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Causality Testing of Industrialisation, Trade Openness and Carbon Dioxide Emissions for South Africa

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ABSTRACT

This study test causality between industrialisation, trade openness and carbon emissions and examined shocks from innovations for the period from 1990 to 2023. Results from Johansen Cointegration test showed presence of long-run association among industrialisation, trade openness and carbon emissions. Empirical results obtained from DOLS estimator indicated that industrialisation is instrumental in lowering carbon emissions. While trade openness promotes carbon dioxide emissions, suggesting high carbon content of international trade. Granger causality reveals that industrialisation Granger cause trade openness, whereas industrialisation and CO_2 jointly cause trade. Variance decomposition suggested unidirectional tendencies from LOC2 and TRADE to LINDUS. Impulse response results indicate bi-directional Granger causality tendency between TRADE and carbon emissions, and one-way causal link from industrialisation to trade. The study results indicate that industrialisation is a contributor to finding sustainable solution for carbon free economy. The outcome underscore important role of industrialisation in driving green investment and development of green technology. Government should allocate scarce resources to the industrial sector for innovation and development of domestic green technologies. Global development of green technologies and transfer is required for effective reduction of CO_2 emitted during trade related production and transportation. To promote environmentally friendly trade, reduction of trade barriers on green technologies is recommended.

Keywords: Carbon Emissions, DOLS, South Africa, Trade Openness, Industrialisation
JEL Classifications: F18, L6, O14

1. INTRODUCTION

It is widely acknowledged that industrialisation is the driver of sustainable and inclusive economic growth across the globe. According to the United Nations Industrial Development Organisation (UNIDO) (2020) industrialisation is not only a tool to stimulate economic growth and boost infrastructure development but also an engine of technological innovation, job creation, improve productivity and a channel trough which greener production technologies can be developed. It is perceived that industrialisation have effect across various dimensions of development. Additionally, industrialisation through manufacturing have direct and indirect linkages with other sectors of the economy. Therefore, paying attention to industrialisation as backbone of development is the path in realisation of 2030 agenda particularly delivery of Sustainable Development Goal (SDG) 9. SDG 9 focuses on building resilient infrastructure, promotion of sustainable and inclusive industrialisation and foster innovation (Statistics South Africa, (Stats SA, 2023).

It is against this background, that one of the goals of African Union Agenda 2063 is transformation of African economies industrialisation driven by science-technology and innovation (The African Union Commission, 2015). In a similar manner, African Development Bank (2019) recognised industrialisation as pivotal in achieving developmental goals of African countries. The African Development Bank (2019) advocates for industrialisation of Africa for purposes of achieving sustainable economic growth.

This call is motivated amongst other factors by the fact that Africa has the second-highest urbanisation rate in the world and by 2050 approximately 56% of its population will be urban. This translates into new infrastructure development opportunities. The increase in urbanisation has potential of strengthening middle class, which is envisaged to rise from 210 million in 2020 to 490 million in 2040. This will lead to increase in consumption expenditure of finished and manufactured goods. Additionally, spending in supermarkets and retail stores will rise a market with an estimated value of around $250bn and is expected to grow at a rate of 5% per annum (African Development Bank, 2019).

Moreover, estimates further indicate that Africa's population will grow by more than projected 0.2% global population. Specifically, in 2050 Africa will register 2 billion people characterised by youngest workforce and over 500 million economical active people in labour market. Consequently, development industrial sector will help in job creation and absorb this workforce. On the contrary, African countries have been struggling to reduce carbon dioxide emissions, despite having adopted the Paris Climate Agreement in which they committed to develop green, low-carbon economic growth that support environmental quality.

With regard to trade openness, trade is meant to ensure efficiency of industrialisation. It is like the heart of developed and developing economies. It controls the flow of goods and service in and outside the country. Trade has potential of accelerating industrialisation through flow of critical inputs. In the past decades, South Africa has experienced rapid population growth coupled with rising demand for manufactured goods. In an effort to meet the growth in aggregate demand for goods and services, South Africa started integrating with the world economy in the 1990s. As a consequence of participating in regional and global value chain, in 2022 South Africa was able to record total trade of around 65% of GDP compared to 38% registered in 1990 (World Bank, 2022). This trend validates government's commitment to increase trade with existing trading countries and creating more trade relationships with other countries.

Even though, South Africa have potential for green economic opportunities (green investment, green trade, green employment and green innovation) in Southern Africa (Global Green Growth Institute technical, 2023) is still struggling to reduce carbon emissions. The World Bank (2023) indicated that South Africa is the largest emitter of carbon emissions in Sub-Saharan African countries. For instance, in 2022 the world average of carbon dioxide (CO_2) emissions per capita stood at 4.6 metric tons, while Libya and South Africa emitted 8.0 and 6.5 metric tons respectively. With regard to production based carbon dioxide emissions, South Africa dominated by contributing 405 million tons while Egypt is responsible for 271 million tons to World's 37 billion tons (World Bank, 2022). This put South Africa at risk of being targeted by green protectionism than many other countries in African continent.

Concerning industrialisation, African Development Bank (2023) indicated that South Africa is the major market for manufactured exports and source of manufactured goods for neighbouring countries. South Africa is having stable macroeconomic environment for industrialisation as noted by African Development Bank (2022). The country is having potential inputs for the manufacturing sector and performing well in producing manufactured products and exports. For instance, South Africa is ranked amongst the top 5 African countries in terms of Africa Industrial Index with a score of (0.84), followed by Morocco (0.83), Egypt (0.79), Tunisia (0.77) and Mauritius (0.67). Therefore, South Africa is expected to play a dual role of leading industrialisation and reduction of carbon dioxide emissions in Sub-Saharan Africa. However, Appiah et al. (2021) and Aquilas et al. (2024) discovered that industrialization is detrimental to environmental sustainability. Aquilas et al. (2024) explain that industrialisation entails economic activities associated with air pollution, soil erosion, water pollution and climate change. On the other hand, trade openness has a negative impact on environment through its activities such as production, transportation and consumption as noted by (van Hinsberg and Can, 2024). By bringing together industrialisation and trade openness in a comprehensive analysis, this research provides deeper understanding into their causal effect on carbon dioxide emissions.

Empirically, very few studies concentrated on the interrelationship between industrialisation, trade openness and CO_2 emissions in a South African context. A recent study conducted by Chhabra et al. (2023) assessed the contribution of trade openness and institutional quality to CO_2 emissions in BRICS countries as a group. While Dingiswayo et al. (2023) and Lanhui and Ibrahim (2024) focused on carbon emission effect of trade openness and other macroeconomic variables in South Africa. However, Amoah et al. (2024) combined industrialisation, carbon emissions and trade openness in the Sub-Saharan Africa context. On the other hand, Appiah et al. (2021) integrated economic growth, industrialisation, trade, and electricity production and carbon dioxide emissions for Ghana.

