Research Article

Coal Consumption and Environmental Sustainability in South Africa: The role of Financial Development and Globalization

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ABSTRACT. This paper aims to investigate coal consumption and environmental sustainability in South Africa by examining the role of financial development and globalization by using a dataset covering the period from 1980 to 2017. The study utilized the Auto-regressive Distributed Lag Model (ARDL) approach in addition to the Bayer and Hank combined co-integration, fully modified Ordinary least squares (FMOLS), and Dynamic ordinary least Squares (DOLS). The study further utilized the frequency domain causality test to capture the causal linkage between the series. The advantage of the frequency domain causality is that it can capture causal linkages between series at different periods. The Bayer and Hanck co-integration and ARDL bounds tests reveal co-integration among the series. The empirical findings based on the ARDL long-run estimation reveal that a 1% increase in coal consumption increases environmental degradation by 1.077%, while a 1% increase in financial development decreases the environmental degradation by 0.973%. Furthermore, a 1% increase in economic growth decreases environmental quality by 1.449%. The outcomes of the FMOLS and DOLS approaches also provide supportive evidence for the ARDL long-run results. Furthermore, the results of the frequency domain causality test reveal that at a significance level of 1%, coal consumption Granger causes CO_2 emissions at different frequencies, while financial development Granger causes CO_2 emissions in the long run and short run at a significance level of 10%. In terms of policy suggestions, South Africa should embrace policies that encourage energy consumers to shift toward renewable energy. Furthermore, financial reforms should be implemented to curb environmental degradation.

Keywords: CO_2 Emissions; Coal Consumption; Economic Growth; Financial Development; Globalization; South-Africa

1. Introduction

The famous saying that pollution is an issue for developing countries and not for developed nations is no longer valid, at least in terms of its implications. The predominant use of coal in developed and developing economies is aimed at meeting the high demand for energy consumption. Additionally, coal is more available and cost-effective compared to other forms of energy. Globally, coal is the second-largest energy source, accounting for close to

30%, and is primarily used for power generation, with more than 40% used in the generation of electricity (Adedoyin *et al*. 2020). The rise in demand for coal releases increased energy pollutants, which causes a potential threat to human health and the environment. This environmental pollution is a global problem, and the earth is exposed to threats arising from the degradation of environmental conditions (Adebayo, 2021). Thus, the obligation to save the planet from such problems falls

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primarily to countries that are the major producers of carbon dioxide emissions.

In the Sub-Saharan region, South Africa is the biggest producer and exporter of coal, ranked fifth in terms of global consumption, and about 85.7% of the country's main energy needs are provided by coal (EIA, 2020). According to Shahbaz, Tiwari, and Nasir (2013), coal is a major energy source in South Africa and constitutes 1% of global emissions, while the average rate of economic growth in South Africa increased from 1.4% in 2017 to 1.9% in 2020 (World Bank, 2018). Global efforts to minimize global CO_2 emissions depend heavily on collective efforts to reduce emissions. However, difficulties may occur for countries where CO_2 emissions are connected to energy production because energy is a driver of economic development.

In South Africa, reducing CO_2 emissions will inevitably slow down the country's economic growth, which is why many countries are very reluctant to implement measures to constrain such emissions. South Africa's financial development has been on the rise, which has been accompanied by an increase in the country's CO_2 emissions; furthermore, it has had a robust financial base since 1994, and this has continued in an upward direction, apart from in 2007 during the financial crisis that severely affected the country. Since then, fiscal and economic growth has been stable and its level of energy consumption has been increasing (Shahbaz *et al*. 2013). Accordingly, the financial development of South Africa is primarily dependent on the use of financial resources by the South Africans to improve the country's financial and economic growth - to increase energy efficiency, improve enterprise performance, business opportunities, investment efficiency, exchange of goods and services, reduce CO_2 emissions and develop technology and energy. On this basis, there has been a continuous and increasing demand for the development of the South African energy and environment sector. From this perspective, there are few empirical studies on the subject matter, particularly those that focus on financial improvement, economic growth, and the demand for coal consumption in South Africa. Among the few studies carried out on the field, Joshua and Bekun (2020) called for more pragmatic approaches to extricate economic growth from CO_2 emissions in South Africa's energy policy.

Over the years, several studies have been conducted regarding the association between CO_2 emissions, financial development, globalisation and coal consumption. For instance, Belaid and Youssef (2017) provided evidence that non-renewable energy deteriorates Algeria's environmental quality. Also, Attiaoui et al. (2017) analyzed the effect of clean and non-renewable energy on ecological emission levels in 22 African countries by applying the ARDL techniques. The investigators found that non-renewable energy contributes significantly to environmental pollution and clean energy reduces pollution. Also, Sarkodie and Adams (2018) confirmed that non-renewable energy increases pollution in South Africa. Coal continues to be the primary energy source for emerging economies, and South Africa is not excluded from the list of top coal-consuming countries. The study of Joshua and Bekun (2020) supported the environmental Kuznets curve (EKC) hypothesis that there is a feedback relationship between CO_2 emissions and revenue (GDP).

