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

N. Norouzi, M. Fani*

Department of Energy Engineering and Physics, Amirikabir University of Technology (Tehran Polytechnic), Tehran, Iran

ABSTRACT

Coal is one of the main primary energy resources in South Africa. This energy carrier is also one of the primary indicators in the energy security of the country. This paper is aimed to examine coal consumption and environmental sustainability in South Africa by examining the role of financial development and globalization phenomena using a data set gathered from 1980 to 2017. Based on this paper’s scope, ARDL Bounds, Bavaria, and the combined Hank, FMOLS, DOLS, and frequency domain tests of the causality test are used. Bayer and Hank integration tests and ARDL constraints (with Kripfganz and Schneider’s approximations) showed a common integration between this set. Findings based on ARDL short-term and long-term estimates present that economic development improves environment preservation, while economic growth and coal consumption increased environmental degradation. The frequency-domain causality test results showed that coal consumption and financial development significantly determine the environment’s stability at different frequencies.

INTRODUCTION

The famous saying that pollution is a problem for developing countries and not for developed countries is not valid, at least for the results. As a result, the predominant use of coal in developed and developing economies meets high energy demand. Besides, coal availability and cost-effectiveness are advantages over other forms of energy. Globally, coal is the second-largest energy source, accounting for nearly 30%, and is primarily used for electricity generation. More than 40% of energy emissions are due to coal; therefore, increasing demand for coal is a potential threat to humans and environment [1]. This pollution is a global problem, and the earth is pregnant to threats from climate change. Therefore, the obligation to preserve those problems’ planet is mainly the countries’ responsibility that are the main emitters of carbon dioxide emissions.

In sub-Saharan Africa, South Africa is the largest producer and exporter of coal, the fifth largest coal consumer, and about 85.7% of the country’s main energy comes from coal [2]. According to Adedoyin et al. [3], coal consumption is the main source of energy in South Africa and accounts for 1% of the world’s greenhouse gas emissions, with the average growth rate of South Africa from 1.4% in 2017 to 1.9% in 2020 [4]. Global efforts to minimize global CO$_2$ emissions depend largely on collective efforts to reduce emissions. However, there may be problems for countries where CO$_2$ contamination is linked to energy supply because power and energy are the source 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 reluctant to implement it. Like CO₂ emissions and a strong financial base, South Africa’s economic development has been on the rise since 1994, and it remains on the rise, except in 2007 when the financial crisis hit the country hard. Since then, economic and financial growth has been stable and predictable [5], and its level of energy consumption is increasing. As a result, South Africa’s financial development, which depends solely on South Africa’s use of financial resources to improve the country’s economic and economic growth: increase energy efficiency, improve business performance, business opportunities, investment efficiency, trade in goods and services, reducing CO₂ emissions and developing technology and energy. Accordingly, there has been a growing and growing demand for South Africa’s energy and environmental development. There are few empirical studies in this area from this empirical perspective, especially those focusing on financial recovery, economic growth, and coal demand in South Africa [6-9]. Among the few studies in this field, Belaid and Youssef [10] called for more practical approaches to the economic growth of CO₂ emissions in South African energy policy. They have added that energy consumption significantly affects South Africa’s short-term and long-term economic growth. Considering financial development, globalization, and economic growth, it remains the most important export product for its economic and economic development [11]. These characteristics of South Africa’s energy sector are a compelling reason to take a new approach that examines ARDL testing in the country and assesses GDP growth, globalization, economic improvements, and coal demand. This study is one of the few coal industry attempts as an independent determinant of CO₂ contamination in this investigation [12]. Therefore, it is important to study the role of economic growth, globalization and financial development, and coal consumption in CO₂ emissions in South Africa. This study also serves as a mechanism for South African stakeholders and policymakers to develop policies that maximize coal consumption and its impact on environmental sustainability in South Africa [13].

**Literature review**

The South African economy has experienced a significant slowdown in economic growth over the past three decades. South Africa’s recovery from the recession in the late 2000s was largely driven by private and public consumption growth, while private exports and private investment were not fully recovered [15]. As the second-largest economy in Africa, it is the middle and middle-income economy and the pole of production, the most industrial and diverse economy among all eight African countries. South Africa’s GDP was approximately $400 billion in 2011 but has since fallen to about $283 billion in 2020 [16]. However, as economic growth slows, South African coal consumption is rising, as shown in Figure 1. As shown in Figures 1 and 2, declining economic growth has no significant effect on South—Africa’s coal consumption since the global recession in 2009. South Africa’s coal consumption has been multiplying since 2003, while economic growth continued to improve until 2010 when both coal consumption and economic growth were declining. Figure 3 shows the CO₂ emission trend in South Africa.

