new dynamic ARDL simulations model calculates short- and long-run coefficients. The robustness of estimates is ensured through the Breitung and Candelon (2006) robust testing method and the frequency domain causality (FDC) approach to capture permanent causality across medium-, short-, and long-term variables, offering comprehensive insights into the connection between tourism and CO_2 emissions in South Africa.

3.1 Functional form

This study employs the standard EKC hypothesis methodology to explore the dynamic interplay between South Africa's tourist development and CO_2 emissions. The EKC theory suggests that economic growth initially prioritizes income over ecological concerns, leading to environmental deterioration. As societies advance, they become more ecologically conscious and enforce regulations to enhance environmental quality. This explains the positive association between economic expansion (scale effect) and environmental degradation. Simultaneously, the negative link between the technique effect (square of economic growth) and the environment is justified by this logic. This typical EKC hypothesis, in line with existing research, underpins the investigation's framework, shedding light on the complex connection between tourism development, economic growth, and environmental impact in South Africa.

$$\mathrm{InCO}_{2t} = \alpha + \varphi \, \mathrm{InS}\,E_t + \beta \, \mathrm{In}\, TE_t + \varepsilon_t \tag{1}$$

where $\mathrm{InCO_2}$ stands for the logarithm of $\mathrm{CO_2}$ emissions, an environmental quality metric; InSE stands for the logarithm of scale effect, a measure of economic growth; and InTE is the logarithm of the technique effect, which captures the square of economic growth. To accurately represent the long-term elasticity of our variables, the functional connection in Equation (1) has been stated in logarithmic form. As income rises, the scale effect (economic expansion) causes environmental health to decline, while the technique effect–following the adoption of environmental regulations and people's propensity for a clean environment–improves environmental quality (Udeagha and Muchapondwa, 2022a; Ngepah and Udeagha, 2019). Considering this context, the conceptual requirements call for the following in order for the EKC hypothesis to exist: $\varphi > 0$ and $\beta < 0$. We follow the literature and utilize foreign direct investment, energy consumption, trade openness, industrial value-added, economic complexity index, and composition effect as the control variables in the equation relating tourist development and CO_2 emissions. Equation (2) is enhanced as follows to take into account all of these factors as well as tourism development variable:

$$\ln CO_{2t} = \alpha + \varphi\, \text{InSE}_t + \beta\, \text{InTE}_t + \rho\, \text{InTOU}_t + \pi\, \text{InEC}_t + \delta\, \text{InFDI}_t + \tau\, \text{InOPEN}_t + \omega\, \text{InIGDP}_t + \Omega\, \text{InECI}_t + \S\, \text{InC}\, E_t + U_t \quad (2)$$

where InTOU_t is tourism development; InEC_t denotes energy consumption; InFDI captures foreign direct investment; InOPEN_t represents trade openness, InIGDP_t denotes industrial valueadded, ECI_t denotes economic complexity index, and CE_t captures composition effect. All variables are in natural log. φ, β, ρ, π, $\delta\tau$, ω, Ω, and § are the estimable coefficients capturing different elasticities whereas U_t captures the stochastic error term with standard properties.

3.2 Measuring trade openness

Following Squalli and Wilson (2011), the composite trade intensity (CTI) is employed in this study as an indicator for trade openness to adequately account for trade's contribution in GDP and its magnitude in relation to international commerce. We can successfully overcome the limitations of the standard trade intensity (TI) extensively employed in past research by using this method of measuring trade openness. More crucially, the novel CTI offers more significant data about a nation's trade contribution to the world market. Additionally, because it includes both aspects of a nation's relationships with the global market, it reflects the reality of trade outcomes. The CTI is shown as follows:

$$CTI = \frac{(X+M)_i}{\frac{1}{n}\sum_{j=1}^{n}(X+M)_j}\frac{(X+M)_i}{GDP_i} \quad (3)$$

where South Africa is represented by i and her trading partners are shown by j. The first part of Equation (4) signifies the world economy contribution, and the second part the South African trade contribution.

3.3 Variables and data sources

This study analyzes the tourism-environment link using 1960-2020 time series data. CO_2 emissions (kg per 2015 US$ of GDP) are the dependent variable, sourced from the World Bank's World Development Indicators. It tests the Environmental Kuznets Curve (EKC) hypothesis using scale and technique effects as economic growth proxies. Tourism development approximates via international tourist arrivals. Variables include energy consumption (EC), foreign direct investment (FDI), trade openness (OPEN), economic complexity index (ECI), industrial value-added to GDP (IGDP), and the composition effect (CE). Data comes from sources like BP Statistical Review and the Observatory Economic Complexity. The study assesses their impact on the tourism-CO_2 emissions equation. Energy usage, FDI, industrial value-added, ECI, trade openness, and composition effect are explored. These variables provide insights into the complex tourism-environment-economic relationship.

3.4 Narayan and Popp's structural break unit root test

It is crucial to perform a stationarity test on the variables taken into account in order to determine their integration orders before putting the novel dynamic ARDL simulations framework into practice. As a

Table 1. Definition of variables and data sources.

Variable	Description	Expected sign	Source
CO_2	CO_2 emissions (kg per 2010 US$ of GDP)	N/A	WDI
EC	Energy consumption, million tonnes oil equivalent	Positive	BP Statistical Review of World Energy
TOU	Tourism development measured by the numbers of international tourist arrival	negative	WDI
OPEN	Trade openness computed as composite trade intensity introduced by Squalli & Wilson (2011) capturing trade effect	Positive or negative	WDI, Authors
SE	Real GDP per capita capturing scale effect	Positive	WDI
TE	Real GDP per capita squared capturing technique effect	Negative	WDI, Authors
FDI	Foreign direct investment, net inflows (% of GDP)	Positive	WDI
ECI	Economic complexity index is measured by a country's diversity of exports and its ubiquity	Positive or negative	OEC 2020
CE	Composition effect is captured by interacting capital-labour intensities with trade openness	Positive or negative	WDI, PWT
IGDP	Industry, value added (% of GDP)	Positive or negative	WDI

N/A: Not available; WDI: World Development Indicator; PWT: Penn World Table

result, this study makes use of the unit root tests Dickey-Fuller GLS (DF-GLS), Phillips-Perron (PP), Augmented Dickey-Fuller (ADF), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS). Since empirical data demonstrates that structural breaks are persisting in the sense that numerous macroeconomic variables, such as CO_2 emissions and tourist development, are impacted by structural breaks, the Narayan and Popp's structural break unit root test is further applied.

The bounds test is used in this study to look at the relationship between the variables under consideration over the long term. Following Pesaran et al. (2001), the ARDL bounds testing method is stated as follows:

$$\begin{aligned}\Delta \mathrm{InCO}_{2t} = {} & \gamma_0 + \sum_{i=1}^{n}\gamma_{1i}\Delta \mathrm{InCO}_{2t-i} + \sum_{i=0}^{n}\gamma_{2i}\Delta \mathrm{InSE}_{t-i} + \sum_{i=0}^{n}\gamma_{3i}\Delta \mathrm{InTE}_{t-i} + \sum_{i=0}^{n}\gamma_{4i}\Delta TOU_{t-i} \\ & + \sum_{i=0}^{n}\gamma_{5i}\Delta EC_{t-i} + \sum_{i=0}^{n}\gamma_{6i}\Delta \mathrm{InFDI}_{t-i} + \sum_{i=0}^{n}\gamma_{7i}\Delta \mathrm{InOPEN}_{t-i} + \sum_{i=0}^{n}\gamma_{8i}\Delta \mathrm{InIGDP}_{t-i} \\ & + \sum_{i=0}^{n}\gamma_{9i}\Delta \mathrm{InECI}_{t-i} + \sum_{i=0}^{n}\gamma_{10i}\Delta \mathrm{InCE}_{t-i} + \theta_1 \mathrm{InCO}_{2t-i} + \theta_2 \mathrm{InSE}_{t-i} + \theta_3 \mathrm{InTE}_{t-i} \\ & + \theta_4 \mathrm{InTOU}_{t-i} + \theta_5 \mathrm{InEC}_{t-i} + \theta_6 \mathrm{InFDI}_{t-i} + \theta_7 \mathrm{InOPEN}_{t-i} + \theta_8 \mathrm{InIGDP}_{t-i} \\ & + \theta_9 \mathrm{InECI}_{t-i} + \theta_{10} \mathrm{InCE}_{t-i} + \varepsilon_t \qquad (4)\end{aligned}$$