Likewise, Joshua *et al.* (2020) established that economic growth exerts a positive influence on CO_2 emissions. According to Odhiambo (2016), there are consistent CO_2 emissions in South Africa that are traced to rapid economic growth. Furthermore, prior studies have also reported that a rise in economic growth raises CO2 emissions (Akinsola & Adebayo, 2021). Similarly, in the study conducted by Adebayo (2020), the frequency domain technique adopted revealed a feedback causality between growth and CO_2 in Mexico. In Turkey, Kirikkaleli and Kalmaz (2020) studied the interconnection between CO_2 emissions and the economy, revealing that an increase in environmental degradation accompanies an increase in economic growth.

Regarding the linkage between financial development and economic growth, several studies have been conducted. For instance, Ozatac *et al.* (2017) examined the environmental Kuznets curve (EKC) hypothesis for the case of Turkey and found that financial development did not affect CO_2 emissions, whereas energy consumption, trade openness, and urbanization increased CO_2 emissions. Furthermore, Pata (2018a) also utilized the ARDL bounds test for the period from 1974 to 2013 and confirmed the EKC hypothesis's validity. The author reported that financial development increased CO_2 emissions. Similarly, Pata (2018b) reported that financial development increased CO_2 emissions. Shahbaz et al. (2013) studied the relationship between financial development, economic growth, trade openness, CO_2 emissions, and coal consumption in South Africa, and their findings clearly showed that financial development minimizes CO_2 emissions. Umar et al. (2020) employed the Bayer-Hanck co-integration and wavelet coherence approaches to examine the determinants of CO_2 emissions in China. Their study revealed that there are negative correlations between financial development and CO_2 emissions in the long run.

Odugbensan and Adebayo (2020) recently examined the interconnection between financial development and environmental sustainability in Nigeria and their empirical findings showed that environmental sustainability in Nigeria has been harmed by financial development. This result was not in agreement with the outcome of Adebayo and Odugbesan (2020), who utilized the wavelet coherence method to gather information on the correlation and causal relationship between financial development, real growth, and urbanization, and CO_2 emissions in South Africa and they found that financial development impacts CO_2 emissions positively in South Africa.

Globalization is the last factor considered in our study, which has been shown to facilitate the transition of advanced technologies from industrialized to emerging economies, aids in fostering the division of work, and improves the economic benefit of different countries. Globalization enhances economic growth through foreign direct investment and technological innovations from industrialized countries to developing countries. Liu et al. (2020) examined the relationship between globalization and CO_2 emissions in the G7 countries. Their analysis showed that the connection between globalization and CO_2 emissions is an inverted U-shaped, strongly confirmed by the environmental Kuznets curve hypothesis. Similarly, Nguyen and Le (2020) explored the effect of globalization on CO_2 emissions in Vietnam. The authors used the ARDL

technique on time series data for the period from 1990 to 2016. Their analysis showed that globalization is causing CO_2 emissions to increase in Vietnam, and therefore, globalization is not advantageous for long-term environmental health. Contrarily, Khan *et al.* (2019) analyzed the effect of globalization, economic factors, and energy use on CO_2 emissions in Pakistan from 1971 to 2016 using the dynamic ARDL simulation model. The outcomes of the dynamic ARDL simulations revealed that energy use, financial growth, foreign direct investment, trade, economic globalization, political globalization, and social globalization significantly impact CO_2 emissions in Pakistan.

Based on the reviewed studies, it is evident that they have produced mixed findings. Thus, this study takes it a step further by including the financial development index, which is a broader measure of financial development.

2. Materials and Methods

2.1 Materials

This study examines the impact of coal consumption, economic growth, financial development, and globalization on CO_2 emissions in South Africa. This study uses data from 1980 to 2018 on an annual basis. In this analysis, all indicators are converted into their normal logarithms. This is done to ensure that the data comply with normality (Adebayo and Demet 2020). Table 1 illustrates the unit of measurement, source, and description of data. Furthermore, Figures 1, 2 and 3 depict the trend of key variables in this study.

In line with Shahbahz *et al.* (2013), the economic function, economic model, and econometric model of the analysis are represented in Equations 1, 2, and 3, respectively.

$$CO_{2t} = f(CC_t, FD_t, GLO_t, GDP_t) \qquad (1)$$

$$CO_{2t} = \vartheta_0 + \vartheta_1 CC_t + \vartheta_2 FD_t + \vartheta_3 GLO_t + \vartheta_4 GDP_t \qquad (2)$$

$$CO_{2t} = \vartheta_0 + \vartheta_1 CC_t + \vartheta_2 FD_t + \vartheta_3 GLO_t + \vartheta_4 GDP_t + e_t \qquad (3)$$