It is evident that current studies so far were unable to disclose the simultaneous direct contribution of industrial activities and trade on carbon dioxide emissions for the South African economy. The isolation perspective restrict policy makers from implement intervention strategies that deal with carbon emission effect of both industrialisation and trade openness at the same time. This study strives to contribute to that gap in the literature and offer policy with recommendations for promoting green industrialisation driven by green trade practices. There is a need for South authorities to implement the Just Energy Transition Investment to hasten reliance on renewable energy to ensure that South African manufactured exports have lower levels of embedded carbon emissions.

This study lays foundation and offers framework that can influence formulation of decarbonisation strategies that are effective towards achieving sustainable industrialisation. It is also important to highlight that, deeper understanding of casual link between industrialisation, trade and carbon emissions is not only important for South Africa but has implications for other countries in Southern Africa. The outcomes of this research also intend to offer evidence-based insights for aligning domestic carbon emission strategies to adopt green technologies through industrialisation and trade.

The remaining sections are organised as follows. Section 2 discusses literature review, while section 3 presents data and methodology. Section 4 provides results. Section 5 offers conclusion and policy recommendations.

2. LITERATURE REVIEW

There is a wide range of studies that attempted to explain relationship between CO_2 emissions and other macroeconomic related variables. However, the question of interdependence between industrialisation, trade and carbon dioxide emissions did not receive much attention. For example, scholars such as Appiah et al. (2019) and Patel and Mehta (2023) found that industrialisation have a negative impact on environment quality through its association with high-energy consumption. They argue that in the absence of renewable energy, industrialisation relies on use of non-renewable energy sources such as fossil fuels as primary source of energy. Non-renewable energy consumption is empirically proven to have a significant damaging effect on the environment. Patel and Mehta (2023) premised their work on the Environmental Kuznets Curve (EKC) hypothesis.

Thus, during early stages of industrialisation, emphasis is not on environmental sustainability countries are inclined to achieve economic growth. In the framework of EKC, once a country reaches a certain level of industrialisation, policies and strategies focusing on environmental sustainable production methods and practices will be in place to enhance environmental preservation and reduce CO_2 emissions (Al-Ayouty and Hassaballa, 2022).On the same issue, Huo et al. (2022) observed that governments spend more on research and development and innovation projects that promote environmental quality. It is also assumed that countries economic activities will shift toward services, slowing carbon dioxide emissions and eventually decreasing them (Andriamahery et al., 2022).

Majeed and Tauqir (2020) are of the view that developing countries tend to specialise in the production of polluted product and this make them prone to environmental disaster partly due to comparative weak environmental regulations. Caetano et al. (2025) support this view by adding that developing countries attract and accept polluting industries from developed economies with stricter environmental standards and regulations, worsening carbon leakage.

Notwithstanding the role of trade openness in industrialisation, growing body of evidence suggests that trade related activities increase carbon dioxide emissions and damage environmental quality (Khan et al., 2021, Afesorgbor and Demana, 2021; Chhabra et al., 2023). Lanhui and Ibrahim (2024) explains the EKC hypothesis as revealing non-linear association between trade openness and environmental quality. In other words, intensification of trade result into increased environmental pollution confirming pollution haven hypothesis in the case of South Africa. The non-linearity among trade and openness and the environment was discovered Grossman and Krueger (1991).

In an attempt to validate Grossman and Krueger (1991) researchers such as Copeland and Taylor (2003) identified scale, composition and technological effects as channels through which trade openness affects the environment. They alluded that the scale effect refers to the rise in the value of production in the economy. Holding input and good mix, the expansion effect is an adverse effect of trade on the environment. Afesorgbor and Demana (2021) explained that the techniques effect occurs when trade openness reduces level of emissions. Trade openness stimulates economic growth which then increase national income and induce campaigns for cleaner environment as noted by Xia (2022). Hence, policy makers introduce and enforce stricter regulation to uphold environmental standards (Lanhui and Ibrahim, 2024).

As far as composition effect is concerned, Afesorgbor and Demana (2021) indicate that the concept measures the proportion of polluting goods in the national income. While Xia (2022) contends that, composition effect is evident when trade openness induces changes in a range of economic activities. Consequently, positive environmental outcomes will be realised only if changes facilitate industries in curbing pollution.

Clearly, on the nexus between trade and carbon dioxide emissions, much debate is still going on in the literature. Interesting insights can also be found from the work of Appiah et al. (2021, from 1971 to 2014 the researchers separated trade into export and imports in a quest to distinguish individual effects on carbon dioxide emissions in Ghana. With the aid of ARDL model, results indicated that trade exports and imports are vital in mitigating environmental damage by reducing CO_2 emissions. Specifically, 1 % rise in trade exports and imports curb emissions by approximately 27.7% and 4.1% respectively. Huo et al. (2022) support that environmental quality can be improved when trade openness increase. The scholars argue that trade openness provide opportunities to invest in environmentally friendly.

For the Sub- Saharan African (SSA) countries, Ewane and Ewane (2023) assessed carbon dioxide emission effects of trade and FDI inflows from 1975 to 2020. The authors utilised a quadratic modelling and turning point approach. The results showed a U-shaped relationship between trade openness and CO_2 emissions. The outcomes suggest that in the short-run trade openness decrease environmental degradation, reaches a turning point of around 3.54. However, when trade openness is above 34.5% of GDP, the level of CO_2 emissions accelerates. It is for this reason that the researchers recommend adoption of green technologies. Amoah et al. (2024) selected 28 SSA focusing on the moderating role of trade openness on carbon emissions effect of industrial activities. During 2003-2021, GMM and PMG estimators revealed that industrialization and trade encourage carbon dioxide emissions. However, trade openness moderates the positive influence of industrialisation on carbon emissions.

Thi et al. (2023) applied FMOLS, DOLS and GMM estimators to investigate connection between renewable energy consumption, international tourism, trade openness and innovation on CO_2 emissions. The authors focused on 53 countries covering the period of 1990-2019. In the case of aggregated income groups, results indicate that trade openness as instrumental in environmental sustainability by reducing CO_2 emissions. Whereas, for high- income countries trade openness has a negative connection with CO_2 emissions. In low-middle income, economies trade openness cause environmental degradation. Hence, the scholars suggested investment in renewable energy consumption and implementation of environmental quality policies in middle-low-income countries. Meanwhile, Sharif et al. (2022) emphasise that carbon dioxide emission effect of trade liberalisation is heterogenous across different income groups, necessitating country specific environmental measures and initiatives.