The slowdown in economic growth and coal consumption has shown that the South African economy depends on high coal use [17, 18]. About 85.7% of South Africa’s main energy needs come from coal, followed by nuclear 5.2%, natural gas 3.2%, and diesel 1.7%. Solar energy is 0.9%, wind energy is 0.9%, and others are 2.4% [19, 20]. Besides, the country’s electricity demand is projected to exceed 56,000 MW by 2030, which will increase coal consumption if aggressive alternative energy is not used. According to statistics [21], in 2019, South Africa was the fifth largest coal consumer globally (3.81% of the world). According to literature [22], dedicating natural resources through economic rents increases economic recovery. These natural resources are attached to coal and lead to coal rents, thus providing coal mining incentives. The authors also point out that coal rental incentives contribute to economic growth by increasing coal production and supplying it to global commodity markets, and this good goal has negative consequences.

**Coal demand and carbon dioxide contamination**

A predominant consequence of dependence on fossil fuels such as coal is environmental degradation. Several previous studies have agreed that consuming coal as non-renewable energy makes the environment worse. This expectation is also supported by empirical findings such as the related literature [23] for Italy, another study [24] for the USA, and a review [25] for the ten largest power generators in sub-Saharan Africa. Besides, an innovative work [26] provides evidence that non-renewable energy degrades the Algerian environment’s quality. Also, Khan et al. [27] analyzed the effect of clean and non-renewable energy on the level of ecological emissions using the self-recurring distribution delay (ARDL) method and the combined group mean (PMG) [28]. The authors found that non-renewable energy significantly contributes to environmental pollution and that clean energy reduces pollution. Besides, Kirikkaleli et al. [29] confirmed that non-renewable energy increases pollution in South Africa. Coal remains the main source of energy in emerging economies, and South Africa is no exception. According Liu et al. [30], coal consumption contributes to environmental degradation in South Africa. As shown in Figure 3, although South Africa’s annual CO₂ emissions decreased sharply after the 2009 global recession, its coal demand increased significantly during that period, according to Figure 2. Such energy use’s devastating consequences have led to condemnation by
international institutions and pressure groups such as the United Nations. These helped countries agree to reduce carbon dioxide emissions [31-35]. However, the energy, climate, and social policies of developing countries are in a transition phase, as policymakers find it difficult to strike the right balance between economic growth, sustainable development, and social sustainability as they move towards green growth and politics. They take steps toward environmental sustainability [36].

Coal demand and carbon dioxide contamination
Most studies have shown that GDP growth contributes to carbon dioxide contamination in developing and emerging economies and is unlikely to slow down if renewable energy is not widely used in the industry. Ozatac et al. [37] examined the relationship of economic development, coal demand, CO₂ contamination, and overall natural resource leases, using annual data from the South African time series from 1970 to 2017. Their analysis findings support the EKC theory that there is a relationship between carbon dioxide emissions and revenue (Gross domestic production). Although there is a relationship between coal use and CO₂ emissions; in fact there is a correlation [38]. These findings have far-reaching implications. The authors also point out that feedback of causal relation of GDP growth and coal demand indicates that the South African government cannot implement energy-saving measures or policies that adversely affect economic growth. Likewise, a report [39] proved that GDP growth affects carbon dioxide emissions. According to literature [40, 41], there are CO₂ emissions in South Africa due to rapid economic growth. Previous studies have also reported that increased economic growth resulted in an increase in CO₂ emissions [43-45]. Similarly, in a study conducted by Ozatac et al. [37], the frequency domain method showed the causality of feedback between growth and CO₂ in Mexico. In Turkey, Udi et al. [46] studied the relationship between CO₂ emissions and the economy and presented that increasing climate change is associated with increased GDP growth.

Financial development and CO₂ emissions
Over the years, several studies have examined the relationship between financial development and CO₂ emissions. However, their results are different. For example, a paper [35] used the ARDL and ECM boundary tests to test the Kuznets Environmental Curve (EKC) hypothesis for the Turkish case. They found that economic development does not affect CO₂ emissions, while energy consumption, trade openness, and urbanization increase CO₂ emissions. Odugbesan, and Adebayo [35, 47] used the ARDL bounds test from 1974 to 2013 and validated the EKC hypothesis. The author reports that financial development increases CO₂ emissions. Similarly, it was reported that economic development increases CO₂ emissions [38]. The relationship between financial development, economic growth, trade openness, CO₂ emissions, and coal consumption in South Africa explicitly reported that economic development minimizes CO₂ emissions and was also studied by Raza and Shah [41]. Financial development was considered in this study because an advanced financial sector attracts foreign direct
investment (FDI), affects economic growth, and consequently affects the environment’s quality [32]. A reference [37] uses Bayer-Hank, and wavelet cohesion approached to examine the deriving variables of carbon dioxide contamination in China in 1971-2018. Their paper showed a negative link between financial development and carbon dioxide contamination in the long run. A 2020 study [33] recently examined the relationship between financial development and environmental sustainability in Nigeria using a data set between 1981 and 2016 using linear and nonlinear ARDL techniques to determine this dynamic. Their empirical findings show that environmental sustainability in Nigeria has been damaged by economic development. The result is not confirmed by the results of a study in 2020 [33]. They used the wavelet cohesion method to gather information on the correlation and causal relationship between economic development, real growth and urbanization, and CO₂ emissions in South Africa for the period. From 1971 to 2016. The authors report that economic development has a positive effect on CO₂ emissions in South Africa.