In Equations 1, 2, and 3, CO_2, CC, FD, GLO, and GDP illustrate CO_2 emissions, coal consumption, financial development, globalization, and economic growth, respectively. Coal consumption is expected to exert a positive impact on CO_2 emissions. Thus, coal consumption will deteriorate the quality of the environment, i.e., $(\vartheta_1 = \frac{\partial CO_2}{\partial CC} > 0)$. Financial development is expected to negatively impact CO_2 emissions. Thus, an increase in financial development will also increase environmental sustainability, i.e., $(\vartheta_2 = \frac{\partial CO_2}{\partial FD} < 0)$ otherwise $(\vartheta_2 = \frac{\partial CO_2}{\partial FD} > 0)$. It is anticipated that the interconnection between globalization and CO_2 emissions will be negative. Thus, a rise in GLO will improve the quality of the environment, i.e., globalization $(\vartheta_3 = \frac{\partial CO_2}{\partial GLO} < 0)$ otherwise $(\vartheta_3 = \frac{\partial CO_2}{\partial GLO} > 0)$. Economic growth is expected to increase CO_2 emissions. Therefore, a rise in economic growth will deteriorate environmental quality, i.e., $(\vartheta_4 = \frac{\partial CO_2}{\partial GDP} > 0)$.
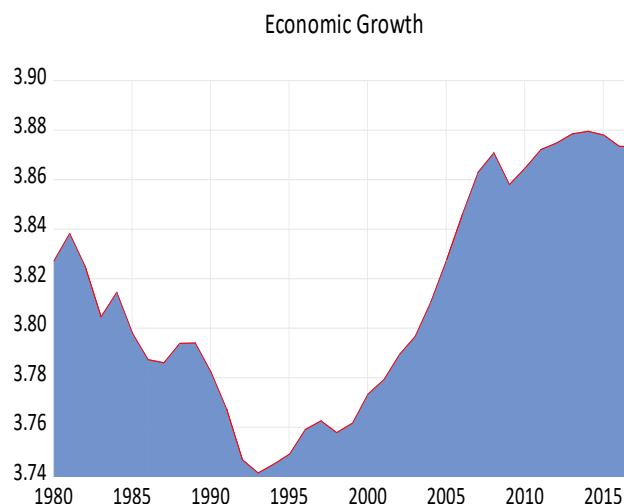

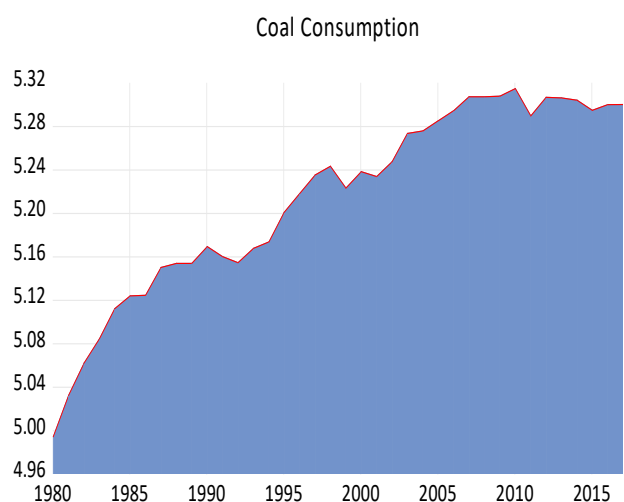**Fig 1.** Economic Growth in South Africa from 1980 to 2017

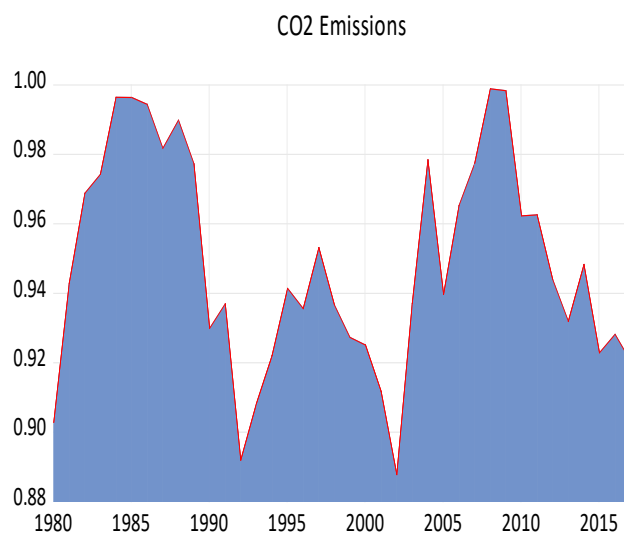
Fig 2. Coal Consumption in South Africa from 1980 to 2017

Fig 3. CO_2 Emissions in South Africa from 1980 to 2017

Table 1
Data Description and Units

Variables	Unit	Measurements
CO₂	Carbon Emissions	Metric tonnes of CO₂
GDP	Gross Domestic Product	Constant US Dollars, 2010
CC	Coal Consumption	Million Tonnes of Oil Equivalent (Mtoe)
FD	Financial Development Index	A broad measure for financial development by taking into account its efficiency, accessibility, and depth
GlO	Economic Globalization Index	Index-Based on FDI, trade and portfolio investment

Source: WDI (2020), IMF (2020), and Gygli, et al. (2019)

2.1 Methods

2.1.1. Unit Root Tests

It is essential to examine the order of integration of the series before conducting further analysis. Thus, the study evaluates the integration features of the series by employing unit root tests. First, the study uses the conventional augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. Second, due to structural break(s) in series, traditional unit root tests can produce inaccurate results. Therefore, the study uses the unit root tests developed by Zivot and Andrews (2002) and Lee, and Strazicich (2004), which can simultaneously capture the stationarity features of the series and the structural break(s).