Focusing on South African economy, Dingiswayo et al. (2023) conducted a study to explore the nexus between trade openness and environmental quality. The ARDL estimation output showed that trade openness exacerbates CO_2 emissions both in the short and long run. Granger causality test confirmed one-way causal link flowing from trade openness to environmental quality, implying that trade openness damages the environment. Driven by these outcomes, the authors advocate for regional and global cooperation for knowledge sharing and technological transfers. In order to unveil green impact of trade liberalization, Dingiswayo et al. (2023) believe that government should consider imposing green tariffs or carbon taxes on important goods.

Regarding industrialisation, many researchers contributed to the nexus between industrialisation and carbon dioxide emissions in developed and developing countries using different econometric techniques. Appiah et al. (2019) analysed time series data for the period 1990-2014 using Autoregressive Distributed Lag (ARDL) to access contribution of industrialisation, economic growth and energy intensity to carbon dioxide emissions. The ARDL estimation results indicated presence of long-run causality from industrialisation to carbon dioxide emissions for the economy of Uganda. Appiah et al. (2019) recommended increase in energy intensity in Uganda, based on short-run findings that industrialisation, economic growth and energy intensity jointly reduce carbon dioxide emissions. Scholars such as (Al-Ayouty and Hassaballa, 2022; Appiah et al., 2021; Majeed and Tauqir, 2020; Sampath et al., 2024 and Shang et al., 2023) confirm that industrialisation contribute to environmental degradation by increasing carbon dioxide emissions.

Aquilas et al. (2024) focused on 46 African countries to investigate the influence of industrialization on environmental sustainability. The study applied panel fixed effect and generalised least squares. For intensive, analysis the scholars accounted for the moderation effect of renewable energy consumption. The outcome revealed that industrialisation is detrimental to environmental sustainability. Contrary, when considering the moderation effect of renewable energy consumption, industrialisation emerged instrumental in achieving sustainable environment. In the case of Su-Saharan Africa, Jinapor et al. (2024) discovered institutional quality could play an important role in moderating the harmful effect of industrialisation on environmental quality.

Avengo and Tregenna (2021) are of the view that to deal with the dual challenge of industrialisation and climate change mitigation, developing countries should focus on high-technology industrialisation. Estimating the effects of technology intensity in manufacturing on CO_2 emissions, separately for low, medium and high technology, GMM estimation results show medium and high technology significantly increase carbon dioxide emissions in 56 developing countries from 1991 to 214. While, carbon dioxide emissions are lower from high technology industries. Whereas, Mosikari (2024) established unequal carbon dioxide emissions effect of industrialization in the context of SACU. The results suggested an inverted U-shaped curve for 2000-2007 period. Quantile regression outcome disclose that at the lower and higher quantiles industrialisation has minor influence on the environment. Whereas, industrialisation promote carbon dioxide emissions in the 4th to the 6th quantiles. However, in the 7th and 8th quantiles carbon dioxide promotional effect of industrialisation diminishes.

In 8 selected ASEAN+3 economies, Elfaki et al. (2022) came to a conclusion that in the long-run industrialisation reduce carbon dioxide emissions for 1994-2018. The authors based their decision on estimation output from the Pooled Mean Group (PMG), Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS) and Seemingly Unrelated Regression (SUR) panel estimators. To provide deeper understanding, the study regarded economic growth, energy consumption, financial development and industrialisation as independent variables and carbon dioxide emissions was the dependent variable.

Of all studies reviewed so far, irrespective of the carbon dioxide emissions indicator used and estimation technique applied contradictory outcomes are discovered.

3. DATA AND METHODOLOGY

This study aims to determine causal association between industrialisation, trade openness and carbon dioxide emissions in South Africa. Quantitative data for this study is obtained from the World Bank Development Indicators (2022) and South African Reserve Bank (SARB) online database for the period 1990-2023. Carbon dioxide emissions (CO_2) represent the dependent variable, while trade openness (TRADE) and industrialisation (INDUS) are explanatory variables respectively.

3.1. Variable Description

This section gives detailed account of study variable.

3.1.1. Industrialisation (INDUS)

In compliance with AfDB (2022) and following the works of Aquilas et al. (2024); Lugina et al. (2022) and Mosikari (2024) this study applied manufactured value added (MVA) as a share of GDP to capture industrialisation. MVA is an indicator that is utilised to examine performance dimension in the African Industrial Index. It is also important to mention that MVA is a valuable measure to trace growth dynamics of manufacturing in the country as well as its importance within the country. Additionally, MVA is instrumental in revealing structural and economic changes (AfDB, 2022).

3.1.2. Trade openness (TRADE)

The African Development Bank (2022) identified trade as a tool to achieve industrialisation objectives in Africa. It is the measure of economic relations with other economies thus indicating openness. Therefore, trade openness is the sum of imports and exports as proportion of GDP (Sarkodike et al., 2020). This study used trade to GPD following empirical works of Chhabra et al. (2023) and Dingiswayo et al. (2023). According to Chhabra et al. (2023) and Sarkodike et al. (2020) trade openness can be a channel through which pollution can be transferred across boundaries. However, using trade smartly to unveil its green impact can lead to sustainable industrialisation (African Development Bank, 2022; Dingiswayo et al. 2023).

3.1.3. Carbon dioxide emissions (CO_2)

CO_2 emissions measured in metric tons per capita are carbon dioxide emissions stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid and gas fuels and gas flaring (World Bank, 2022). This indicator is used as a proxy by many scholars (Al-Ayouty and Hassaballa, 2022; Appiah et al., 2021; Dingiswayo et al., 2023; Sampath et al., 2024).

3.2. Model Specification

Informed by reviewed empirical studies, this study adopt the following functional form:

$$CO_2 = f\,(INDUS,\ TRADE) \quad (1)$$

In order to stabilise variance of the data (Habanabakize and Dickason-Koekemoer, 2023) variables CO_2 and INDUS were converted into natural logarithms and the model become:

$$LCO2_t = \beta_{0t} + \beta_{1t}\, LINDUS + \beta_{2t}\, TRADE + \varepsilon_t \quad (2)$$

Where β_0 indicates the constant term, β_1 and β_2 are parameters of explanatory variables and ε_t is the error term.

3.3. Estimation Techniques

This research applied an integrated econometrics approach for the expansion of knowledge and understanding of causality between industrialisation, trade and carbon emissions. However, as noted by Sampath et al. (2024) that assessing stationarity properties of dataset is one of the requisites prior to selection of the suitable data analysis model. If the dataset has a unit root carrying out regression analysis will be impossible. Matenda et al. (2024) argued that stationarity tests help to avoid spurious regression. For this purpose, the study performed Augmented Dickey-Fuller (ADF) stationarity test introduced by Dickey and Fuller (1979). For robustness check, the researcher applied Phillips-Perron (PP) unit root test proposed by Phillips and Perron (1988).