Globalization and CO₂ emissions
Globalization is the last factor examined in our study and has been proven to facilitate the transfer of advanced technologies from industrial economies to emerging countries, help divide labor, and improve different countries’ economic benefits. Globalization increases economic growth through foreign direct investment and technological innovations from industrialized to developing countries. Numerous studies have used various indicators of globalization to explore their impact on environmental degradation. Belay Kassa [48] examined the relationship between globalization and CO₂ emissions in the G7 for 1970-2015. Their analysis showed that the Kuznets environment curve hypothesis inversely strongly confirms the relationship between globalization and CO₂ emissions. Besides, increased economic production is associated with a significant increase in CO₂ emissions. The study conducted by Belay Kassa [48] also examines the impact of globalization and trade openness on CO₂ emissions on annual data from 1990-2015 for NAFTA countries. The author took a panel data approach, and the results of this study showed a positive and significant relationship between trade openness, economic globalization, and CO₂ emissions.

Similarly, Asian based article by Khan et al. [26] examined the impact of globalization on CO₂ emissions in Vietnam. The authors used the ARDL method for time series data for the period 1990 to 2016. Their analysis showed that globalization is increasing CO₂ emissions in Vietnam, and therefore globalization is not beneficial to long-term environmental health.

In contrast, Mirzaei Darian et al. [49] analyzed the effect of globalization, economic factors, and energy use on CO₂ emissions in Pakistan from 1971 to 2016 using a dynamic ARDL simulation model. Dynamic ARDL simulations showed that energy use, financial growth, foreign direct investment, trade, economic globalization, political globalization, and social globalization significantly affect Pakistan’s CO₂ emissions. Finally, Tamoor et al. [50] examined globalization’s role in Turkey’s ecological impact using a dual adjustment approach on annual data between 1985 and 2017. The authors reported that globalization has a positive long-term ecological impact. Previous studies have shown that there is a long-term correlation between economic globalization and environmental degradation. Global climate change, ozone depletion, biodiversity loss, ecosystem degradation, rampant deforestation, and rising temperatures are examples of the global environmental degradation that has arisen and intensified.

MATERIAL AND METHODS

Model and data collection
This paper examines the impact of coal demand, GDP growth, economic development, and globalization on carbon dioxide contamination in South Africa. This study uses data from 1980 to 2018 on an annual basis. In this analysis, all indices become their natural logarithm. This is done to ensure that the data match normal [51]. Table 1 shows the unit of measurement, source, and description of the data. The study flow chart is shown in Figure 4.

The economic function, economic model, and an econometric model of the analysis are represented in Equations (1), (2), and (3), respectively, stated as follows:

\[
\frac{\partial C_{E}}{\partial C_{D}} = f(D, G, F, I, C_{E} \times G_{D P})
\]

(1)

\[
C_{O_{2}} = \beta_{0} + \beta_{1} C_{D} + \beta_{2} F I_{t} + \beta_{3} G I_{t} + \beta_{4} G D P_{t}
\]

(2)

\[
C_{O_{2}} = \beta_{0} + \beta_{1} C_{D} + \beta_{2} F I_{t} + \beta_{3} G I_{t} + \beta_{4} G D P_{t} + \epsilon_{t}
\]

(3)

In Equations (1), (2), and (3), CE, CD, FI, GI, and GDP illustrate CO₂ emissions, coal consumption, financial development, globalization, and economic growth. In line with the literature [31, 37, 41], coal consumption is expected to impact CO₂ emissions positively. Thus, coal consumption would deteriorate the quality of the environment. i.e. \(\beta_{1} = \frac{\partial C_{E}}{\partial C_{D}} > 0\). Financial development is expected to negatively impact CO₂ emissions [1-3]. Thus, an increase in financial development would also increase environmental sustainability, i.e. \(\beta_{2} = \frac{\partial C_{E}}{\partial F I} < 0\) otherwise \(\beta_{2} = \frac{\partial C_{E}}{\partial F I} > 0\). It is anticipated that the interconnection between globalization and CO₂ emissions is negative [22, 26, 27]. Thus, a rise in GLO would improve the environment’s quality, i.e., globalization \(\beta_{3} = \frac{\partial C_{E}}{\partial G I} < 0\) otherwise \(\beta_{3} = \frac{\partial C_{E}}{\partial G I} > 0\). Economic growth is expected
to increase CO₂ emissions [41]. Therefore, the rise in economic growth would deteriorate environmental quality, i.e., \( \beta_4 = \frac{\partial CE}{\partial GDP} > 0 \).

### Techniques employed

**Unit root tests**

Before further analysis, it is necessary to check the order of the integration set. Therefore, we evaluate the series of integration features using unit root tests. In this study, the Dickey-Fuller (ADF) and Phillips-Perron (PP) unit amplified root tests were used. Second, due to structural ruptures in the series, traditional unit root experiments can produce inaccurate results [21-24]. Thus, we used unit root tests initiated by a study in 2000s [15], simultaneously recording fixed serial characteristics and structural interruptions.