2.1.2. Bayer and Hanck Combined Cointegration Test

This research further uses the integrated co-integration test of Bayer and Hanck (2013) as a rigorous co-integration test, which is a combination of the Banerjee *et al.* (1998), Boswijk (1995), Johansen (1991), and Engle and Granger (1987) co-integration tests. According to Abdullah *et al.* (2021) and Kirikkaleli and Kalmaz (2020), the combined co-integration test focuses on eliminating unnecessary extensive testing methods generated by other co-integration tests. In constructing the co-integration test, Bayer and Hanck (2013) used the Fisher formula to implement the test. The Bayer and Hanck (2013) equations are depicted as follows:

$$EG - JOH = -2[ln\,(PEG) + ln(PJOH)] \qquad (4)$$

$$\begin{aligned} EG - JOH &- BO - BD \\ &= -2[ln\,(PEG) + ln\,(PJOH) + ln(PBO) \\ &\quad + ln(PBDM)] \end{aligned} \qquad (5)$$

Where PEG indicates the level of significance for Engle and Granger (1987), and PJOH refers to the level of significance for Johansen (1991). The significance levels for the co-integration tests of Boswijk (1994) and Banerjee et al. (1998) are expressed by PBO and PBDM, respectively.

2.1.3 ARDL Approach

To verify the combined cointegration test, the researchers utilized the ARDL bounds test to capture the co-integration amongst the series. The bounds test of Pesaran et al. (2001) is preferred over other co-integration tests due to the following reasons. Firstly, it can be utilized when series are integrated of mixed order; secondly, it is significantly more reliable, particularly for small sample sizes (Kirikaleli and Adebayo, 2021); and thirdly, it offers accurate estimations of the long-term model. The bounds test follows the F-distribution, and its critical values were proposed by Pesaran and Timmermann (2005). Pesaran et al. (2001) illustrated the ARDL bounds test as follows in Equation 6.

$$\begin{aligned} \Delta CO_{2t} &= \vartheta_0 + \beta_1 CO_{2t-1} + \beta_2 CC_{t-1} + \beta_3 FD_{t-1} + \beta_4 GLO_{t-1} \\ &\quad + \beta_5 GDP_{t-1} \sum_{i=1}^{t} \vartheta_1 \Delta CO_{2t-i} \\ &\quad + \sum_{i=1}^{t} \vartheta_2 \Delta CC_{t-i} + \sum_{i=1}^{t} \vartheta_3 \Delta FD_{t-i} \\ &\quad + \sum_{i=1}^{t} \vartheta_4 \Delta GLO_{t-i} + \sum_{i=1}^{t} \vartheta_5 \Delta GDP_{t-i} \\ &\quad + \varepsilon_t \end{aligned} \qquad (6)$$

The null hypothesis and the alternative hypotheses are no co-integration and evidence of co-integration, respectively. The study fails to accept the null hypothesis since the F-statistics is more than the lower and upper bound critical values. As illustrated by Pesaran et al. (2001), the null and alternative hypotheses are depicted in Equations 7 and 8.

$$H_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = \vartheta_5 \qquad (7)$$

$$H_a \neq \vartheta_1 \neq \vartheta_2 \neq \vartheta_3 \neq \vartheta_4 \neq \vartheta_5 \qquad (8)$$

Where H_0 denotes the null hypothesis and H_a illustrates the alternative hypothesis. The study utilizes the criteria of Kripfganz and Schneider (2018), which require the generated T-statistics and F-statistics to be higher than the corresponding upper critical values, an essential requirement for deciding on co-integration, unlike the prior decision-making criteria that require the F-statistic to be higher than the upper critical values for co-integration. Additionally, the p-values produced should be below the target levels.

After co-integration among the parameters is confirmed, the study utilizes the ARDL approach. After the long-term linkages have been identified, short-term interconnections are investigated using the Error Correction Model (ECM) developed by Engle and Granger (1987) for the assessment of short-term coefficients and the Error Correction Term (ECT). According to Pesaran et al. (2001), this is done by integrating the ECM into the ARDL framework as shown in Eq 9.

$$\Delta CO_{2t} = \vartheta_0 + \beta_1 CO_{2t-1} + \beta_2 CC_{t-1} + \beta_3 FD_{t-1} + \beta_4 GLO_{t-1}$$
$$+ \beta_5 GDP_{t-1} \sum_{i=1}^{t} \vartheta_1 \Delta CO_{2t-i}$$
$$+ \sum_{i=1}^{t} \vartheta_2 \Delta CC_{t-i} + \sum_{i=1}^{t} \vartheta_3 \Delta FD_{t-i}$$
$$+ \sum_{i=1}^{t} \vartheta_4 \Delta GLO_{t-i} + \sum_{i=1}^{t} \vartheta_5 \Delta GDP_{t-i}$$
$$+ \rho ECT_{t-i}$$
$$+ \varepsilon_t \qquad (9)$$

Where the speed of adjustment is depicted by ρ and the error correction term is depicted by ECT_{t-1}.