Following this step, the study examined cointegration employing Johansen test for cointegration introduced by Johansen and Juselius (1990). The test is based on two likelihood ratios namely maximum eigenvalue statistic and trace statistic. The underlying null hypothesis of this test is there is no cointegration between variables. While alternative hypothesis suggests presence of long run relationship among study variables.

The validation of co-movement between the study variables inspired determination of long-run coefficients. For this reason, the study implemented Dynamic Ordinary Least Squares (DOLS) estimator. The DOLS estimator generate more reliable and unbiased estimators (Stock and Watson, 1993). DOLS consist of three advantages; amongst others is inclusion of lagged and lead values to regressors to capture the dynamic nature of the connection between study variables. This research may face challenges such as omitted variables and specification errors suggesting evidence of endogeneity. The endogeneity problem could undermine the power and relevance of other estimator, thus rendering DOLS as suitable estimator. Additionally, DOLS is able to cope with variables integrated at level and at order I (1) as indicated by Ajisafe et al. (2024). DOLS provide more accurate coefficient by accounting for cointegration.

The estimated model was subjected to several diagnostic tests to ascertain well specification and non-violation of classical regression assumptions. To ensure reliability and validity of estimated parameters, research conducted tests for heteroscedasticity, serial correlation and normality. After determining long-term parameters, the study conducted causality testing with the help of VAR Granger causality/Block exogeneity Wald test. The study further examined if there are any significant effects from the shocks by conducting variance decomposition and impulse response analysis.

4. RESULTS

4.1. Unit Root Tests

The research applied two tests to determine stationarity of the series, the ADF and PP as indicated in Table 1. The results demonstrate that variables became stationary after first difference, that means the series is integrated at order I (1) under intercept and trend and intercept assumptions.

Table 1: Stationarity results

	ADF at level		PP at level	
Variables	**Intercept**	**Trend and Intercept**	**Intercept**	**Trend and Intercept**
LCO_2	−1.577177	−1.965532	−1.377871	−1.796774
LINDUS	−2.320716	−1.636537	−3.968576	−1.522591
TRADE	−1.343096	−3.119682	−0.725208	−2.959837
ADF and PP at First Difference				
LCO_2	−7.303626**	−7.349491**	−7.511113**	−8.207888**
LINDUS	−5.036429**	−5.541760**	−5.036429**	−5.931828**
TRADE	−5.863342**	−5.755958**	−11.09844**	−10.77816**

Source: Author's computation based on E-views 12

***, ** and *denote significance at 1%, 5% and 10% respectively

Table 2: Lag length selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−85.86381	NA	0.062013	5.733149	5.871922	5.778386
1	18.20258	I81.2769	0.000135	−0.400167	0.154925*	−0.219221
2	29.51182	17.51108*	0.000119*	−0.549150*	0.422261	−0.232494

*Indicates lag order selected by the criterion. LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan- Quinn information criterion

Table 3: Johansen cointegration results

Hypothesized No. of CE (s)	Eigenvalue	Trace Statistic	0.05 Critical value	Prob.**	Max-Eigen statistic	0.05 Critical value	Prob.**
None*	0.743798	54.61723	29.79707	0.0000	40.85371	21.13162	0.0000
At most 1	0.362689	13.76352	15.49471	0.0897	13.51494	14.26460	0.0654
At most 2	0.008252	0.248576	3.841465	0.6181	0.248576	3.841465	0.6181

Trace test indicates 1 cointegrating eqn (s) at the 0.05 level, Max-eigenvalue test indicates 1 cointegrating eqn (s) at the 0.05 level *denotes rejection of the hypothesis at the 0.05 level

4.2. The Optimal Lag Length

For both DOLS and Johansen test for co-integration Akaike Information Criterion (AIC) selected 2 lags as can be seen from Table 2.

In the next step, the study conducted cointegration test in all three variables. Pamba (2025) highlighted that co-integration assess long-term effect of change in one variable in another.

4.3. Cointegration Test

Table 3, indicates existence of co-integration in the variables at 5% level of significance implying rejection of the null hypothesis of no co-integrating equation.

The results confirm presence of long-run relationship between industrialisation, carbon dioxide emissions and trade openness. Trace and Max-eigenvalue test indicate one co-integrating equation respectively. The results suggest that industrialisation, trade and carbon emissions have a long-run relationship. Borrowing from Kwakwa (2023) cointegration indicates that carbon emissions depend on industrialisation and trade openness. Table 3, further reveal Johansen cointegration null hypothesis of none was rejected.

4.4. Dynamic Ordinary Least Squares Results

Table 4 presents results of long-run association between industrialisation, trade openness and carbon emission. Findings demonstrate that elasticity coefficient of LINDUS has statistical long-run effect on carbon emissions at 5% level of significance. Specifically, a 1% increase in manufacturing activities would decrease carbon emissions by 0.36%. This outcome suggest that intensive industrial development lower carbon dioxide emissions in South Africa during the period under review. The findings is aligned with previous empirical work of Elfaki et al. (2022), Avengo and Tregenna (2021) supporting the argument that promotion of industrialisation improve environmental quality through innovations and development of environmental friendly technology. Avengo and Tregenna (2021) argued that acceleration effect of industrial activities on CO_2 emissions depend on degree of technological intensity in manufacturing.

Aquilas et al. (2024) discovered that combining industrial growth with use of renewable energy decreased carbon emissions. This suggest that even though industrial activities may accelerate carbon dioxide emissions, employing renewable energy for industrial purposes is beneficial in curbing carbon emission effects associated with industrial activities. On the same issue, Mosikari (2024) is of the view that industrial carbon emission effect is unequal distributed suggesting non-linear influence of industrial activities on emissions of CO_2. However, research conducted by Aquilas et al. (2024) reported carbon dioxide promotion effect of industrialisation in 46 African countries.

Table 4: Results of DOLS

Variables	Coefficients	t-statistics	Prob
LINDUS	−0.360058	−3.701553	0.0021
TRADE	0.030759	4.337204	0.0006
R-squared			0.807237
Adjusted R-squared			0.653026
Durban- Watson			2.647999
Post estimation tests	**Statistical value**		**Prob**
Serial Correlation	6.189244		0.0453
Heteroskedasticity	6.824521		0.8690
Jarque-Bera	0.184691		0.911790

Source: Author's computation using Eviews 12

Furthermore, results in Table 4 reveal that trade openness promote carbon dioxide emissions. Quantitatively, a one-percentage change in trade accelerate carbon emissions by 0.030. This finding is consistent with results discovered by Jun et al. (2020), Sarkodike et al. (2020), Ayun and Khasanah (2022). Chhabra et al. (2023) indicated that carbon dioxide effect of trade openness is an affirmation that benefits of composition and technology effects derived from trade are less than scale of production effects. Additionally, Ayun and Khasanah (2022) argued that rising, demand for exports drives energy consumption and stimulate productivity. This in turn stimulate productivity that produce waste and residues with adverse effect on the environment. On the other hand, Kwakwa (2023) is of the view that trade openness might have attracted energy intensive goods which triggered higher carbon emissions. At the same time, imported goods may promote carbon emissions, suggesting energy inefficiencies.