**Combined cointegration test**

This research further uses the integrated co-integration test of Bayer and Hanck [27] as a rigorous co-integration test, which is a combination of several methods [13, 28, 51], and Engle and Granger [17] co-integration tests. According to the literature [43], the combined co-integration test eliminates needless extensive testing methods to accurately estimate the typical problem generated by other co-integration tests. In constructing the co-integration test, Bayer and Hanck [13, 47] used the Fisher formula to implement the test. The fisher’s equation is shown in literature [12] stated as follows:

\[
EG - JOH = -2[\ln(PEG) + \ln(PJOH)]
\]  

\[ (4) \]

PEG shows the level of significance for Engle and Granger [17], and where PJOH refers to the level of significance for Johansen [11]. The significance level for the co-integration tests mentioned by related literature [18-22] is expressed by PBO and PBDM, respectively.

**ARDL bounds test**

To verify the combined correlation test, the investigators utilized the ARDL bounding test to capture the correlation. The Pesaran method [17] is bounding test is preferred to other co-integration tests for the following reasons. Firstly, it can be utilized when series are integrated in mixed order; secondly, it is significantly more reliable, particularly for a small sample size [9], and thirdly, it offers accurate estimations of the long-term model. The bounds test follows the F-distribution, and Pesaran initiates its critical values. The ARDL bounds test is depicted as follows in Equation (4):

\[
\Delta CO_2 = \theta_0 + \beta_1 CE_t + \beta_2 CD_t + \beta_3 FI_t + \beta_4 GI_t + \beta_5 GDP_t \sum_{i=1}^{t} \Delta CE_{t+i} + \sum_{i=1}^{t} \Delta CD_{t+i} + \sum_{i=1}^{t} \Delta FI_{t+i} + \sum_{i=1}^{t} \Delta GI_{t+i} + \sum_{i=1}^{t} \Delta GDP_{t+i} + \varepsilon_t
\]  

\[ (6) \]

The null hypothesis and the alternative hypotheses are no co-integration and evidence of co-integration, respectively. We fail to accept the null hypothesis if the F-statistics is more than the lower and upper bond critical

![Figure 4. Schema of the model of this study](image-url)
values. Equations (8) and (9) illustrate the null and alternative hypotheses, correspondingly:

\[ H_0 = \hat{\theta}_1 = \hat{\theta}_2 = \hat{\theta}_3 = \hat{\theta}_4 = \hat{\theta}_5 \] (7)

\[ H_a \neq \hat{\theta}_1 \neq \hat{\theta}_2 \neq \hat{\theta}_3 \neq \hat{\theta}_4 \neq \hat{\theta}_5 \] (8)

where \( H_0 \) denotes the null hypothesis and \( H_a \) illustrates the alternative hypothesis.

The study utilizes the criteria of Kripfganz and Schneider test methods [41, 51], which requires 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 demand the F-statistic higher than the upper critical values for co-integration. Besides, the p-values produced should be below the target levels.

**ARDL approach**

After co-integration among the parameters is confirmed, the study utilized 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 method [17] for the assessment of short-term coefficients and the Error Correction Term (ECT). This is done by integrating the ECM into the ARDL framework as follows:

\[
\Delta C_{t2} = \theta_0 + \sum_{i=1}^t \theta_1 \Delta C_{t+1} + \sum_{i=1}^t \theta_2 \Delta D_{t+i} + \sum_{i=1}^t \theta_3 \Delta H_{t+i} + \sum_{i=1}^t \theta_4 \Delta L_{t+i} + \rho \varepsilon_{t-1} \] (9)

where the speed of adjustment is depicted by \( \rho \) and the error correction term depicted by \( ECT_{t-1} \).

**Long-run estimators**

To confirm the outcomes of the ARDL long-run estimates, we employ 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 method and the Dynamic OLS approach developed by Stock and Watson methodology were used in this analysis [48-50]. 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 with FMOLS and DOLS estimators is calculated in this study.

**Frequency domain causality**

Current research also tends to document the causal effects of CD, FI, GI, and GDP on CO₂ emissions at different frequencies in South Africa. Therefore, the present study uses the Breitung and Candelon method frequency domain causality test. The time range method’s fundamental variation and the frequency range method is that the time range method tells us where a particular change occurs in a time series, while the frequency method tells us the size of a particular change is evaluated in time series [51]. The frequency-domain causality test allows the elimination of seasonal fluctuations in small sample data [11]. This frequency amplitude testing can detect nonlinear and causal stages, while testing often facilitates causal detection between low, medium, and long frequency variables [2]; Guan method; besides, the Breitung and Candelon frequency range causality test allows the ability to distinguish long-term causality from short-term causality between time series [7, 8]. Breitung and Candelon frequency range causality test below given; \( X_t = [H_t, C_t, D_t] \), where \( X_t \) is the 3D vector of the steady parameters noticed at time parameter of \( t= 1, \ldots, T \). \( X_t \) is assumed to have a finite-order VAR illustration procedure as:

\[
\theta(L)X_t = \epsilon_t \] (10)

where \( \theta \) denotes 3x3 polynomial lag order of \( p(L) \) which is illustrated as \( \theta(L) = I - \Theta L^1 - \Theta_1 L^2 \cdots - \Theta_p L^p \) with \( L^5 X_t = X_{t-k} \). \( \epsilon_t \) illustrates the error term, which follows the process of white noise with zeros expectancy and \( (\epsilon_1, \epsilon_2, \ldots, \epsilon_t) \) stands for the positive and symmetric. For simplicity of analysis, in line with Breitung & Candelon’s [17] analysis, no deterministic terms are applied to Equation (12). G’G = \( \Sigma^{-1} \) is Cholesky decomposition, while \( G \) stands for the lower triangle-matrix. Also, \( G^t \) stands for upper triangle-matrix. \( E(n_1 n_2) = 1 \) and \( n_1 = \varepsilon_t \). Utilizing the decomposition of Cholesky, the MA description of the framework is defined as follows:

\[
X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \Theta(L) \begin{bmatrix} \varepsilon_t \\ \varepsilon_t \\ \varepsilon_t \end{bmatrix} = \begin{bmatrix} \Theta_{11}(L) & \Theta_{12}(L) & \Theta_{13}(L) \\ \Theta_{21}(L) & \Theta_{22}(L) & \Theta_{23}(L) \\ \Theta_{31}(L) & \Theta_{32}(L) & \Theta_{33}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \varepsilon_t \\ \varepsilon_t \end{bmatrix} \] (11)

\[
X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \Phi(L) \begin{bmatrix} \varepsilon_t \\ \varepsilon_t \\ \varepsilon_t \end{bmatrix} = \begin{bmatrix} \Phi_{11}(L) & \Phi_{12}(L) & \Phi_{13}(L) \\ \Phi_{21}(L) & \Phi_{22}(L) & \Phi_{23}(L) \\ \Phi_{31}(L) & \Phi_{32}(L) & \Phi_{33}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \varepsilon_t \\ \varepsilon_t \end{bmatrix} \] (12)

where \( \Theta(L) = \Theta(L)^{-1} \) and \( \Phi(L) = \Phi(L)G^{-1} \). By utilizing this depiction, the ray density of \( H_t \) can be illustrated as follows:

\[
f_{\psi} = \frac{1}{2\pi} \left( |\Phi_{11}(e^{i\psi})|^2 + |\Phi_{12}(e^{i\psi})|^2 \right) \] (13)

In Equations (10) and (11), \( H_t \) can be defined as the total value of two uncorrelated MA processes: an integral part guided by previous \( H_t \) implementation and an element containing the \( C_t \) and \( D_t \) variable’s predictive ability. The \( C \) and \( D \) variable’s predictive power can be calculated regarding the spectrum’s predictive portion at each frequency of the \( C_t \) and \( D_t \) variables. The Granger causality null hypothesis is checked in the series. For example, \( C_t \) does not Granger cause \( H_t \) at the frequency \( \psi \) if the \( H_t \) ray’s dependent parameter at the frequency \( \psi \) is 0. This is the explanation for the estimate of causality proposed by Hosoya and Geweke and described in literature [17, 19].
\[ M_{x \rightarrow y}(\psi) = \ln \frac{2\pi f_0(\psi)}{|\Phi(1)(e^{-\psi})|^2} \]  
\[ = \ln \left[ 1 + \frac{\Phi(2)(e^{-\psi})^2}{|\Phi(1)(e^{-\psi})|^2} \right] \]

The above equations linked to Geweke’s estimation would be zero (0) when \( |\Phi(1)(e^{-\psi})|^2 = 0 \). A simple linear constraint is extended to the VAR Equation (1), as described as follows:

\[ \text{CO}_2 = \theta_1 \text{CC}_t + \theta_2 \text{CD}_t + \gamma_1 \text{FD}_{t-1} + \gamma_2 \text{GDP}_{t-1} + \gamma_3 \text{GDR}_{t-1} + \varepsilon_t \]

where the coefficients of the lag polynomials are illustrated by \( \theta's \) and \( \gamma's \). The null hypothesis of \( H_0: R(\psi) \gamma = 0 \) equal to the linear constraint,

\[ H_0: R(\psi) \gamma = 0 \]

where \( \gamma = [\gamma_1, ..., \gamma_3]' \) is the vector coefficient, whereas \( R(\psi) \) is explained below:

\[ R(\psi) = \begin{bmatrix} \cos(\psi) & \cos(2\psi) & \cdots & \cos(6\psi) \\ \sin(\psi) & \sin(2\psi) & \cdots & \sin(6\psi) \end{bmatrix} \]

The standard F-stat is estimated as \( F(2, T-2p) \) for \( \varepsilon(0, \pi) \), where 2 is the number of limitations, and \( T \) is the number of the observations utilize to calculate the VAR framework of order \( p \).