where Δ denotes the first difference of InCO_2, InSE, InTE, InTOU, InEC, InFDI, InOPEN, InIGDP, InECI and ε_t captures the white noise. t-i denotes the optimal lags chosen using Schwarz's Bayesian Information Criterion (SBIC), γ and θ are the estimated coefficients for short run and long run, respectively. The variable lags required in Equation (4) are ARDL (1, 2, 2, 0, 0, 1, 1, 0, 0.1). The shortand long-run ARDL models could be approximated when variables are having a long-run relationship. The null hypothesis ($H_0 : \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = \theta_7 = \theta_8 = \theta_9 = \theta_{10} = 0$ versus the alternative hypothesis ($H_1 : \theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq \theta_6 \neq \theta_7 \neq \theta_8 \neq \theta_9 \neq \theta_{10} \neq 0$) checks whether there is a long-run connection. Whether the null hypothesis is accepted or rejected relies on the estimated F-statistic's value The null hypothesis is rejected and cointegration or a long-term link between the variables is inferred if the estimated F-statistic value exceeds the upper threshold. If the estimated F-statistic value is smaller than the lower limit, cointegration does not occur. Additionally, the bounds test is unconvincing if the estimated F-statistic value is between the lower and higher boundaries. If there is a long-term link between the variables, the following is the long-term ARDL model that has to be estimated:

$$\begin{aligned}\Delta \text{InCO}_{2t} = \beta_0 &+ \sum_{i=1}^{q} \omega_1 \text{InCO}_{2t-i} + \sum_{i=0}^{q} \omega_2 \text{InSE}_{t-i} + \sum_{i=0}^{q} \omega_3 \text{InTE}_{t-i} + \sum_{i=0}^{q} \omega_4 \text{InTOU}_{t-i} \\ &+ \sum_{i=0}^{q} \omega_5 \text{InEC}_{t-i} + \sum_{i=0}^{q} \omega_6 \text{InFDI}_{t-i} + \sum_{i=0}^{q} \omega_7 \text{InOPEN}_{t-i} + \sum_{i=0}^{q} \omega_8 \text{InIGDP}_{t-i} \\ &+ \sum_{i=0}^{q} \omega_9 \text{InECI}_{t-i} + \sum_{i=0}^{q} \omega_{10} \text{InCE}_{t-i} + \varepsilon_t \end{aligned} \tag{5}$$

ω signifies the variables' long-term variance in Equation (5). The study makes use of the SBIC to select the appropriate lags. The variable lags required in Equation (5) are ARDL (1,2,2,1,0,1,0,2, 2,0). The error correction model utilized for the short-run ARDL model is as follows:

$$\begin{aligned}\Delta InCO_{2t} = \beta_0 &+ \sum_{i=1}^{q} \pi_1 \Delta InCO_{2t-i} + \sum_{i=0}^{q} \pi_2 \Delta InSE_{t-i} + \sum_{i=0}^{q} \pi_3 \Delta InTE_{t-i} + \sum_{i=0}^{q} \pi_4 \Delta\ \text{InTOU}_{\ t-i} \\ &+ \sum_{i=0}^{q} \pi_5 \Delta\ \text{InEC}_{t-i} + \sum_{i=0}^{q} \pi_6\ \text{In}\ \Delta FDI_{t-i} + \sum_{i=0}^{q} \pi_7 \Delta\ \text{InOPEN}_{t-i} + \sum_{i=0}^{q} \pi_8 \Delta\ \text{InIGDP}\ P_{t-i} \\ &+ \sum_{i=0}^{q} \pi_9 \Delta\ \text{InECI}\ I_{t-i} + \sum_{i=0}^{q} \pi_{10} \Delta\ \text{InC}\ E_{t-i} + ECT_{t-i} + \varepsilon_t \end{aligned} \tag{6}$$

In Equation (6), π represents the variables' short-run variability, while ECT stands for the errorcorrection term, which describes the disequilibrium's rate of adjustment. The range of the calculated ECT coefficient is from −1 to 0 . The variable lags required in Equation (6) are ARDL $(1, 2, 2, 1, 2, 1, 1, 2, 1, 0)$. The diagnostic tests for model stability are also used in this work. The Ramsey RESET test is performed to guarantee that the model has been properly stated, and the Jarque-Bera Pagan-Godfrey analysis and the ARCH check are both utilized to screen for heteroscedasticity. This work uses the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) to analyse structural stability.

3.4.1 Dynamic autoregressive distributed lag simulations

The conventional ARDL approach by Pesaran et al. (2001) has been commonly used to analyse the connection between tourism development and ecological sustainability. This approach, widely employed in energy, economics, and environmental studies, is suitable for smaller sample sizes, addresses endogeneity issues, and can be applied to stationary variables at levels I(0) or first differences I(1). In contrast, the dynamic ARDL simulation framework, gaining attention in energy and climate economics, is a robust method to extract practical insights from time-series models

with complex coefficients. This technique, as shown by Jordan and Philips (2018), overcomes challenges associated with traditional ARDL, yielding precise results in short- and long-term coefficients. It demands first-differenced response variables and no variable with integration order above I(1). This innovative approach enhances research quality, supported by its application in various practical studies worldwide, such as Pata and Isik's (2021) investigation of energy intensity, income, and environmental factors in China from 1981 to 2017. Similarly, Li et al. (2021) explored income inequality's impact on environmental integrity, and Khan and Ulucak (2021) assessed technology's role in environmental health. This dynamic ARDL simulations model is characterized by its rigorous methodology, including 1000 simulations and graphical analysis, ensuring reliable findings. The novel dynamic ARDL simulations model is described as follows:

$$\begin{aligned} \text{InCO}_{2t} = {} & \alpha_0 + \nu_0 \,\text{InCO}_{2t-1} + \varphi_1 \Delta SE_t + \rho_1 SE_{t-1} + \varphi_2 \Delta TE_t + \rho_2 TE_{t-1} + \varphi_3 \Delta TOU_t + \rho_3 TOU_{t-1} \\ & + \varphi_4 \Delta EC_t + \rho_4 EC_{t-1} + \varphi_5 \Delta FDI_t + \rho_5 FDI_{t-1} + \varphi_6 \Delta OPEN_t + \rho_6 OPEN_{t-1} \\ & + \varphi_7 \Delta IGDP_t + \rho_7 IGDP_{t-1} + \varphi_8 \Delta ECI_t + \rho_8 ECI_{t-1} + \varphi_9 \Delta CE_t + \rho_9 CE_{t-1} + \varepsilon_t \end{aligned} \tag{7}$$

3.5 Frequency domain causality test

Lastly, this study explores the causal connections between the variables under investigation using the frequency domain causality (FDC) technique, a reliable testing procedure recommended by Breitung & Candelon (2006). FDC allows one to predict the response variable at a given time frequency, which is virtually impossible with the traditional Granger causality framework. It also makes it possible to identify permanent causality for medium-, short-, and long-term relationships among the variables being studied. In this investigation, the robustness of our estimates is checked using this test.

Table 2. Descriptive statistics.

Variables	Mean	Median	Maximum	Minimum	Std. Dev	Skewness	Kurtosis	J-B Stat	Probability
CO_2^b	0.264	0.238	0.477	0.084	0.120	0.217	1.652	4.682	0.196
SE^c	7.706	7.959	8.984	6.073	0.843	-0.511	2.156	4.102	0.129
TE^d	60.316	63.754	80.717	36.880	12.663	-0.387	2.082	3.422	0.181
TOU^e	9.510	9.202	11.502	8.630	0.816	0.071	1.615	4.412	0.117
EC^f	4.220	4.422	4.840	3.177	0.527	-0.558	1.921	5.621	0.160
EDI^g	13.203	13.286	14.659	11.913	0.738	0.056	2.463	0.702	0.704
$IGDP^h$	3.513	3.580	3.813	3.258	0.161	-0.215	1.697	4.474	0.107
ECI^i	4.291	4.030	5.114	2.031	0.184	-0.151	1.473	2.462	0.189
CE^j	3.034	3.012	4.531	2.610	0.131	-0.147	1.320	2.215	0.104
$OPEN^k$	6.060	6.512	7.665	2.745	1.329	0.636	2.077	5.757	0.156

Source: Authors' calculations

a. Data source: the data was collected from World Development Indicators (see Table 1 for more details).
b. The unit of CO_2 emissions was kg per 2015 US$ of GDP.
c. SE: scale effect denoting real GDP per capita, the unit of SE was current US$.
d. TE: technique effect capturing the square of real GDP per capita, the unit of TE was current US$.
e. TOU: International tourism, number of arrivals/total population
f. EC: energy consumption, the unit of EC was kg of oil equivalent per capita.
g. FDI: foreign direct investment, the unit of FDI was in % of GDP.
h. IGDP: Industry, value added, the unit of IGDP was in % of GDP.
i. ECI: Economic complexity index, measured by a country's diversity of exports and its ubiquity.
j. CE: Composition effect, measured by interacting capital-labour ratio with trade openness.
k. OPEN: trade openness, the unit of OPEN was in % of GD

4. Empirical results and their discussion

4.1 Summary statistics

The descriptive analysis of variables used in the study is conducted before delving into the findings. Table 2 provides an overview, indicating that CO_2 emissions have a mean score of 0.264 . Notably, the technique effect (TE), representing the square of GDP per capita, is significantly larger at 60.316. Foreign direct investment (FDI) follows at 13.203. The table also presents kurtosis for peak characterization and employs the Jarque-Bera test to assess data normality. Trends reveal that scale effect, trade openness, energy consumption, FDI, industrial value-added, and tourist development are positively oriented, while technique effect shows a negative trend. Of these, technique effect exhibits the highest variability, signifying significant instability. CO_2 emissions show lower variability, rendering them more predictable. Scale effect, trade openness, and tourist development exhibit notably higher variances. Importantly, the Jarque-Bera statistic confirms data normality.