4.5. Post Estimation Tests

Regarding diagnostic tests, Table 4, indicates that DOLS model does not suffer from serial correlation. The study confirmed normality of residuals through the Jarque-Bera, an outcome with P-value of 0.911790 validates that residuals are normally distributed. The test of heteroscedasticity suggest acceptance of null of homoscedasticity. While CUSUM and CUSUM of Squares tests endorse stability of the model. Figures 1 and 2 provide evidence of stability.

Figures 1 and 2 in both CUSUM and CUSUM of Squares stability of DOLS model is approved as blue lines fall with the 5% level of significance.

4.6. Causality Test

The study applied VAR Granger Causality/Block exogeneity Wald test to assess direction of causality among the variables. The test was conducted on three models, log of Carbon dioxide emissions (LCO_2), log of industrialisation (LINDUS) and Trade openness (TRADE).

Results in Table 5, provide empirical evidence that industrialisation foster trade openness. Trade driven by industrialisation have a potential of encouraging adoption of greener technologies leading to environmentally sustainable manufacturing practices that reduce carbon emissions (Wang et al., 2022). At the same time, the results not only indicate unidirectional causality from industrial activities, but also show joint causality from industrialisation and carbon emissions to trade openness. This outcome underscore alignment of domestic carbon emission strategies with industrialisation policy. Development and diffusion of green technologies will assist in reducing carbon emissions and accelerate transition towards low carbon economy. This in turn can result in reduction of transfers of embodied carbon. As noted by Zhang et al. (2023) reduction of carbon emissions in developed countries is realised at the expense of developing economies. In other words, carbon emissions influence trade openness by dictating where and when production take place. However, the study results reveal that industrialisation can contribute in bringing sustainable solution.

Figure 1: CUSUM test results

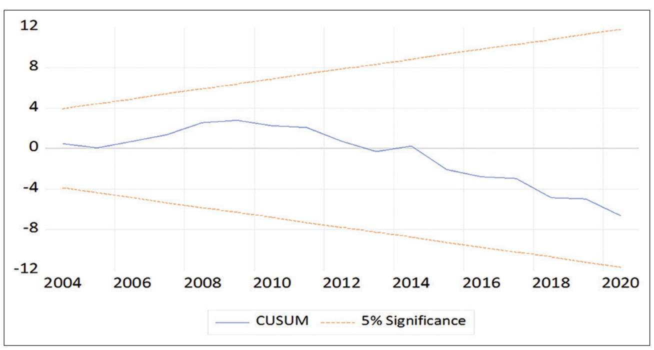
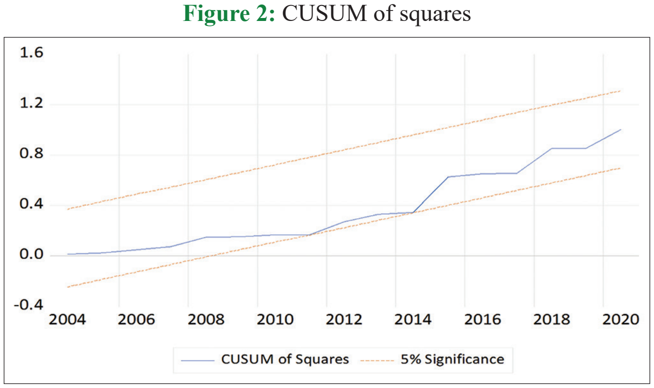


Figure 2: CUSUM of squares



4.7. Variance Decomposition

The study applied variance decomposition test to forecast sensitivity of variables for the next 10 years. The period from the first year to the third year is the medium term while from the fourth year to the tenth year represent the long term. Outcome in Table 6a, indicate that LCO_2 is strongly endogenous implying that 100% of forecast error variance is explained by itself in year one. That means LINDUS and Trade have strong exogenous impact on LCO_2.

However, from year 3-10th year, 97 % of forecast variance in LCO_2 is explained by itself. From the medium term, LINDUS is responsible for approximately 0.54% variation in LCO_2 and trade account for 2.51%. Table 6a further reveal that shocks to LINDUS and TRADE cannot contribute much LCO_2 neither in the medium nor long-term.

According to Table 6b, innovation to LINDUS account for 94% variation of fluctuation to LINDUS in the medium term. While shock to LCO_2 and TRADE cause 3. 39% and 2.5% respectively. As shown in Table 6b, LCO_2 is the very strong influencer of LINDUS. The influence is increasing from the medium term

Table 5: Granger causality/block exogeneity wald tests results

Dependent variable: LCO_2			
Excluded	**Chi-square**	**df**	**Prob.**
LINDUS	1.386870	2	0.4999
TRADE	1.352468	2	0.5085
All	2.304669	4	0.6799
Dependent Variable: LINDUS			
Excluded	**Chi-square**	**df**	**Prob.**
LCO_2	4.921476	2	0.0854
TRADE	1.843128	2	0.3979
All	5.100254	4	0.2772
Dependent Variable: TRADE			
Excluded	**Chi-square**	**df**	**Prob.**
LCO_2	2.25450	2	0.3231
LINDUS	10.30086	2	0.0058
All	10.78879	4	0.0290

Source: Author's computation

Table 6a: Variance decomposition of LCO_2

Period	S.E	LCO_2	LINDUS	TRADE
1	0.071240	100.0000	0.000000	0.000000
2	0.083829	97.45650	0.023957	2.519540
3	0.093071	96.95437	0.538009	2.507616
4	0.100408	97.18205	0.616077	2.201872
5	0.105102	97.27125	0.645670	2.083079
6	0.108625	97.33808	0.629271	2.032646
7	0.111322	97.37460	0.632142	1.993256
8	0.113422	97.38644	0.659509	1.954054
9	0.115079	97.37540	0.703593	1.921006
10	0.116401	97.35146	0.753450	1.895093

Source: Author's calculations using Eviews 12 into the future. On the other hand, the effect of TRADE to LCO_2 is insignificant during the same time horizon. In the long term, impulse on LINDUS can contribute 69.75% fluctuations on its self.