\section*{RESULTS AND DISCUSSION}

Table 2 portrays the summary of variables utilized. The skewness value for all the variables shows that the parameters are normal. Furthermore, the Kurtosis value illustrates that all the variables conform to normality. The Jarque-Bera probability value revealed that globalization does not conform to normality while CO\(_2\) emissions, coal consumption, economic growth, and financial development conform to normality.

This paper utilizes both conventional unit root tests, namely ADF and PP, and more recent Zivot-Andrew (ZA) and Lee-Stratchwich (LS) unit root tests, capturing both stationarity property and structural break of time series variables. The results of ADF and PP is depicted in Tables 3 and 4. The findings revealed 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 stationary. Furthermore, the outcomes of the ZA and LS are presented in Tables 3 and 4. The ZA and LS outcomes show that all the series are stationary at mixed level, i.e., I(0) and I(1).

Because the parameters are constant in a mixing step, the ARDL boundary test proposed by Pesaran was used to study the integration of CO\(_2\) emissions and explanatory variables. The fusion results are shown in Table 4. The results of Table 5 showed that both F and T statistics are greater than the critical values of Kripfganz and Schneider at a significance level of 1 greater [18]. Therefore, it is confirmed that in the long term, parameters have participated. Therefore, we cannot consider the null hypothesis. So there is a long-term integration between the indicators. Accordingly, we use ARDL long-term and short-term estimators to understand the impact of economic development, GDP growth, coal demand, and globalization on carbon dioxide contamination in the long and short term. The CUSUM and CUSUM SQ findings in Figures 5a and 4b also are shown that the model is significantly stable at 5%. We used the Bayer and Hanch method to combine the co-integration test to capture the correlation among the parameters in this analysis [21]. The results show evidence of long-run co-integration among the variables used in this study at a 5% level of significance. This study used long-term, and short-term ARDL estimates to evaluate the impact of coal consumption and economic growth on environmental sustainability in South Africa after the long-term integration of parameters. Besides,
this study also examines the role of financial development and globalization in South Africa’s environmental sustainability from 1980 to 2017. The results of long-term and short-term ARDL estimates are shown in Table 6. Economic growth has a positive effect on environmental degradation. With other indicators’ stability, the 0.69% increase in carbon dioxide contamination is due to the 1% increase in economic growth. This finding is confirmed with the results of Usman for the USA, Adebayo for Mexico, Awosusi et al. for the economies of MINT, and Alola for the largest European states that have established a positive relationship between CO2 emissions and economic growth [27, 31, 32, 47]. The positive impact of economic growth on environmental pollution is that the main sources of industry and agriculture are fossil fuels that cause environmental degradation and economic growth [19, 51]. The increase in environmental pollution is attributed to the fact that industrial growth in South Africa is associated with the expansion of infrastructure, trade development, and economic capital, which positively impacts investment and economic production, and therefore increased energy use [33].

Table 7 also reports that internationalism has a negligible positive impact on climate change in South Africa. Coal consumption, as expected, is positively correlated with carbon dioxide contamination. The discovery shows that coal demand is detrimental to the quality of the environment in South Africa. This is obvious because South Africa ranks sixth in the world as the highest consumer of coal. It can be seen that a 1% capital to sustainable environmental initiatives and the growth in coal demand increases carbon dioxide contamination by 1077%. This result is consistent with the results of Pata [38-40] for Turkey, Shabahz for South Africa, and Al-Mawali [13, 22, 31] for selected countries. South Africa is significantly dependent on the energy sector, where development operations are influenced by coal use [17, 22]. Approximately 70% of primary energy sources and 93% of power generation come from coal reserves. This high dependence on coal consumption concerning population and the economy’s size is an important factor in CO2 emissions [6]. In South Africa, the coal industry emits 87% CO2 emissions, 94% nitrogen oxide emissions, and 96% sulfur dioxide (SO2) emissions in terms of energy emissions [17].

Table 3. Unit-root tests (level)

<table>
<thead>
<tr>
<th>Tests</th>
<th>CE</th>
<th>CD</th>
<th>FI</th>
<th>GI</th>
<th>GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF</td>
<td>-2.71557</td>
<td>-2.72844</td>
<td>-2.49084</td>
<td>-2.10375</td>
<td>-2.6037</td>
</tr>
<tr>
<td>PP</td>
<td>-2.94129</td>
<td>-2.72547</td>
<td>-2.94921</td>
<td>-1.7315*</td>
<td>-1.70775</td>
</tr>
<tr>
<td>ZA K &amp; T</td>
<td>-4.44213</td>
<td>-4.65102</td>
<td>-4.23324</td>
<td>-3.5679*</td>
<td>-3.548**</td>
</tr>
<tr>
<td>LS</td>
<td>-5.95881*</td>
<td>-6.936**</td>
<td>-6.8745*</td>
<td>-6.01227</td>
<td>-7.60815</td>
</tr>
</tbody>
</table>

Note: *, **, and *** represents 1%, 5% and 10% respectively.