4.2 Order of integration of the respective variables

Table 3's findings indicate that all non-stationary variables achieve stationarity at I(1) after first differencing, as revealed by DF-GLS, PP, ADF, and KPSS tests (1). This suggests all series are either I(0) or I(1), ruling out I(2). However, conventional unit root tests don't address structural breaks. Thus, this study employs Narayan and Popp's unit root test with two structural breaks, as seen in the right-hand panel of Table 3. Empirical data confirms variable stationarity even in the presence of structural breaks.

Table 3. Unit root analysis.

Variable	Dickey-Fuller GLS	Phillips-Perron	Augmented Dickey-Fuller	Kwiatkowski-Phillips-Schmidt-Shin	Narayan and Pop (2010) Unit Root Test			
	(DF-GLS)	(PP)	(ADF)	(KPSS)	Model 1		Model 2	
Level			Test - Statistics value		Break-Year	ADF-stat	Break-Year	ADF-stat
$InCO_2$	-0.570	-0.464	-1.152	0.966	1982 : 1985	-3.132	1987:1994	–8.160***
InSE	–0.116**	-0.079	-1.308	0.833***	1979:1988	-2.914	1982:1990	–7.601***
InTE	–0.112*	-0.076	-1.268	0.848***	1979:1990	-1.939	1982:1994	–6.791***
InTOU	–0.201***	–0.214***	-2.042	0.241***	1991:2008	-4.216	2003:2009	–7.631***
InEC	-0.011	-0.014	-0.366	1.300***	1982:1989	–4.372**	1985:1991	–8.521***
InEDI	–0.032*	-0.001	-0.012	0.640	2001:2006	-2.021	2004:2010	–8.362***
InQPEN	-0.072	-0.082	-1.335	1.080*	1996:2001	-3.053	2003:2009	–7.318***
InCE	-0.061	-0.070	-1.261	0.104**	1991:2001	-3.053	2006:2012	–8.314***
InECI	–0.048**	-0.071	-1.188	0.538***	2001:2005	-1.821	2007:2017	–7.620***
JnIGDP	0046	0071*	-1718	1060**	1972 · 1985	-3815	1982 · 1991	–7521***
First Difference								
Δ $InCO_2$	–0.995***	–0.996***	–7.176***	0.705***	1999:2005	–4.801**	1980:1991	–5.832***
Δ*InSE*	–0.695***	–0.707***	–5.319***	0.585***	1983 : 1997	–5.831***	1985 : 1995	–6.831***
Δ*InTE*	–0.694***	–0.707***	–5.316***	0.589***	1991:2000	–8.531***	1987 : 1996	–5.893***
Δ InTOU	–1.021***	–1.021***	–7.318***	0.417***	1996:2009	–4.836**	2004:2012	–5.041***
Δ*InEC*	–1.105***	–1.121***	–8.142***	0.586***	1985 : 1993	–5.921***	1989:1997	–7.942 * **
Δ*InFDI*	–0.207**	–0.209**	–6.443***	0.609***	2005 : 2008	–6.831***	2001:2008	–6.973***
Δ*InOPEN*	–0.935***	–0.938***	–6.699***	0.626***	1996:2004	–6.842**	2001:2007	–8.942***
Δ InCE	–0.148***	–0.215***	–5.603***	0.624***	1998:2002	–5.803**	2009:2009	–9.901***
Δ*InECI*	–0.898***	–0.613***	–5.803***	0.549 * **	1999:2000	–5.857***	2001:2016	–5.854***
Δ*InIGDP*	–0.799***	–0.801***	–5.878***	0.431***	1975 : 1990	–7.742***	1988 : 1992	–7.892***

Source: Authors' calculations. Note: *, ** and *** denote statistical significance at 10%, 5% and 1% levels, respectively. MacKinnon's (1996) one-sided p-values. Lag Length based on SIC and AIC. Probability-based on Kwiatkowski-Phillips-Schmidt-Shin (1992). The critical values for Narayan-Popp unit root test with two breaks are followed by Narayan and Pop (2010). All the variables are trended.

4.3 Lag length selection results

The results of several test criteria for lags selection are presented in Table 4. In the empirical literature, it is noted that the most often used methods for choosing optimal lags are HQ, AIC, and SIC. Lag selection in this analysis involves the usage of SIC. This tool suggests that lag one is appropriate for our model. This is such that, unlike other methods, SIC yields the lowest value at lag one.

4.4 Cointegration test results

The outcomes of the cointegration test using the surface-response regression proposed by Kripfganz &Schneider (2018) are shown in Table 5. We reject the null hypothesis because the F- and t-statistics

Table 4. Lag length criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	178.453	NA	3.2e – 12	-6.594	-6.331	-6.493
1	607.095	857.28	1.5e – 18	-21.195	–19.094*	–20.390*
2	661.093	108	1.4e – 18	-21.388	-17.448	-19.877
3	719.755	117.32	1.2e – 18*	-21.759	-15.981	-19.544
4	784.113	128.72*	1.3e – 18	–22.350*	-14.733	-19.430

Source: Authors' calculations Note: * indicates lag order selected by the criterion.

are higher than the upper bound critical values at different degrees of significance. Therefore, cointegration between the variables under discussion is supported by our empirical results.

Table 5. ARDL bounds test analysis.

Test statistics	Value	K	H_0	H_1		
F-statistics	16.591	8	No level relationship	Relationship exists		
t-statistics	-10.731					
Kripfganz &Schneider (2018) critical values and approximate p-values						
Significance	F-statistics		t-statistics		p-value F	
	1(0)	1(1)	1(0)	1(1)	1(0)	1(1)
10%	2.12	3.23	-2.57	-4.04	0.000***	0.000***
5%	2.45	3.61	-2.86	-4.38	p-value t	
1%	3.15	4.43	-3.43	-4.99	0.000***	0.002**

Note: *, ** and *** respectively represent statistical significance at 10%, 5% and 1% levels. The respective significance levels suggest the rejection of the null hypothesis of no cointegration. The optimal lag length on each variable is chosen by the Schwarz's Bayesian information criterion (SBIC).

4.5 Diagnostic statistics tests

Table 6 displays the outcomes of several diagnostic statistical tests employed in this study to ensure the reliability and accuracy of the selected model. All diagnostic tests confirm the model's suitability. The Breusch Godfrey LM test verifies the absence of serial correlation or autocorrelation. The Ramsey RESET test confirms proper specification. Heteroscedasticity is examined using the Breusch-Pagan-Godfrey test and the ARCH test, indicating minor concerns. Lastly, the Jarque-Bera test confirms the normal distribution of the model's residuals.

Table 6. Diagnostic statistics tests.

Diagnostic statistics tests	(P values)	Results
Breusch Godfrey LM test	0.3042	No problem of serial correlations
Breusch-Pagan-Godfrey test	0.2942	No problem of heteroscedasticity
ARCH test	0.6042	No problem of heteroscedasticity
Ramsey RESET test	0.5153	Model is specified correctly
Jarque-Bera Test	0.2052	Estimated residual are normal

Source: Authors' calculations

4.6 Dynamic ARDL simulations model results

Table 7 presents the dynamic ARDL simulation analysis findings. Results indicate that long- and short-term economic growth coefficients (scale effect, InSE) are positive and significant, linking economic expansion to increased CO_2 emissions. Conversely, the technique effect coefficient (InTE) is negative and significant in the long term, indicating a positive impact on environmental quality. This supports the Environmental Kuznets Curve (EKC) hypothesis in South Africa. The inverted U-shaped relationship between income and pollution is attributed to factors such as institutional change, technological advancement, and stringent environmental regulations. Our results align with Udeagha and Breitenbach (2023a), Ngepah and Udeagha (2022c) but differ from Bandyopadhyay and Rej (2021).