2.1.4 FMOLS and DOLS Long-run Estimators

To confirm the outcomes of the ARDL long-run estimates, the study employs the FMOLS and DOLS tests. While various econometric approaches can be used to evaluate the long-run interconnection between variables, the Fully Modified OLS (FMOLS) introduced by Phillips and Hansen (1990) and the Dynamic OLS (DOLS) approach developed by Stock and Watson (1993) are used in this analysis. These methods permit asymptotic coherence to be obtained by considering the impact of serial correlation. FMOLS and DOLS can only be done if there is proof of co-integration between the series. Therefore, long-term elasticity is calculated with FMOLS and DOLS estimators in this study.

2.1.5 Frequency Domain Causality

The current research also intends to capture the causal effects of coal consumption, financial development, globalization, and economic growth on CO_2 emissions at different frequencies in South Africa. Thus, the present study employs the frequency domain causality test of Breitung and Candelon (2006). "The key distinction between the time domain method and the frequency-domain method is; the 'time-domain' method informs us where a particular change arises inside a time series, while the "frequency-domain" method evaluates the extent of a specific variation in time series" (Khan et al. 2020; Gokmenoglu et al. 2019). The frequency-domain causality test enables the removal of seasonal fluctuations in small sample data (Breitung & Candelon, 2006).

Additionally, the frequency domain test can identify non-linearity and causality phases, while the test often facilitates the detection of causality between variables at low, medium, and long frequencies (Breitung & Candelon, 2006). Furthermore, this technique enables us to differentiate long-term causality from short-term causality between time series.

3. Results and Discussion

3.1. Results

Table 2 presents a summary of the variables utilized. The skewness values for all the variables show that the parameters are normal. Furthermore, the Kurtosis values illustrate that all the variables conform to normality.

Table 2
Descriptive Statistics of variables used

Tests	CO₂	CC	FD	GLO	GDP
Mean	0.948	5.214	-0.368	1.716	3.812
Median	0.942	5.235	-0.346	1.738	3.801
Maximum	0.999	5.315	-0.202	1.849	3.879
Minimum	0.888	4.995	-0.533	1.569	3.741
Std. Dev.	0.031	0.087	0.110	0.114	0.046
Skewness	0.044	-0.677	0.047	-0.096	0.137
Kurtosis	2.077	2.552	1.402	1.206	1.636
Jarque-Bera	1.368	3.223	4.056	5.151	3.065
Probability	0.506	0.199	0.131	0.076	0.215
Observations	38	38	38	38	38

Note: CO_2, CC, FD, GLO, GDP depict carbon emissions, coal consumption, financial development, globalization and economic growth
Source: Authors Compilation with EViews 12

The probability value of Jarque-Bera reveals that globalization does not conform to normality, while CO2 emissions, coal consumption, economic growth, and financial development conform to normality.

This paper utilizes both conventional unit root tests, namely ADF and PP, and the more recent Zivot-Andrew (ZA) and Lee-Stratchwich (LS) unit root tests, to capture both stationarity properties and structural break of time series variables. The results of the ADF and PP test are depicted in Tables 3 and 4, respectively. The findings reveal that all the parameters are non-stationary at level, i.e. I(0). However, after taking the first difference, i.e., I(1), all the variables are found to be stationary. Furthermore, the outcomes of the ZA and LS are presented in Tables 3 and 4, respectively. The outcomes of the ZA and LS show that all the series are stationary at a mixed level i.e., I(0) and I(1).

Table 3
Unit-Root Tests Results of Variables at Level

Tests	CO₂	CC	FD	GLO	GDP
ADF	-2.743	-2.756	-2.516	-2.125	-2.63
PP	-2.971	-2.753	-2.979	-1.749	-1.725
ZA	-4.487	-4.698	-4.276	-3.604	-3.584
	[2003]	[2007]	[1996]	[1981]	[1990]
LS	-6.01***	-7.007*	-6.94**	-6.073**	-7.685*
	[1997]	[1997]	[1996]	[1988]	[1991]
	{2001}	{2001}	{2001}	{2008}	{2004}

Note: 1%, 5% and 10% represents *, **, and *** respectively. [] and {} means first and second break.
Source: Authors Compilation with EViews 12

Table 4
Unit-Root Tests Results of Variables at First Difference

Tests	CO₂	CC	FD	GLO	GDP
ADF	-6.301*	-6.246*	-5.702*	-4.232*	-4.222*
PP	-6.318*	-6.253*	-5.702*	-3.234*	-4.289*
ZA	-7.763*	-7.763*	-6.256**	-5.080**	-5.980**
	[1993]	[1993]	[2000]	[1993]	[2009]
LS	-6.69**	-7.361*	-6.573**	-7.217	-6.185**
	[1990]	[1992]	[1996]	*[1990]	[1993]
	{1994}	{2009}	{2001}	{2000}	{2006}