Table 4. Unit-root tests (first difference)

<table>
<thead>
<tr>
<th>Tests</th>
<th>CE</th>
<th>CD</th>
<th>FI</th>
<th>GI</th>
<th>GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF</td>
<td>-6.351**</td>
<td>-6.266**</td>
<td>-5.712***</td>
<td>-4.261*</td>
<td>-4.212**</td>
</tr>
<tr>
<td>PP</td>
<td>-6.328**</td>
<td>-6.153**</td>
<td>-5.402***</td>
<td>-3.434***</td>
<td>-4.589*</td>
</tr>
<tr>
<td>ZA K &amp; T</td>
<td>-7.793*</td>
<td>-7.753*</td>
<td>-6.276 **</td>
<td>-5.010**</td>
<td>-5.901**</td>
</tr>
</tbody>
</table>

Note: *, **, and *** represents 1%, 5% and 10% respectively.

Table 5. Bound test

<table>
<thead>
<tr>
<th>Model</th>
<th>F-Stat.</th>
<th>T-Stat.</th>
<th>( \chi^2 ) ARCH</th>
<th>( \chi^2 ) RESET</th>
<th>( \chi^2 ) Normality</th>
<th>( \chi^2 ) LM</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.91*</td>
<td>-5.45*</td>
<td>1.47(0.29)</td>
<td>2.19(0.14)</td>
<td>0.13(0.93)</td>
<td>1.33(0.10)</td>
<td></td>
</tr>
</tbody>
</table>

Kripfganz and Schneider (2018) critical and P-values

<table>
<thead>
<tr>
<th>10%</th>
<th>5%</th>
<th>1%</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.18196</td>
<td>3.2868</td>
<td>3.85209</td>
<td>3.53628</td>
</tr>
<tr>
<td>-2.47005</td>
<td>-3.76002</td>
<td>-4.16493</td>
<td>-3.5046</td>
</tr>
</tbody>
</table>

Note: * represent a 1% level of significance, and PV denotes probability value both F-stat and T-stat are greater than critical values.
In South Africa, the impact of economic development on carbon dioxide contamination is confirmed at a significant level of 5%. The results show that a 0.973% decrease in carbon dioxide contamination comes from a 1% improvement in financial development. The negative correlation indicates that the economic sector in South Africa has reached maturity due to the allocation of encouragement of companies to use new development technologies to increase production. This result is consistent with Shahbaz and Charfeddine & Khedira's findings, who found that economic development improves the environment's quality [19, 27].

Table 7. ARDL estimations

<table>
<thead>
<tr>
<th>Long-Run Result</th>
<th>CO\textsubscript{2} := f(CD, FI, GI, GDP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>** Regressors</td>
<td>** Coefficient</td>
</tr>
<tr>
<td>CE</td>
<td>1.066**</td>
</tr>
<tr>
<td>FL</td>
<td>-0.974*</td>
</tr>
<tr>
<td>GI</td>
<td>0.232</td>
</tr>
<tr>
<td>GDP</td>
<td>1.451**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Short-Run Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>** Regressors</td>
</tr>
<tr>
<td>ECM(-)</td>
</tr>
<tr>
<td>CD</td>
</tr>
<tr>
<td>FI</td>
</tr>
<tr>
<td>GI</td>
</tr>
<tr>
<td>GDP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diagnostic Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>R\textsuperscript{2}</td>
</tr>
<tr>
<td>Adj. R\textsuperscript{2}</td>
</tr>
</tbody>
</table>

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

In South Africa, the impact of economic development on carbon dioxide contamination is confirmed at a significant level of 5%. The results show that a 0.973% decrease in carbon dioxide contamination comes from a 1% improvement in financial development. The negative correlation indicates that the economic sector in South Africa has reached maturity due to the allocation of encouragement of companies to use new development technologies to increase production. This result is consistent with Shahbaz and Charfeddine & Khedira’s findings, who found that economic development improves the environment’s quality [19, 27].

The findings from the FMOLS and DOLS are reported in Table 8. The outcomes show that coal

Table 6. Combined cointegration test

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EG-JOH</td>
<td>EG-JOH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO\textsubscript{2} := f(CD, FI, GDP, GI)</td>
<td>14.088**</td>
<td>27.795**</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Critical value: 10.576, 20.143