Table 7. Dynamic ARDL simulations analysis.

Variables	Coefficient	St. Error	t-value
Cons	-1.1501	1.2071	-0.81
InSE	0.2162***	0.1872	3.91
Δ*InSE*	0.3116***	0.2705	2.93
InTE	–0.5104**	0.7182	-2.54
Δ InTE	-0.7258	0.1383	-1.45
InTOU	–0.5114***	0.4210	-3.76
Δ*InTOU*	–0.1075**	0.0423	-2.87
InEC	0.2745***	0.1717	3.20
Δ*InEC*	0.3010*	0.1550	1.98
InEDI	0.9024	0.0814	1.50
Δ*InFDI*	0.2814**	0.2615	2.63
InQPEN	0.1841***	0.0413	4.07
Δ*InOPEN*	–0.3032**	0.0504	-2.87
InECI	0.2105**	0.8026	2.76
Δ*InECI*	0.1073	0.1352	0.85
InCE	0.2401***	0.3480	3.05
Δ*InCE*	0.1051**	0.0423	2.71
InIGDP	0.3406**	0.1528	2.61
Δ*InIGDP*	0.5320	0.2361	0.67
ECT(-1)	–0.8204***	0.1362	-3.81
R-squared	0.7980		
Adj R-squared	0.7758		
N	55		
P val of F-sta	0.0000***		
Simulations	1000		

Source: Authors' calculations Note: *, ** and *** denote statistical significance at 10%, 5% and 1% levels, respectively.

The study findings reveal a significant and negative coefficient for tourism development in both short and long terms. A 1% increase in tourism corresponds to a 0.511% long-term and 0.107% short-term reduction in CO_2 emissions. This implies that South Africa's tourism sector is energy-efficient and environmentally friendly. Government policies, such as promoting renewable energy, energy-efficient construction, and green transportation, have contributed to this sector's sustainability. Regulatory changes have led to reduced energy consumption in the tourism industry.

Initiatives like the Integrated Resource Plan and the Renewable Energy Independent Power Producer Procurement Program have emphasized renewable energy adoption. Additionally, South Africa has introduced market-based mechanisms and emissions trading to encourage low-carbon practices in aviation. The study's conclusions align with Tian et al. (2021) but differ from Yue et al. (2021), emphasizing the tourism sector's potential to positively impact environmental sustainability.

The study's long-term trade openness coefficient (InOPEN) is significant and positive, indicating that a 1% increase in trade openness leads to a 0.188% rise in CO_2 emissions. Supported by Baek et al. (2009), it suggests trade can harm developing nations' environments, as shown by our empirical data for South Africa. Contrary to short-term effects, long-term access to global markets does not benefit the country's environmental quality, emphasizing potential drawbacks to economic liberalization. The dominance of resource-intensive exports may explain why trade openness negatively affects the environment, given South Africa's advantage in goods requiring significant natural resources. Ngepah and Udeagha (2018), and others reinforce these findings regarding trade's environmental impact.

Energy consumption coefficients (InEC) are significant and positive, signifying higher energy usage leads to increased CO_2 emissions in South Africa, linked to economic growth. This aligns with Ling et al. (2015) and Saboori et al. (2012) findings. Short-term foreign direct investment (InFDI) has a significant positive impact, but its influence lessens over the long term, suggesting increased FDI worsens environmental quality. Abdouli and Hammami (2017) similarly find FDI increases CO_2 emissions, backing pollution haven theory.

The statistically significant and positive long-term coefficient for the economic complexity index (InECI) suggests a 1% increase in ECI causes a 0.2303% rise in CO_2 emissions in South Africa over time. The evidence indicates that greater product complexity and economic sophistication impact the country's ecological quality. Shahzad et al. (2021) find similar effects in the US, while Yilanci and Pata (2020) suggest ECI decreases China's environmental quality. Our findings align with Wang et al. (2021) but oppose Can and Gozgor (2017). Doğan et al. (2021) support the significance of ECI in reducing environmental deterioration.

The significant and positive long-term coefficient for the industrial value-added share of GDP (InIGDP) suggests that the growth of South Africa's industrial sector over time contributes to worsened environmental quality. The expansion of the industrial sector is a key driver of increased CO_2 emissions in the country. Despite policies aimed at structural transformation, industrialization has led to environmental changes and biodiversity effects, endangering human survival. Our results align with Al Mamun et al. (2014) and Sohag et al. (2017), linking manufacturing growth to rising CO_2 emissions. However, Tian et al. (2014) attribute domestic emissions to heavy industry, and Lin et al. (2015) argue Nigeria's manufacturing has no environmental impact. Conclusive evidence for manufacturing reducing CO_2 emissions is found in Xu and Lin (2016). The composition effect (InCE), reflecting the interplay of capital-labour ratio and trade openness, has statistically significant positive short- and long-run coefficients. A 1% increase in this variable corresponds to a 0.240% long-term rise in CO_2 emissions. South Africa's comparative advantage drives this relationship, with increased trade intensifying production of capital-intensive goods. This shift can erode technical competitiveness, raising energy demand and CO_2 emissions. Our results align with Sadat and Alom (2016) and Ling et al. (2015), demonstrating that trade-driven specialization in capital-intensive goods leads to environmental deterioration. Yet, Managi et al. (2009) found a negative trade-induced composition effect, differing from our findings.

The error correction term (ECT) reflects significant negative adjustment speed, implying consistent long-term connection between variables. The ECT of -0.824 suggests 82% equilibrium correction. Explanatory factors explain 78% of CO_2 emission fluctuations with good model fit per F-statistics. The dynamic ARDL simulations dynamically illustrate the predictions of actual regressor change and its influence on the dependent variable while holding other explanatory factors constant.

The scale effect, technique effect, tourism development, trade openness, energy usage, foreign direct investment, and industrial value-added are expected to have a 10% positive and negative impact on CO_2 emissions in South Africa.

Figure 1. The Impulse Response Plot for Scale Effect (Economic Growth) and CO_2 Emissions.

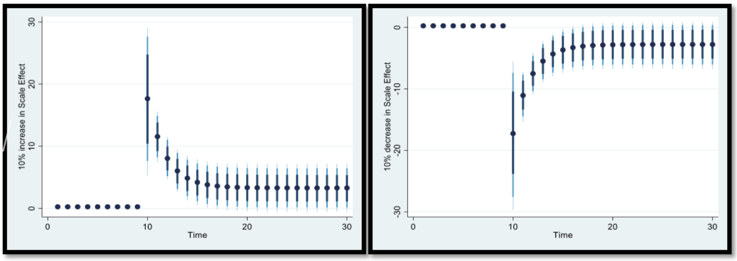


Figure 1 shows a 10% increase and a decrease in scale effect and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively.

The link between scale effect (economic growth) and CO_2 emissions is depicted by the impulse response plot in Figure 1. The change of scale effect and its implications on CO_2 emissions are depicted in the graphic. A 10% decline in scale effect suggests a negative effect of economic growth on CO_2 emissions; however, the impact of a 10% rise in scale effect is greater than that of a 10% decrease in scale effect. A 10% rise in scale effect connotes a positive impact of economic growth on CO_2 emissions in the short run and long run. This suggests that in South Africa, a rise in the scale effect (economic expansion) worsens the environmental quality, but a drop in the scale effect enhances the atmosphere both in the short and long terms (Ngepah and Udeagha, 2022c). The

Figure 2. The Impulse Response Plot for Technique Effect and CO_2 emissions.

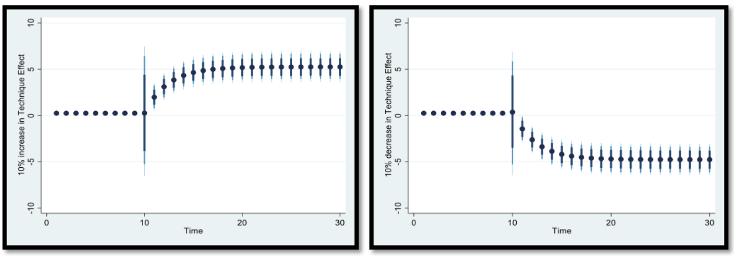


Fig. 3 shows a 10% increase and a decrease in technique effect and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively.

impulse response graph of the technique effect and CO_2 emissions in South Africa is shown in Figure 2. The technique effect figure shows that a 10% rise is strongly correlated with both a short- and long-term negative impact on CO_2 emissions. However, both in the long and medium terms, a 10% reduction reduces CO_2 emissions. This indicates that in South Africa, a rise in the technique effect (square of economic development) improves environmental quality, whereas a drop in the technique effect worsens climatic conditions over the long and short terms (Ngepah and Udeagha, 2022d).