Regarding variance decomposition of trade, in year 3, impulse to LCO_2 can cause 8.27% fluctuation in TRADE and 61.61% of forecast error variation is explained by LINDUS. During the same period, TRADE predict around 30.11% of variations to itself. In the long-run LINDUS exhibit strong exogenous impact on TRADE, by predicting 61.9%, while TRADE account for 28.66% to its own variation. Suggesting that trade is weakly endogenous.

Table 6b: Variance decomposition of LINDUS

Period	S.E	LCO_2	LINDUS	TRADE
1	0.045354	2.451686	97.54831	0.000000
2	0.060791	1.372923	96.41579	2.211287
3	0.077929	3.392353	94.08297	2.524682
4	0.089044	5.614511	92.26153	2.123962
5	0.098962	9.370842	88.82388	1.805275
6	0.109168	13.65677	84.79019	1.553040
7	0.119226	17.92277	80.73093	1.346302
8	0.128995	22.01783	76.81041	1.171762
9	0.138480	25.83933	73.13377	1.026891
10	0.147724	29.33772	69.75473	0.907556

Source: Author's calculations using Eviews 12

Table 6c: Variance decomposition of TRADE

Period	S.E	LCO_2	LINDUS	TRADE
1	4.160737	2.342172	61.10761	36.55022
2	4.731446	4.145416	64.81401	31.04058
3	4.855624	8.272330	61.61297	30.11470
4	4.885411	9.296592	60.89958	29.80383
5	4.920213	9.466511	60.99735	29.53614
6	4.955015	9.504587	61.25939	29.23603
7	4.972023	9.507562	61.43736	29.05507
8	4.983046	9.471560	61.59552	28.93292
9	4.994884	9.434563	61.76035	28.80509
10	5.008020	9.430197	61.90688	28.66293

Source: Author's calculations using Eviews 12

Table 6c also indicate that impulse to LCO_2 can cause around 9% fluctuations in TRADE throughout the long-term. Overall, combined shocks to LCO_2 and LINDUS can contribute much in the long-term. We can observe similarities between results in causality and variance decomposition results of TRADE.

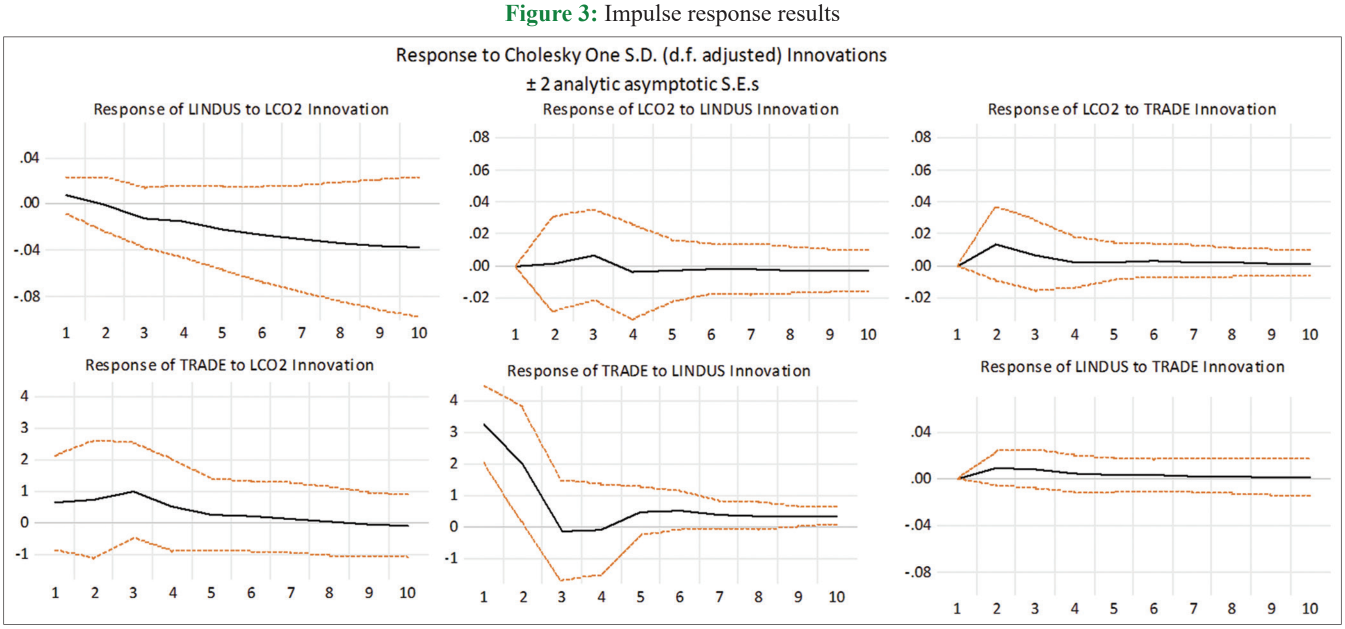
4.8. Impulse Response Function

The study conducted impulse response analysis to establish effects on present and future value of endogenous variable of one standard deviation shock to one of innovations. Figure 3, shows that one standard deviation innovation introduced to LCO_2 initially has no significant effect in period 1. However, from period 2, the response is declining at a faster rate and remains in the negative zone. Suggesting that innovations to LCO_2 will have a negative effect on LINDUS in the future.

Looking at the response of Trade, a one standard deviation shock to LCO_2 increase TRADE and attains the highest point in period 3. From period 4 to 5 this positive impact gradually declines but still in the positive zone. Beyond period 5, reaches the steady state, and remains at zero beyond period 7-10. On the other hand, reaction of LCO_2 to standard deviation shock to TRADE initially induces LCO_2 in period 1, reaches a maximum point in period 2. Beyond period 2, the response gradually declines and becomes zero from period 4. The results between TRADE and LCO_2 exhibit bidirectional Grangers causality tendencies.

Regarding response of TRADE to LINDUS innovation, one standard deviation shock experienced by LINDUS lead to a noticeable rise in the response of TRADE. A gradual decline is indicated from period 2 to period 3 but still in the positive region. TRADE response becomes zero beyond period 3 to around period 4. From around period 5 it starts to rise up to period 6 and remains constant from period 7 to period 10. The results are similar to the Granger Causality/Block exogeneity Wald test (Table 5). Contrary, one standard deviation impulse to TRADE has no significant

Figure 3: Impulse response results



Source: Author's calculations using Eviews 12 impact on LCO_2. Furthermore, reaction of LCO_2 to LINDUS innovation seems to have weak impact.