Note: 1%, 5% and 10% represents *, **, and *** respectively. [] and {} means first and second break.
Source: Authors Compilation with EViews 12

As the parameters are stationary at a mixed level i.e. I(0) and I(1), the ARDL bounds test proposed by Pesaran et al. (2001) is used to investigate the co-integration of CO_2 emissions and the explanatory variables. The co-integration results are shown in Table 4. The outcomes from Table 5 reveal that both F-statistics and T-statistics are greater than Kripfganz and Schneider's (2018) critical value at a significance level of 1%. Therefore, the study affirms that in the long run, all variables are co-integrated. Thus, the null hypothesis is not considered, indicating that there is long-term co-integration among the indicators. Accordingly, the study employs the ARDL long-run and short-run estimators to capture the impact of financial development, economic growth, coal consumption, and globalization on CO_2 emissions in the long and short run. The results of the CUSUM and CUSUM squares in Figures 4 and 5 also show that the model is stable at a significance level of 5%.

The study uses Bayer and Hanck (2013) combined the co-integration test to capture the co-integration among the variables in this analysis. The results of the Bayer and Hanck (2013) combined co-integration test are depicted in Table 6. The results show that there is evidence of long-run co-integration among the variables used in this study at a 5% level of significance, indicating that the combination of coal consumption, financial development, economic growth, globalization significantly affect CO_2 emissions in the long-run. This outcome allows the present study to investigate the short-run and long-run effect of coal consumption, financial development, economic growth, globalization on CO_2 emissions.

The study uses the long-run and short-run ARDL estimates to evaluate the impact of coal consumption and economic growth on environmental sustainability in South Africa after the long-run co-integration of the parameters has been established. In addition, the study also explores the role of financial development and globalization in South Africa's environmental sustainability over the period from 1980 to 2017. The results of the ARDL long-run and short-run estimations are depicted in Table 7. The findings from the ARDL long and short-run estimation revealed that economic growth exerts a positive influence on environmental degradation. This means that by holding other indicators stable, a 0.69% rise in CO_2 emissions is caused by a 1% increase in economic growth. Also, globalization exerts a positive and insignificant impact on environmental degradation in South Africa. Coal consumption is, as predicted, positively connected with CO_2 emissions. It was found that a 1% rise in the usage of coal increases CO_2 emissions by 1.077%.

Fig 4. Stability Test Using CUSUM

Fig 5. Stability Test Using CUSUM of Squares

Table 6
Bayer and Hack Combined Cointegration Result

Model Specifications	Fisher Statistics	Fisher Statistics
	EG-JOH	EG-JOH-BAN-BOS
CO_2=f(CC, FD, GDP, GLO)	14.088**	27.795**
	Critical value	Critical value
	10.576	20.143

Note: 10% and 5% level of significance is depicted by ** and *, respectively.

Source: Authors Compilation with Stata 15

Furthermore, financial development exerts a negative impact on CO_2 emissions at a 5% level of significance. The findings suggest that a decrease of 0.973% in CO_2 emissions is due to a 1% increase in financial development. Furthermore, the analysis used the FMOLS and DOLS estimators to check the ARDL estimator's long-run results. The findings from the FMOLS and DOLS are reported in Table 8. The outcomes show that keeping other indicators constant, a 1% increase in coal consumption and economic growth increase CO_2 emissions 1.077% and 1.449% respectively.

Table 5
ARDL Bounds Test Cointegration Result

F-Statistics	T-Statistics		
5.86*	-5.21*		
Kripfganz and Schneider (2018) critical and P-values			
T-statistics (CV)		F-statistics (CV)	
LB	UB	LB	UB
-2.495	-3.798	2.204	3.320
-2.843	-4.207	3.891	3.891
-3.54	-5.021	3.572	5.112

Note: * represent a 1% level of significance, and CV denotes critical value. UB and LB denote a lower and upper bound critical value
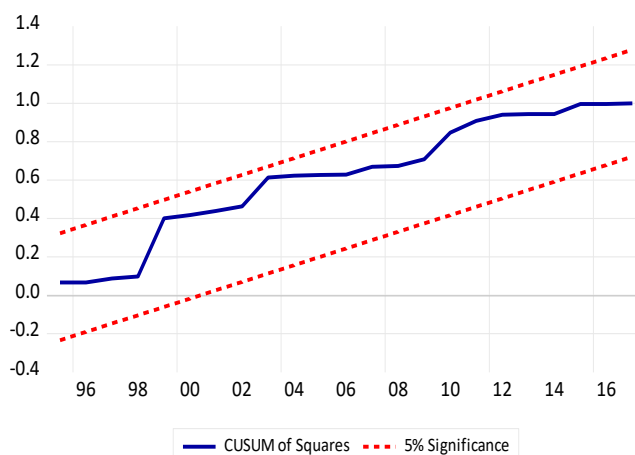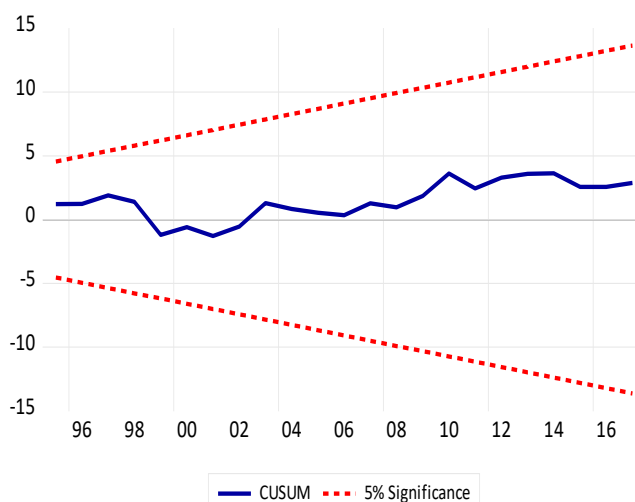
Source: Authors Compilation with EViews 12