The impulse response diagram relating trade openness and CO_2 emissions is shown in Figure 3. The graph demonstrates how a 10% rise in trade openness has a long-term positive impact on CO_2 emissions but a short-term negative impact. In stark contradiction, a 10% reduction in trade openness has a short-term positive impact on CO_2 emissions but a long-term negative impact. This shows that while increased trade openness boosts South Africa's ecological integrity temporarily, it actually worsens it over time. However, a decline in trade openness improves South Africa's environment over the long term but worsens it over the short term (Ngepah and Udeagha, 2023a).

The impulse response curve showing the link between energy use and CO_2 emissions is shown

Figure 3. The Impulse Response Plot for Trade Openness and CO_2 emissions.

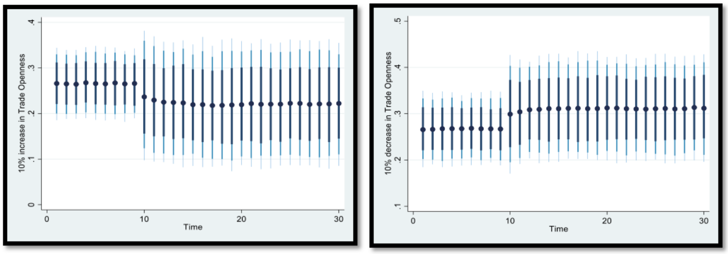


Fig. 3 shows a 10% increase and a decrease in trade openness and its influence on CO_2 emissions where dots specify average prediction value. . However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively.

Figure 4. The Impulse Response Plot for Energy Consumption and CO_2 emissions.

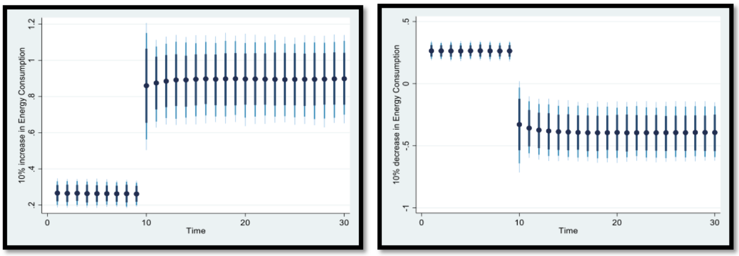


Figure 4 shows a 10% increase and a decrease in energy consumption and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively.

in Figure 4. The figure depicting the relationship between energy consumption and CO_2 emissions demonstrates that a 10% increase in energy use has a positive influence on CO_2 emissions over the short and long terms, whereas a 10% reduction in energy use has the opposite effect. This suggests that, in South Africa, a rise in energy utilization worsens the ecological integrity, but a reduction in energy usage enhances the atmosphere both immediately and over time (Ngepah and Udeagha, 2021).

Figure 5. The Impulse Response Plot for Foreign Direct Investment and CO_2 emissions

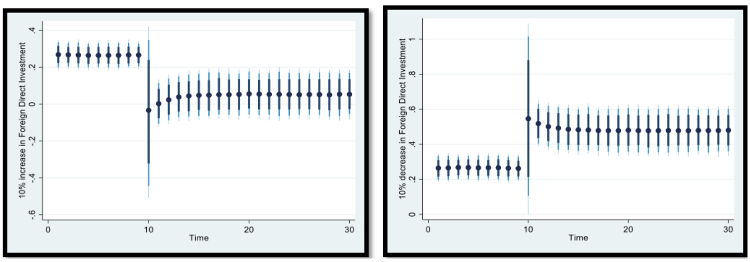


Figure 5 shows a 10% increase and a decrease in foreign direct investment and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively.

The impulse response graph of foreign direct investment and CO_2 emissions in South Africa is shown in Figure 5. The plot of foreign direct investment shows that both a long-term and short-term reduction in CO_2 emissions is strongly correlated with a rise of 10% in foreign direct investment. However, a 10% reduction has both a long-term and short-term negative impact on CO_2 emissions. This indicates that a growth in foreign direct investment worsens South Africa's environmental quality over the long and short terms.

Figure 6 shows the impulse response diagram between South Africa's tourist growth and CO_2 emissions. The figure shows that a 10% rise in tourist development has both a long-term and

Figure 6. The Impulse Response Plot for Tourism development and CO_2 emissions.

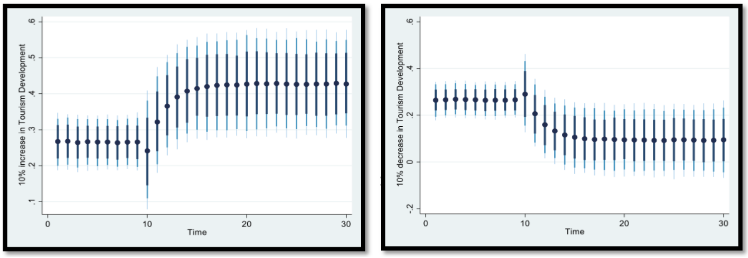


Figure 6 shows a 10% increase and a decrease in tourism development and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively.

short-term negative impact on CO_2 emissions. However, a 10% reduction in tourist development has a positive long- and short-term impact on CO_2 emissions. This implies that while a drop in tourist development worsens the atmosphere's health in South Africa over the long and short terms, a rise in tourism sector enhances the country's ecological integrity.

Figure 7. The Impulse Response Plot for Industrial Value-added and CO_2 emissions.

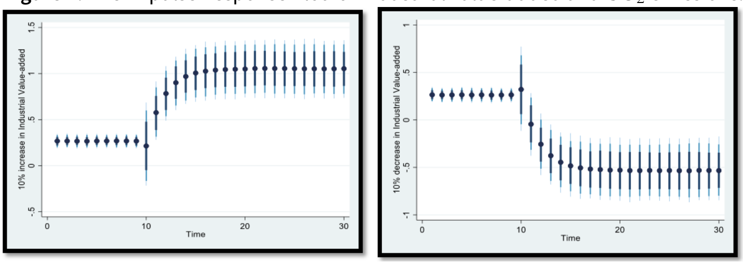


Figure 7 shows a 10% increase and a decrease in industrial value-added and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence

The impulse response graph of the link between industrial value added and CO_2 emissions is shown in Figure 7. The graph demonstrates that a 10% rise in industrial value-added has a positive influence on CO_2 emissions both in the short and long terms, whereas a 10% drop in industrial value-added has the opposite effect. This implies that while a reduction in industrial value-added protects the atmosphere in South Africa over the long and short terms, an expansion in industrial value-added worsens the sustainability of the environment.

Figure 8. The Impulse Response Plot for Economic Complexity Index and CO_2 emissions.

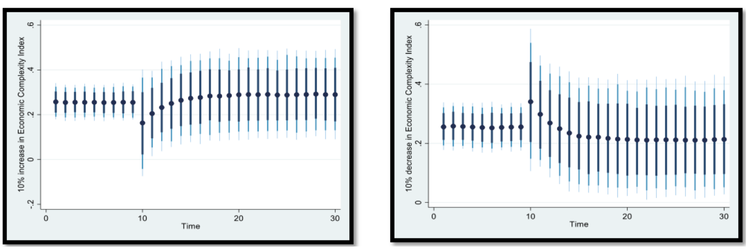


Figure 8 shows a 10% increase and a decrease in economic complexity index and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively

The impulse response curve showing the link between economic complexity index and CO_2 emissions is shown in Figure 8. The figure depicting the relationship between economic complexity index and CO_2 emissions demonstrates that a 10% increase in economic complexity index has a positive influence on CO_2 emissions over the short and long terms, whereas a 10% reduction in economic complexity index has the opposite effect. This suggests that, in South Africa, a rise in economic complexity worsens ecological quality, but a reduction in economic complexity enhances the atmosphere both immediately and over time.

Figure 9. The Impulse Response Plot for Composition Effect and CO_2 emissions.