5. CONCLUSION AND POLICY RECOMMENDATIONS

South Africa has a developed industrial base and is the major market for manufactured exports for neighbouring countries. It is expected to play a leading role in driving green economy due its potential for green economic opportunities in areas such as green investment, green employment and green innovation. However, South Africa is struggling to reduce carbon emissions due high level of fossil fuel reliance. In Sub Saharan Africa, South Africa is the largest emitter of carbon dioxide putting it at a risk of being targeted by green protectionism than many other countries in Africa. Promotion of industrial sector through manufacturing is one of other ways to stimulate green innovations and green investment. This study test causality between industrialisation, trade openness and carbon emissions. Furthermore, it conducts impulse response as well as variance decomposition to examination shocks from innovations. In pursuance of the study objective time series data spanning from 1990 to 2023 was analysed.

The results from Johansen Cointegration test showed presence long-run association among industrialisation, trade openness and carbon emissions as displayed in Table 3. Moving forward, Table 4, present results obtained from the DOLS. The outcome indicated that in the long- run industrialisation is instrumental in lowering carbon emissions. This outcome highlight that industrialisation is not the source of problem rather contributor to finding sustainable solution for carbon free country by 2050. The industrial sector is the hub of innovation and is crucial for development of domestic green technologies through research and development investment. The results provide deep understanding of vital role of industrialisation in driving green investment and transition towards carbon free production processes.

In addition, results indicated trade openness as leading to carbon dioxide emissions. The outcome suggest high carbon content of international trade. Specifically, international trade contributes 3% to CO_2 emissions, as trade increases carbon emissions embedded in trade will rise by 3%, greater than the growth of gross domestic product. It is worth noting that carbon emissions embedded in trade are associated with transportation and production of goods that are imported and exported.

Regarding, Granger causality industrialisation Granger cause trade openness, whereas industrialisation and CO_2 jointly cause trade. According to variance decomposition, results expose LCO_2 and trade have exogenous impact on industrialisation in the long run. These results suggest unidirectional causality tendencies. The impulse response results indicate bi-directional Granger causality tendency between TRADE and carbon emissions, and one-way causal link from industrialisation to trade. This outcome unveil interplay between industrialisation, trade openness and carbon dioxide emissions. The industrial sectors' forward and backward linkages with the rest of the economy can be beneficial in promoting green production. In addition, industrialisation has a potential in diffusing green technologies.

Based on results, the study recommends domestic policy initiatives to focus on enhancing greening of existing production processes through apprenticeship for green industry. Government should invest in technologies that promote green economy and provide funding for research on green innovations. The industry sector is well suited for the allocation of scarce resources in order produce green goods and pass them to other sectors of the economy. Given that carbon emissions are country, regional and global externalities suggest a need for cooperation. Global development of green technologies and transfer is required for effective reduction of CO_2 emitted during trade related production. This calls for intervention of World Trade Organisation (WTO) in fostering environmental friendly trade. By reducing trade barriers on green technologies to ease access and facilitate diffusion and adoption of these technologies. This in turn, will speed transition towards low carbon emissions.

This study has established empirical based evidence about causality between industrialisation, trade openness and carbon dioxide emissions in South Africa. However, it did not account for other factors such as consumption of renewable energy, population growth and R & D. Other studies can be conducted to include these factors. Furthermore, other studies may also look at indirect impact of industrialisation to carbon emissions. Future studies can shed more light on trade –carb emission nexus by considering sectoral composition of trade flows. This research applied CO_2 emissions as a primary indicator future study can benefit from using more comprehensive indicator to provide clear picture of overall environmental impact of industrialisation and trade openness.

REFERENCES

Afesorgbor, S.K., Demana, B.A. (2021), Trade openness and environmental emissions: Evidence from a meta-analysis. Environmental and Resource Economics, 81(2), 287-321.

African Development Bank. (2019), Industrialise Africa, African Development Bank Group, Communication and External Relations Department. Abidjan: African Development Bank. Ivory Coast.

African Development Bank. (2022), Africa Industrialisation Index, African Development Bank Group, Communication and External Relations Department. Abidjan, Nigeria: African Development Bank. Ivory Coast.

African Development Bank, (2023). South Africa combined country strategy paper 2023-2028 and country portfolio performance review 2023, African Development Group, Abidjan, Ivory Coast.

Ajisafe, R.A., Okunade, S.O., Fatai, M.O. (2024), Modelling structural breaks in social cash transfers effects on poverty and inequality reduction in Africa: A case of Nigeria. Scientific African, 23, 1-12.

Al-Ayouty, I., Hassaballa, H. (2022), The effect of urbanisation and industrialisation on environmental quality: The case of the MENA region. In: 25th RSEP International Conference on Economics, Finance and Business. Mercure Paris, France, Conference Procedings/Full Papers. p37-51.

Amoah, J.O., Alugidede, I.P., Sare, Y.A. (2024), Industrialization and carbon emissions nexus in Sub-Saharan Africa. The moderating role of trade openness. Cogent Economics and Finance, 12(1), 1-17.

Andriamahery, A., Danarson, J.H., Qamruzzaman, M.D. (2022), Nexus between trade and environmental quality in sub-Saharan Africa: Evidence from panel GMM. Frontiers in Environmental Science, 10, 986429.

Appiah, K., Appah, R., Mintah, O.K., Yeboah, B. (2021), Economic growth, industrialisation, trade, electricity production and carbon dioxide emissions: Evidence from Ghana. Journal of Economic Science and Research, 4(1), 31-43.

Appiah, K., Du, J., Yeboah, M., Appiah, R. (2019), Causal relationship between industrialisation, energy intensity, economic growth and carbon dioxide emissions: Recent evidence from Uganda. International Journal of Energy Economics and Policy, 9(2), 237-245.

Aquilas, N.A., Ngangnchi, F.H., Mbella, M.E. (2024), Industrialization and environmental sustainability in Africa: The moderating effects of renewable and non-renewable energy consumption. Heliyon, 10, e25681.

Avengo, E., Tregenna, F. (2021), The Effects of Technology Intensity in Manufacturing on CO_2 Emissions: Evidence from Developing Countries. Economic Research Southern Africa (ERSA) Working Paper 846.

Ayun, I.Q., Khasanah, U. (2022), The impact of economic growth and trade openness on environmental degradation: Evidence from A panel of ASEAN countries. Jurnal Ekonomi and Studi Pembangunan, 23(1), 81-92.

Caetano, R.V., Marques, A.C., Afonso, A.C. (2025), From carbon leakage to (re) industrialisation: As assessment of the ecological footprint of imports in developed countries, Journal of Cleaner Production, 487, 1-17.

Chhabra, M., Giri, A.K., Kumar, A. (2023), Do trade openness and institutional quality contribute to carbon emission reduction? Evidence from BRICS countries. Environmental Science and Pollution Research, 30, 50986-51002.

Copeland, B.R., Taylor, M.S. (2003), Trade, Growth and the Environment. NBER Working Paper 9823, National Bureau of Economic Research, Inc.

Dickey, D., A. & Fuller, W., A.(1979). Distribution of the estimator for autoregressive time series with a unit root. Journal of the American Statistical Association, 74(366a), 427-431.