Moreover, financial development exerts a negative influence on CO_2 emissions, which demonstrates that a 1% increase in financial development will decrease CO_2 emissions by 0.95%. Nonetheless, no significant interconnection was established between globalization and CO_2 emissions. These results comply with the results of the ARDL long-run estimations. The model fitness is illustrated by R^2 (0.98) and adjusted R^2 (0.97) suggesting that 98% of the changes in CO_2 emissions can be explained by financial development, coal consumption, economic growth, and globalization. The remaining 2% is attributed to the error term. Furthermore, the outcomes of the diagnostic tests revealed that there is no serial correlation, residuals are normally distributed, and no misspecification in the model.

Table 7
ARDL Long-run and Short-run Results

	Long-run Results			Short-Run Results		
Regressors	Coefficient	Std. Error	T-prob	Coefficient	Std. Error	T-prob
CC	1.077	0.199	2.290**	1.077	0.315	4.279*
FD	-0.973	0.172	-2.485*	-0.175	0.175	-0.865
GLO	0.231	0.169	0.569	0.231	0.207	0.985
GDP	1.449	0.091	2.279**	0.683	0.215	1.844
ECM(-)				-0.545	0.081	-6.632*
	R^2		0.98			
	Adj-R^2		0.97			
	Diagnostic Tests					
	χ^2 ARCH		1.37(0.33)			
	χ^2 RESET		2.17(0.14)			
	χ^2 Normality		0.13(0.93)			
	χ^2 LM		1.25(0.11)			

Note: 5% and 1% level of significance is depicted by ** and * respectively. CC, FD, GLO and GDP represents coal consumption, financial development, globalisation, and economic growth.
Source: Authors Compilation with EViews 12

Table 8
FMOLS and DOLS Results

	FMOLS			DOLS		
Regressors	Coefficient	Std. Error	T-prob	Coefficient	Std. Error	T-prob
CC	1.103	0.092	5.429*	1.077	0.003	3.818*
FD	-0.515	0.031	-4.679*	-0.973	0.075	-4.144*
GLO	0.274	0.151	1.236	0.231	0.042	0.935
GDP	1.521	0.155	5.475*	1.449	0.200	3.801*
R^2		0.98			0.98	
Adj R^2		0.97			0.97	

Note: * denote 1% level of significance. CC, FD, GLO and GDP represents coal consumption, financial development, globalisation, and economic growth.
Source: Authors Compilation with EViews 12

Table 9
Frequency Domain Causality Results

	Long term Causality		Medium-term Causality		Short term Causality	
Direction of causality	$\omega_i = 0.01$	$\omega_i = 0.05$	$\omega_i = 1.00$	$\omega_i = 1.50$	$\omega_i = 2.00$	$\omega_i = 2.50$
CC → CO_2	< 10.412> (0.005) *	< 10.439> (0.005) *	< 12.569> (0.001) *	< 12.351> (0.002) *	< 12.263> (0.002) *	< 12.225> (0.002) *
FD → CO_2	< 5.294> (0.070) ***	<5.295> (0.070) ***	<0.356> (0.837)	<4.290> (0.117)	< 4.654> (0.097) ***	<4.637> (0.098) ***
GDP → CO_2	< 0.364> (0.833)	<0.355> (0.837)	< 1.094> (0.578)	< 1.229> (0.540)	< 1.265> (0.531)	< 1.278> (0.527)
GLO → CO_2	< 0.298> (0.861)	< 0.296> (0.862)	<0.685> (0.709)	<0.687> (0.709)	< 0.687> (0.709)	<0.687> (0.709)

Note: The values inside < > denote the Wald test statistics whereas the values inside ( ) denote p-values. →portrays the causality path. * and * represent 1 and 10% level of significance. CO_2, CC, FD, GLO and GDP represents CO2 emissions, coal consumption, financial development, globalization, and economic growth.
Source: Authors Compilation with EViews 12

After the long-run effects have been identified, the causal impacts of coal, financial development, globalization, and economic growth on CO_2 emissions at various frequencies are identified in the frequency domain causality test of Candelon and Breitung (2006). As shown in Table 9, at a significance level of 1%, the null hypothesis of coal consumption can be rejected in the short, medium, and long-run because coal consumption Granger causes CO_2 emissions. Furthermore, in the short and long run, financial development Granger causes CO_2 emissions in South Africa at a significance level of 10%. Moreover, there is no causality running from economic growth and globalization to CO_2 emissions at any frequency.