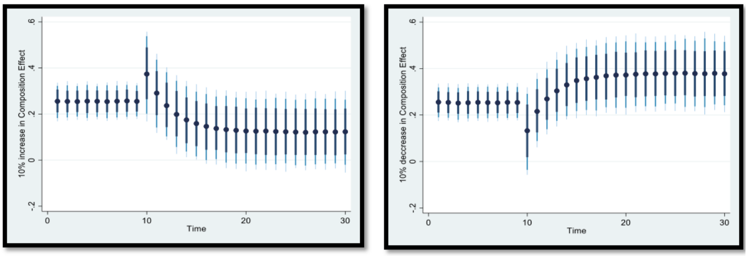


Figure 9 shows a 10% increase and a decrease in composition effect and its influence on CO_2 emissions where dots specify average prediction value. However, the dark blue to light blue line denotes 75, 90, and 95% confidence interval, respectively.

The link between composition effect (i.e., interaction between capital–labour ratio and trade openness) and CO_2 emissions is depicted by the impulse response plot in Figure 10. The change of composition effect and its implications on CO_2 emissions are depicted in the graphic. A 10% decline in composition effect reduces CO_2 emissions; however, the impact of a 10% rise in composition effect is greater than that of a 10% decrease in composition effect. This suggests that in South Africa, a rise in composition effect worsens environmental quality, but a drop in the composition effect enhances the atmosphere both in the short and long terms.

Table 8. Frequency-domain causality test

Direction of causality	Long-term	Medium-term	Short-term
	$\omega i = 0.05$	$\omega i = 1.50$	$\omega i = 2.50$
InSE → InCO_2	< 8.31 > (0.02)**	< 8.50 > (0.00)****	< 9.96 > (0.00)****
InTE_N → InCO_2	< 4.89 > (0.07)*	< 6.49 > (0.03)**	< 6.93 > (0.04)**
InOPEAN → InCO_2	< 8.94 > (0.00)***	< 8.73 > (0.00)***	< 7.28 > (0.01)***
InEC → InCO_2	< 5.12 > (0.08)*	< 6.49 > (0.04)**	< 6.73 > (0.03)**
InEDU → InCO_2	< 8.20 > (0.01)**	< 8.08 > (0.03)**	< 8.62 > (0.00)***
InTOU → InCO_2	< 4.73 > (0.08)*	< 5.20 > (0.03)**	< 7.52 > (0.04)**
InCE → InCO_2	< 4.71 > (0.08)*	< 5.47 > (0.02)**	< 6.81 > (0.04)**
InECL → InCO_2	< 5.62 > (0.00)***	< 5.05 > (0.02)**	< 7.70 > (0.04)**
InIGDP → InCO_2	< 5.46 > (0.07)*	< 8.82 > (0.00)**	< 8.89 > (0.00)**

Source: Authors' calculations Note: *, ** and *** denote statistical significance at 10%, 5% and 1% levels, respectively.

The frequency domain causality test developed by Breitung Candelon (2006) is also used in this study to investigate the relationship between InSE, InTE, InTOU, InEC, InFDI, InOPEN, InIGDP, InECI, InCE, and InCO_2 in South Africa. Table 8 shows that InSE, InTE, InTOU, InEC, InFDI, InOPEN, InECI, InCE, and InIGDP Granger-cause InCO_2 in the short, medium, and long run for frequencies ω_i = 0.05, ω_i = 1.50, ω_i = 2.50 This suggests that the short-, medium-, and long-term effects of InSE, InTE, InTOU, InEC, InFDI, InOPEN, InECI, InCE, and InIGDP on InCO_2 emissions in South Africa are significant. Our empirical data agrees with Udeagha Ngepah (2019) and Sohag et al. (2017).

Figure 10. Plot of Cumulative Sum of Recursive Residuals (CUSUM)

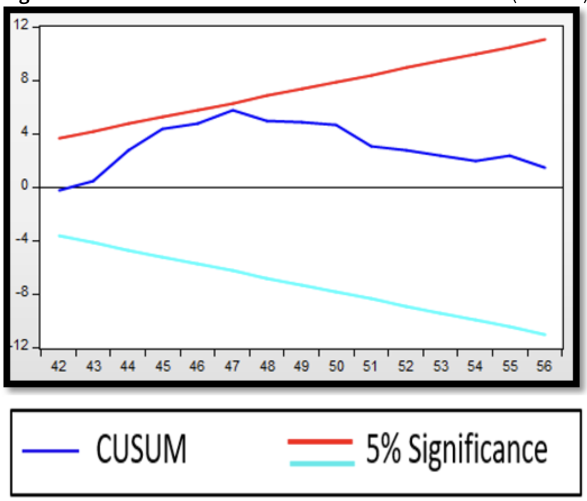
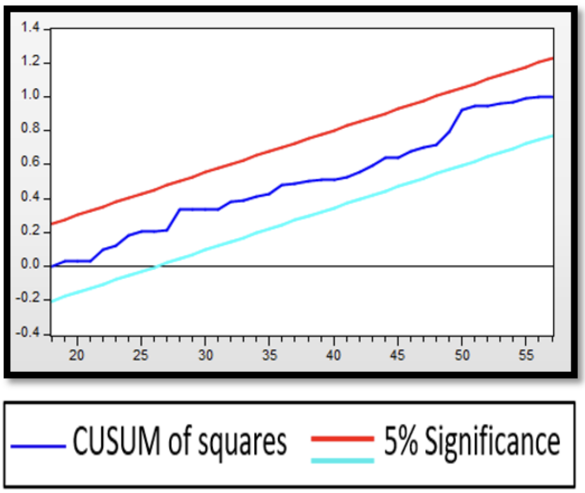


Figure 11. Plot of Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ)



To further confirm the model's robustness, this study performs the structural stability analysis of the model. To achieve this, Pesaran and Pesaran (1997) cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residual (CUSUMSQ) are applied. CUSUM and CUSUMSQ are shown graphically in Figures 11 and 12. Traditionally, if figures are within a crucial cut-off level of 5%, there is a consistency of model parameters over time. Since CUSUM and

CUSUMSQ are inside the bounds at a 5% level and the model trend is depicted in Figures 11 and 12, we may infer that the model parameters are consistent over time.

4.7 Robustness check

This study addresses tourism development's endogeneity issue by employing the two-stage least squares (2SLS) regression method. Endogeneity arises from the potential impact of environmental quality on tourism. The study establishes an equation to regress tourism development on environmental quality, using lnTOU as an instrumental variable with its lagged term. The estimated coefficient on CO_2 emissions (InCO_2) is statistically insignificant, suggesting that South Africa's foreign tourism is not influenced by environmental quality. Findings also reveal positive impacts of visitors' incomes (InY) and trade openness on tourism. South African tourism proves price inelastic, indicating that cost of living changes minimally affect visitor numbers.

5. Conclusions and Policy Implications

This study employs a novel dynamic ARDL simulations framework to analyse the relationship between tourism development and CO_2 emissions in South Africa from 1960 to 2016. The approach overcomes limitations of conventional ARDL techniques, providing insights into positive and negative correlations among various factors. Robustness is assessed using Breitung Candelon (2006)'s frequency domain causality (FDC) approach. Additional contributions are made by incorporating a new trade openness metric and structural break unit root tests. The findings support the Environmental Kuznets Curve theory for South Africa. Factors including scale effect, technique effect, trade, foreign investment, industry, and energy impact CO_2 emissions. FDC results indicate the Granger-causality of these variables in affecting CO_2 emissions over the short, medium, and long terms. Empirical results indicate that South Africa's tourism development reduces CO_2 emissions both in the short and long terms. The tourism industry's energy-efficient practices contribute to this positive impact. The findings point towards a shift in the country's production structure, emphasizing a service-based economy driven by technology, promoting energy efficiency, and utilizing renewable energy sources.

Based on our empirical findings, we propose several policy recommendations. First, South African policymakers could harness tourism for sustainable development and energy efficiency, reinforcing environmental regulations and promoting low-carbon initiatives (Udeagha and Breitenbach, 2023f; Udeagha and Ngepah, 2023g). Second, South African policymakers should prioritise policies that encourage sustainable tourism practices. This includes incentivising eco-friendly accommodations, promoting responsible tourism behaviours, and supporting initiatives that minimise the ecological footprint of tourists (Udeagha and Ngepah, 2023f). Encouraging hybrid engines and alternative fuels for transportation is a third suggestion (Udeagha and Ngepah, 2023e). Fourth, the hospitality industry can transition to renewable energy, with incentives for solar and wind adoption (Udeagha and Ngepah, 2023d). Fifth, boosting green investments and shifting towards renewable energy sources is crucial for ecological sustainability (Udeagha and Ngepah, 2023c). Implementing diverse credit procedures based on environmental impact and offering incentives for low-carbon sectors are other strategies (Udeagha and Ngepah, 2023b). These policies align with multiple Sustainable Development Goals, which foster economic growth, ecological quality, and affordable green energy access.