Dingiswayo, U., Sibanda, K., Dubihlela, D. (2023), Unveiling the green impact: Exploring the nexus between trade openness and environmental quality in South Africa. International Journal of Environmental Sustainability and Social Science, 4(5), 1302-1320.

Elfaki, K.E., Khan, Z., Kirikkaleli, D., Khan, N. (2022), On the nexus between industrialisation and carbon dioxide emissions: Evidence from ASEAN +3 economies. Environmental Sciences and Pollution Research, 29, 31476-31485.

Ewane, B., Ewane, E.I. (2023), Foreign direct investment, trade openness and environmental degradation in SSA countries: A quadratic modelling and turning point approach. American Journal of Environmental Economics, 2(1), 9-18.

Global Green Growth Institute. (2023), Green Growth Index 2022: Measuring Performance in Achieving SDG Targets, GGGI Technical Report No. 32, Republic of Korea.

Grossman, G.M., Krueger, A.B. (1991), Environmental impact of a North American Free Trade Agreement. NBER Working Paper 3914, National Bureau of Economic Research, Inc.

Habanabakize, T., Dickason-Koekermoer, Z. (2023), The role of industrialization on employment and growth in South Africa. International Journal of Economics and Financial Issues, 13(6), 116-123.

Huo, W., Ullah, M.R., Zulfiqar, M., Parveen, S., Kibria, U. (2022), Financial development, trade openness and foreign direct investment: A battle between the measures of environmental sustainability. Frontiers in Environmental Science, 10, 1-10.

Jinapor, J.A., Abor, J.Y., Graham, M. (2024), FDI, industrialisation and environmental quality in SSA- the role of institutional quality towards environmental sustainability. Humanities and Social Sciences Communications, 11, 1484.

Jun, W., Mohamood, H., Zakaria, M. (2020), Impact of trade openness on environment in China. Journal of Business Economics and Management, 21(4), 1185-1202.

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.

Khan, H., Weili, L., Khan, I., Khamphengxay, S. (2021), Renewable energy consumption, trade openness and environmental degradation: A panel data analysis of developing and developed countries. Hindawi Mathematical Problems Engineering, 2021, 1-13.

Kwakwa, P.A. (2023), Sectoral growth and carbon dioxide emission in Africa: Can renewable energy mitigate the effect? Research in Globalisation, 6, 1-11.

Lanhui, W., Ibrahim, A.S. (2024), Unravelling the environmental consequences of trade openness in South Africa: A novel approach using ARDL modelling. Environmental Research Communications, 6, 1-24.

Lugina, E.J., Mwakalobo, A.B.S., Lwesya, F. (2022), Effects of industrialization on Tanzania's economic growth: A case of manufacturing sector. Future Business Journal, 8(62), 1-11.

Majeed, M.T., Tauqir, A. (2020), Effects of urbanisation, industrialisation, economic growth, energy consumption and financial development on carbon emissions: An extended STIRPAT model for heterogenous income group. Pakistan Journal of Commerce and Social Sciences, 14(3), 652-681.

Matenda, F.R., Raihan, A., Zhou, H., Sibanda, M. (2024), The influence of economic growth, fossil and renewable energy, technological innovation, and globalisation on carbon emissions in South Africa. Carbon Research, 3(69), 1-18.

Mosikari, T. (2024), Heterogenous effect of industrialisation on environmental degradation in Southern African (SACU) Countries: Quantile analysis. Economies, 12(71), 1-12.

Pamba, D. (2025), Revisiting the Effectiveness of Fiscal Policy on Economic Growth in South Africa: A Markov Switching Means Var Approach. Available from: https://www.researchgate.net/publication/389651103

Patel, N., Mehta, D. (2023), The asymmetric effect of industrialisation, financial development and globalisation on CO_2 emissions in India. International Journal of Thermofields, 20, 1-9.

Phillips, P., C. & Perron, P. (1988). Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.

Sampath, H.R., Pyeman, J., Othman, N. (2024), Nexus of industrialisation and environmental degradation in newly industrialised countries. Journal of Sustainability and Management, 19(11), 223-233.

Sarkodike, S.A., Owusu, P.A., Leivik, T. (2020), Global effect of urban sprawl, industrialisation, trade and economic development on carbon dioxide emissions. Environmental Research Letters, 15, 034049.

Shang, M., Ma, Z., Su, Y., Shaheen, F., Khan, H.R., Tahir, L.M., Anser, M.K., Zaman, K. (2023), Understanding the importance of sustainable ecological innovation in reducing carbon emissions: Investigating the green energy demand, financial development, natural resource management, industrialisation and urbanisation channels. Economic Research-Ekonomska, 36(2), 2137823.

Sharif, T., Uddin, M.M.M., Alexious, C. (2022), Testing the moderating role of trade openness on the environmental Kuznets curve hypothesis: A novel approach. Annals of Operations Research, 345, 597-635.

Statistics South Africa (Stats SA). (2023), Sustainable Development Goals: Country Report 2023. Republic of South Africa.

Stock, J.H., Watson, M. (1993), A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica, 61, 783-820.

The African Union Commission. (2015), Agenda 2063: The AFRICA We Want. Addis Ababa: African Union.

The World Bank, (2023). Carbon dioxide emissions per capita, global economy website, https:// www.theglobaleconomy.com/ Accessed on 20 December 2024

Thi, D., Tran, V.Q., Nguyen, D.T. (2023), The relationship between renewable energy consumption, international tourism, trade openness, innovation and carbon dioxide emissions: International evidence. International Journal of Sustainable Energy, 42(1), 397-416.

United Nations Industrial Development Organisation (UNIDO). (2020), Industrialization as the Driver of Sustained Prosperity. Vienna: United Nations Industrial Development Organisation.

van Hinsberg, N., Can, M. (2024), The impact of green trade openness on air quality. Ekonomikalia Journal of Economics, 2(2), 105-118.

Wang, W., Rehman, M.A., Fahad, S. (2022), The dynamic influence of renewable energy, trade openness and industrialization on the sustainable environment in G-7 economies. Renewable Energy, 198, 484-491.

World Bank. (2022), World Bank Development Indicators online Database. Available from: https://datatopics.worldbank.org/world-development-indicators/themes/environment.html [Last accessed on 2024 Dec 31].

Xia, R. (2022), A review of trade, finance migration openness and environmental quality under globalisation. Journal of Sociology and Ethnology, 4(10), 34-49.

Zhang, S., Kaikun, W., Yastruskyi, M., Huang, C. (2023), Carbon emissions from international trade and consumption: Assessing the role of cumulative risk for EU and Chinese economic development. Energy Strategy Reviews, 50, 101219.