3.2 Discussion

The effect of economic growth on CO_2 emissions is positive in the long run both the long-run and short-run. This suggests that economic growth deteriorates environmental quality in the long-run and short-run. This outcome corresponds with the findings of Usman et al. (2020) for the United States, Adebayo (2020) for Mexico, Awosusi et al. (2020) for the MINT economies, Kalmaz and Adebayo, (2021) for Egypt, Alola et al. (2019) for Europe's largest states, He et al. (2021) for Mexico and Kirikaleli et al. (2020) using the global economy, who established a positive linkage between CO_2 emissions and economic growth. The reason for the positive effect of economic growth on environmental pollution is that the key sources for industry and agriculture are fossil fuels, which trigger environmental degradation and growth in the economy (Shabahz et al. 2020). The rise in environmental pollution is attributed to the fact that industrial growth in South Africa is linked to the expansion of infrastructure, the development of trade, and economic capitalization, which positively impact investment and economic production and thus raise energy use (Odugbesan & Adebayo, 2020). From the results, financial development decreases CO_2 emissions, and by implication increase environmental sustainability. As the level of financial development increases, economic growth is stimulated which decreases environmental pollution.

The negative relationship suggests that the maturity stage of the financial sector in South Africa has been reached as the sector allocates capital to environmentally sustainable initiatives and also encourages businesses to use new development technologies to raise output levels. This outcome is in line with the findings of Zhang *et al.* (2021), Rjoub *et al.* (2021), and Charfeddine & Khediri (2016), who found that financial development enhances the quality of the environment. However, this outcome is not consistent with the findings of Dogan and Turkeku (2016), Usman et al. (2020), and Zafar *et al.* (2019) who established that financial development increases environmental degradation. The relationship between coal consumption and CO_2 emissions is positive in the long-run and short-run. This is evident since South Africa is ranked 6th globally in terms of coal consumption. South Africa is highly reliant on the energy sector, where development operations are dominated by coal use. Nearly 70% of the primary energy sources and 93% of electricity output come from coal reserves. Relative to the populace and the economy's scale, this high dependence on coal consumption is a significant factor in CO_2 emissions

(Winkler, 2007). This outcome complies with the findings of Pata (2018) for Turkey and Al-Mulali et al. (2018) for selected countries.

The outcomes of the frequency domain causality test revealed one-way causality running from coal consumption and financial development to CO_2 emissions which implies that both coal consumption and financial development can predict significant variation in CO_2 emissions in South Africa. These outcomes align with the study of Kirikaleli et al. (2020) for Turkey, Usman et al. (2020) for the USA, and Shahbaz *et al.* (2020) for South Africa.

4 Conclusion

It is crucial to identify the effect of globalization and coal consumption on environmental degradation in South Africa, as the country is one of the largest CO_2 emitters globally, and also to examine the roles of financial development and economic growth. Therefore, the present study employed the ARDL bounds test using Kripfganz and Schneider's (2018) critical value, ARDL long and short-run estimations, and FMOLS and DOLS. Furthermore, the frequency domain causality test was used to capture the causal linkage between the series in the short run, medium run, and long run. The empirical outcomes revealed an insignificant interconnection between globalization and environmental degradation, while economic growth exerts a positive impact on environmental degradation. Furthermore, financial development exerts a negative impact on environmental degradation. In general, the study found that the growth of the banking sector, which offers per-capita access to private sector domestic finance, aims to mitigate carbon emissions. This means that by implementing financial reforms, financial development can be used as a tool to preserve the quality of the environment. Moreover, coal use significantly contributes to the degradation of environmental sustainability. Furthermore, the findings from the frequency domain causality test revealed that coal consumption Granger causes CO_2 emissions at different frequencies while financial development Granger causes CO_2 emissions in the short run and long run.

In this respect, a sound policy agenda should be developed that provides long-term value for lowering GHGs and continuously encourages the creation of emerging technology that contributes to a less carbon-intensive economy. Furthermore, the growth of a sufficient stock market may be another valuable policy tool that can be implemented. This is because businesses can reduce the liquidity risk that can mobilize the funds needed by diversification of a portfolio that is particularly essential in the long-term growth of a robust technology base. In addition, concerning financial development and environmental deterioration, the study contends that higher levels of development of the financial sector and trade transparency encourage technical advances by increasing R&D expenditure on energy efficiency, resulting in energy savings, and thus reducing pollution. Also, South Africa should embrace policies that encourage energy consumers to shift toward renewable energy.

Although the study used substantial econometric techniques, a limitation of the study is the unavailability

of data beyond 2017. Furthermore, this study used CO_2 as the proxy of environmental quality. Thus, other studies should examine these interconnections by utilizing other proxies of environmental degradation.

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