Appendix

Table 9. Definition of variables and data sources.

Variable	Description	Expected sign	Source
TOU	Tourism development measured by the number of international tourist arrivals	N/A	WDI
CO_2	CO_2 emissions (kg per 2010 US$ of GDP)	Positive or negative	WDI
Y	Real GDP per capita	Positive or negative	WDI
Tv	Total volume of trade	Positive or negative	WDI
P	Price of tourism in destination i calculated using the formula below	Negative	WDI
Ps	Price of tourism in substitute destination k	Positive or negative	WDI, Authors

N/A: Not available; WDI: World Development Indicator; PWT: Penn World Table

Table 10. The empirical test results of the tourism development equation (2SLS).

Variables	Coefficient	t-value
Cons	0.261*	1.99
$InCO_2$	0.310	0.26
InX	0.204***	3.91
InTx	0.113***	4.51
InP	–0.258**	-2.49
InPs	-0.130	-0.76
Kleibergen-Paap rkLM Statistic	53.714***	
Cragg - Donald Wald F Statistic	271.914	
R-squared	0.716	

Biography

Maxwell Chukwudi Udeaghaholds a PhD in Economics from the University of Johannesburg, South Africa. He is a senior researcher and an editorial board member of several Journals including International Journal of Sustainable Development & World Ecology. He has research interest in emerging market economies, development economics, international trade, African environment, regional economic integration, applied economics and applied econometrics. He has published widely in a number of reputable journals including *Journal of African Business; Journal of Economic Integration; Economic change and Restructuring; International Journal of Urban Sciences; Environmental Science and Pollution Research; African Review of Economics and Finance.*

Nicholas Ngepah holds a PhD in Economics from the University of Cape Town. He is a Professor of Economics at the University of Johannesburg. He is an expert in quantitative and qualitative research techniques, economic development and policy impact assessments, including spatial econometrics. He has wide range of experience on development issues, with core expertise in poverty, inequality, labour market dynamics and inclusive economic growth with related policies like agriculture, health issues, gender, climate change, trade, industrialisation etc. Professor Ngepah has undertaken studies for organisations like the World Bank, UK Overseas Development institute, African Economic Research Consortium, Council for Scientific and Industrial Research, Oxfam and the South African Government.

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Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflicts of interest

The authors declare no conflict of interest.

References

Abdouli, M., & Hammami, S. (2017). Investigating the causality links between environmental quality, foreign direct investment and economic growth in MENA countries. International Business Review, 26(2):264–278.

Al Mamun, M., Sohag, K., Mia, M. A. H., Uddin, G. S., & Ozturk, I. (2014). Regional differences in the dynamic linkage between CO_2 emissions, sectoral output and economic growth. Renewable and Sustainable Energy Reviews, 38, 1–11.

Al-Mulali, U., Fereidouni, H. G., & Mohammed, A. H. (2015). The effect of tourism arrival on CO_2 emissions from transportation sector. Anatolia, 26(2), 230–243.

Bandyopadhyay, A., & Rej, S. (2021). Can nuclear energy fuel an environmentally sustainable economic growth? Revisiting the EKC hypothesis for India. Environmental Science and Pollution Research, 28(44), 63065–63086.

Breitung, J., & Candelon, B. (2006). Testing for short-and long-run causality: A frequency-domain approach. Journal of econometrics, 132(2), 363–378.

Can, M., & Gozgor, G. (2017). The impact of economic complexity on carbon emissions: evidence from France. Environmental Science and Pollution Research, 24, 16364–16370.

Doğan, B., Driha, O. M., Balsalobre Lorente, D., & Shahzad, U. (2021). The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries. Sustainable Development, 29(1), 1–12.

Jena, P. K., Mujtaba, A., Joshi, D. P. P., Satrovic, E., & Adeleye, B. N. (2022). Exploring the nature of EKC hypothesis in Asia's top emitters: role of human capital, renewable and non-r enewable energy consumption. Environmental Science and Pollution Research, 29(59), 88557-88576. https://doi.org/10.1007/s11356-022-21551-w

Jordan, S., & Philips, A. Q. (2018). Cointegration testing and dynamic simulations of autoregressive distributed lag models. The Stata Journal, 18(4), 902–923.

Khan, Z. A., Koondhar, M. A., Khan, I., Ali, U., & Tianjun, L. (2021). Dynamic linkage between industrialization, energy consumption, carbon emission, and agricultural products export of Pakistan: an ARDL approach. Environmental Science and Pollution Research, 28, 43698–43710.

Kripfganz, S., & Schneider, D. C. (2018). ARDL: Estimating Autoregressive Distributed Lag and Equilibrium Correction Models. Retrieved July 12, 2019, from Stata: Stata Online

Li C, Cui M, Zheng J, Chen Y, Liu J, Ou J, & Li C (2021) Variability in real-world emissions and fuel consumption by diesel construction vehicles and policy implications. Science of The Total Environment, 786, 147256.

Lin, B., Omoju, O. E., & Okonkwo, J. U. (2015). Impact of industrialisation on CO_2 emissions in Nigeria. Renewable and Sustainable Energy Reviews, 52, 1228-1239.

Ling CH, Ahmed K, Muhamad RB, Shahbaz M (2015) Decomposing the trade-environment nexus for Malaysia: what do the technique, scale, composition, and comparative advantage effect indicate? Environ Sci Pollut Res 22(24):20131–20142

Managi, S., Hibiki, A., & Tsurumi, T. (2009). Does trade openness improve environmental quality?. Journal of environmental economics and management, 58(3), 346-363.

Mkhize, I. B. (1994). South African domestic tourism beyond apartheid. Development Southern Africa, 11(2), 249-252.

Ngepah, N., & Udeagha, M. C. (2018). African regional trade agreements and intra-African trade. Journal of Economic Integration, 33(1), 1176-1199.

Ngepah, N., & Udeagha, M. C. (2019). Supplementary trade benefits of multi-memberships in African regional trade agreements. Journal of African Business, 20(4), 505-524.

Obeng-Odoom F, 2020a, Property, Institutions, and Social Stratification in Africa, Cambridge University Press, New York.

Obeng-Odoom F, 2020b, 'COVID-19, Inequality, and Social Stratification in Africa', African Review of Economics and Finance, vol. 12, no. 1, pp. 3-37.

Obeng-Odoom F, 2021, The Commons in an Age of Uncertainty: Decolonizing Nature, Economy, and Society, University of Toronto Press, Toronto.

Pata, U. K., & Isik, C. (2021). Determinants of the load capacity factor in China: A novel dynamic ARDL approach for ecological footprint accounting. Resources Policy, 74, 102313.

Pesaran, H.M., & Pesaran, B. (1997), Microflt 4.0, Oxford University Press, England.

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.

Rogerson, C. M., & Baum, T. (2020). COVID-19 and African tourism research agendas. Development Southern Africa, 37(5), 727-741.

Rogerson, C. M., & Hoogendoorn, G. (2014). VFR travel and second home tourism: The missing link? The case of South Africa. Tourism Review International, 18(3), 167-178.

Rogerson, C. M., & Rogerson, J. M. (2020). COVID-19 tourism impacts in South Africa: Government and industry responses. Geo Journal of Tourism and Geosites, 31(3), 1083-1091.

Rogerson, C. M., & Rogerson, J. M. (2020). Inclusive tourism and municipal assets: Evidence from Overstrand local municipality, South Africa. Development Southern Africa, 37(5), 840-854.

Saboori, B., Sulaiman, J., & Mohd, S. (2012). Economic growth and CO_2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. Energy policy, 51:184-191.

Sadat, S. D., & Alom, F. (2016). Environmental quality, international trade and economic growth: the case of Malaysia. International Journal of Green Economics, 10(3-4), 302-326.

Shahzad, U., Fareed, Z., Shahzad, F., & Shahzad, K. (2021). Investigating the nexus between economic complexity, energy consumption and ecological footprint for the United States: New insights from quantile methods. Journal of Cleaner Production, 279, 123806.

Sohag, K., Al Mamun, M., Uddin, G. S., & Ahmed, A. M. (2017). Sectoral output, energy use, and CO_2 emission in middle-income countries. Environmental Science and Pollution Research, 24(10),9754-9764.

Squalli, J., & Wilson., K (2011). A new measure of trade openness, The World Economy, 2011, 34 (10):1745–1770.

Tang, Z., Shia, C. B., & Liuc, Z. (2011). Sustainable development of tourism industry in China under the low-carbon Economy. Energy Procedia, 5(April), 1303–1307.

Tian, X. L., Bélaïd, F., & Ahmad, N. (2021). Exploring the nexus between tourism development and environmental quality: Role of Renewable energy consumption and Income. Structural Change and Economic Dynamics, 56, 53-63.

Tian, X., Chang, M., Shi, F., & Tanikawa, H. (2014). How does industrial structure change impact carbon dioxide emissions? A comparative analysis focusing on nine provincial regions in China. Environmental Science & Policy, 37, 243-254.

Uche, E., Das, N., & Bera, P. (2023). Re-examining the environmental Kuznets curve (EKC) for India via the multiple threshold NARDL procedure. Environmental Science and Pollution Research, 30(5), 11913-11925.

Udeagha MC, Breitenbach MC (2023f). The role of fiscal decentralization in limiting CO_2 emissions in South Africa. Biophysical Economics and Sustainability. https://doi.org/10.1007/s41247-023-00112-w

Udeagha MC, Ngepah N (2023e). The role of technological innovation in fostering environmental quality in South Africa: Fresh evidence from the novel dynamic ARDL simulations approach. 107-155.

Udeagha MC, Ngepah N (2023f). Achieving decarbonization goals in BRICS economies: Revisiting the joint role of composite risk index, green innovation, and environmental policy stringency. Cogent Social Sciences, 9(1), 2234230. https://doi.org/10.1080/23311886.2023.2234230

Udeagha, M,C., & Ngepah, N. (2023g) The drivers of environmental sustainability in BRICS economies: Do green finance and fintech matter? World Development Sustainability 3(1) 100096.

Udeagha, M. C., & Breitenbach, M. C. (2021). Estimating the trade-environmental quality relationship in SADC with a dynamic heterogeneous panel model. African Review of Economics and Finance, 13(1), 113-165.

Udeagha, M. C., & Breitenbach, M. C. (2023a). Exploring the moderating role of financial development in environmental Kuznets curve for South Africa: fresh evidence from the novel dynamic ARDL simulations approach. Financial Innovation, 9(1), 5.

Udeagha, M. C., & Breitenbach, M. C. (2023b). On the asymmetric effects of trade openness on CO_2 emissions in SADC with a nonlinear ARDL approach. Discover Sustainability, 4(1), 2.

Udeagha, M. C., & Breitenbach, M. C. (2023c). Revisiting the nexus between fiscal decentralization and CO_2 emissions in South Africa: fresh policy insights. Financial Innovation, 9(1):50.

Udeagha, M. C., & Breitenbach, M. C. (2023d). Can fiscal decentralization be the route to the race to zero emissions in South Africa? Fresh policy insights from novel dynamic autoregressive distributed lag simulations approach. Environmental Science and Pollution Research, 30(16), 46446-46474.

Udeagha, M. C., & Breitenbach, M. C. (2023e). The role of financial development in climate change mitigation: Fresh policy insights from South Africa. Biophysical Economics and Sustainability, 8(1),1.

Udeagha, M. C., & Muchapondwa, E. (2022). Investigating the moderating role of economic policy uncertainty in environmental Kuznets curve for South Africa: Evidence from the novel dynamic ARDL simulations approach. Environmental Science and Pollution Research, 29(51), 77199-77237.

Udeagha, M. C., & Muchapondwa, E. (2023a). Green finance, fintech, and environmental sustainability: Fresh policy insights from the BRICS nations. International Journal of Sustainable Development & World Ecology, 1-17. https://doi.org/10.1080/13504509.2023.2183526

Udeagha, M. C., & Muchapondwa, E. (2023b). Achieving regional sustainability and carbon neutrality target in Brazil, Russia, India, China, and South Africa economies: Understanding the importance of fiscal decentralization, export diversification, and environmental innovation. Sustainable Development, 31: 2620-2635. https://doi.org/10.1002/sd.2535

Udeagha, M. C., & Muchapondwa, E. (2023c) Achieving green environment in BRICS economies: Do composite risk index, green innovation, and environmental policy stringency matter? Sustainable Development. https://doi.org/10.1002/sd.2597

Udeagha, M. C., & Muchapondwa, E. (2023d) Striving for the United Nations (UN) Sustainable Development Goals (SDGs) in BRICS economies: The role of green finance, fintech, and natural resource rent. Sustainable Development. https://doi.org/10.1002/sd.2618

Udeagha, M. C., & Muchapondwa, E. (2023e). Environmental sustainability in South Africa: Understanding the criticality of economic policy uncertainty, fiscal decentralization, and green innovation. Sustainable Development, 31:1638-1651.

Udeagha, M. C., & Ngepah, N. (2019). Revisiting trade and environment nexus in South Africa: fresh evidence from new measure. Environmental Science and Pollution Research, 26(28), 29283-29306.

Udeagha, M. C., & Ngepah, N. (2020) Trade liberalization and the geography of industries in South Africa: fresh evidence from a new measure. International Journal of Urban Sciences 24(3): 354-396

Udeagha, M. C., & Ngepah, N. (2021a) The asymmetric effect of trade openness on economic growth in South Africa: a nonlinear ARDL approach. Economic Change and Restructuring 54(2): 491-540

Udeagha, M. C., & Ngepah, N. (2021b) A step Towards Environmental Mitigation In South Africa: Does Trade Liberalisation Really Matter? Fresh Evidence From A Novel Dynamic ARDL Simulations Approach. Research Square. https://doi.org/10.21203/rs.3.rs-419113/v1

Udeagha, M. C., & Ngepah, N. (2022a) Does trade openness mitigate the environmental degradation in South Africa?.Environmental Science and Pollution Research 29(13): 19352-19377

Udeagha, M. C., & Ngepah, N. (2022b) Dynamic ARDL Simulations Effects of Fiscal Decentralization, Green Technological Innovation, Trade Openness, and Institutional Quality on Environmental Sustainability: Evidence from South Africa. Sustainability 14: 10268.

Udeagha, M. C., & Ngepah, N. (2022c) Disaggregating the environmental effects of renewable and non-renewable energy consumption in South Africa: fresh evidence from the novel dynamic ARDL simulations approach. Economic Change and Restructuring 55:1767-1814.

Udeagha, M. C., & Ngepah, N. (2022d) The asymmetric effect of technological innovation on CO_2 emissions in South Africa: New evidence from the QARDL approach. Frontiers in Environmental Science, 10:985719.

Udeagha, M. C., & Ngepah, N. (2023a) Can public–private partnership investment in energy (PPPI) mitigate CO_2 emissions in South Africa? Fresh evidence from the novel dynamic ARDL simulations approach. Frontiers in Environmental Science, 10: 1044605.

Udeagha, M. C., & Ngepah, N. (2023b) Striving towards environmental sustainability in the BRICS economies: the combined influence of fiscal decentralization and environmental innovation, International Journal of Sustainable Development & World Ecology, 30(2), 111-125.

Udeagha, M. C., & Ngepah, N. (2023c). Striving towards carbon neutrality target in BRICS economies: Assessing the implications of composite risk index, green innovation, and environmental policy stringency. Sustainable Environment, 9(1), 2210950.

Udeagha, M. C., & Ngepah, N. (2023d) Towards climate action and UN sustainable development goals in BRICS economies: Do export diversification, fiscal decentralisation and environmental innovation matter? International Journal of Urban Sustainable Development, 15(1), 172-200.

Wang, L., Zhang, H., & Li, W. (2012). Analysis of Causality between Tourism and Economic Growth Based on Computational Econometrics. Journal of Computers, 7(9), 2152-2159.

Wang, Z., Jebli, M. B., Madaleno, M., Doğan, B., & Shahzad, U. (2021). Does export product quality and renewable energy induce carbon dioxide emissions: Evidence from leading complex and renewable energy economies. Renewable Energy, 171, 360-370.

Wangzhou, K., Wen, J. J., Wang, Z., Wang, H., Hao, C., & Andlib, Z. (2022). Revealing the nexus between tourism development and CO_2 emissions in Asia: does asymmetry matter?. Environmental Science and Pollution Research, 29(52), 79016-79024.

World Bank, 2021. World Development Indicators. http://databank.worldbank.org/data/.

Yilanci, V., & Pata, U. K. (2020). Investigating the EKC hypothesis for China: the role of economic complexity on ecological footprint. Environmental Science and Pollution Research, 27(26), 32683-32694.

Yue, X. G., Liao, Y., Zwangheng, S., Shao, X., & Gao, J. (2021). The role of green innovation and tourism towards carbon neutrality in Thailand: Evidence from bootstrap ADRL approach. Journal of Environmental Management, 292, 112778.