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

Table 8. Robustness check

<table>
<thead>
<tr>
<th>Regressors</th>
<th>Coefficient</th>
<th>t-statistics</th>
<th>Prob.</th>
<th>Coefficient</th>
<th>t-statistics</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>1.101*</td>
<td>5.437</td>
<td>0.002</td>
<td>1.099*</td>
<td>3.838</td>
<td>0.003</td>
</tr>
<tr>
<td>FL</td>
<td>-0.521*</td>
<td>-4.674</td>
<td>0.009</td>
<td>-0.981*</td>
<td>-4.194</td>
<td>0.002</td>
</tr>
<tr>
<td>GI</td>
<td>0.279</td>
<td>1.244</td>
<td>0.267</td>
<td>0.244</td>
<td>0.985</td>
<td>0.356</td>
</tr>
<tr>
<td>GDP</td>
<td>1.533*</td>
<td>5.467</td>
<td>0.000</td>
<td>1.451*</td>
<td>3.851</td>
<td>0.003</td>
</tr>
<tr>
<td>R\textsuperscript{2}</td>
<td>0.9712</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj R\textsuperscript{2}</td>
<td>0.9619</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 10% and 5% level of significance is depicted by ** and *, respectively.
consumption and economic growth significantly influence CO₂ emissions, while financial development negatively influences CO₂ emissions. However, no significant interconnection was established between globalization and CO₂ emissions. These results comply with the ARDL long-run estimations. After the long-run effects have been identified, the causal impacts of CD, FI, GI, and GDP on CO₂ at various frequencies are identified in the frequency range causality test of Candelon and Breitung method [17]. As shown in Table 9, the null hypothesis of PPIE can be rejected in the short-term, medium-term, and long-term because CD can be rejected in the short-term, medium-term, and long-term causality test. GDP in the short-term, medium-term, and long-term South Africa. This result complies with the Pata, Shabaz, and Al-mulali [13, 22, 31]. Furthermore, in the short and long-run, financial development Granger causes CO₂ emissions in South-Africa. This indicates that financial development can predict certain variations in CO₂ emissions in South-Africa in the Long and short term (Figure 6). These results correspond to prior studies [51].

**Table 9. Frequency range causality test**

<table>
<thead>
<tr>
<th>Direction of causality</th>
<th>Long term</th>
<th>Medium-term</th>
<th>Short term</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD → CE</td>
<td>ω₁ = 0.01</td>
<td>ω₁ = 0.05</td>
<td>ω₁ = 1.00</td>
</tr>
<tr>
<td>FI → CE</td>
<td>&lt; 10.433&gt;</td>
<td>&lt; 10.441&gt;</td>
<td>&lt; 12.577&gt;</td>
</tr>
<tr>
<td>GDP → CE</td>
<td>(0.004) **</td>
<td>(0.004) **</td>
<td>(0.001) **</td>
</tr>
<tr>
<td>GI → CE</td>
<td>&lt; 5.298&gt;</td>
<td>&lt; 5.288&gt;</td>
<td>&lt; 0.356&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.069) *</td>
<td>(0.071) *</td>
<td>(0.837)</td>
</tr>
<tr>
<td></td>
<td>(0.361)</td>
<td>(0.341)</td>
<td>(0.194)</td>
</tr>
<tr>
<td></td>
<td>(0.834)</td>
<td>(0.833)</td>
<td>(0.578)</td>
</tr>
<tr>
<td></td>
<td>(0.862)</td>
<td>(0.862)</td>
<td>(0.701)</td>
</tr>
</tbody>
</table>

Note: The values inside < > denotes Wald test statistic whereas The values inside ( ) denotes p-value. ** and * represents 1 and 5% level of significance.

**CONCLUSION**

Recognizing the impact of globalization and coal consumption on environmental degradation in South Africa is crucial because it is one of the largest carbon dioxide emitters globally, and the role of financial development and economic growth must be considered. Therefore, the present study uses the ARDL constraint test using Kripfganz and Schneider’s test critical values, long-term and short-term ARDL, FMOLS, and DOLS estimates. The obvious reason for the increase in carbon dioxide contamination in South Africa over time is the use of coal in energy production, the main material in carbon dioxide contamination. It is universally known that coal consumption significantly contributes to climate change. In this study, we examine the effects of coal demand and internationalism on carbon dioxide contamination in the presence of economic development and GDP growth in South Africa. The present study’s experimental results showed that an increase in economic development is related to the environment’s quality, i.e., reducing energy pollutants in financial development. Overall, we find that the banking sector’s growth, which provides access per capita to the domestic private sector, aims to reduce carbon contamination. This means that economic development can be implemented to maintain climate security by implementing financial reforms. Besides, the use of coal contributes significantly to the destruction of environmental sustainability. In this regard, by formulating a strong policy program that provides long-term value for greenhouse gas emissions and continuously encourages emerging technologies contributing to a low-carbon economy, the markets’ government benefits. Besides, the adequate stock market growth can be another valuable political tool that can be implemented. Companies can decrease the currency risk that can create the necessary budget by diversifying their portfolio, which is essential, especially in the long-term growth of a comprehensive technology base. Besides,
given the economic growth and deteriorating climate, we argue that more significant levels of financial sector growth and business transparency, by increasing R&D costs in energy efficiency, lead to energy savings and reduced pollution, which encourages technology. However, our research is not limited to provide a segregated review, i.e., in the trading phase, because of how the financial development of established stock markets may improve the environment’s quality. Although significant econometric methods have been used in this study. This study’s limitation is the lack of access to data beyond 2017. Besides, this study uses CO₂ as an indicator of environmental quality, and other studies should examine these connections using other environmental degradation proxies.

ACKNOWLEDGEMENT

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REFERENCES


هدف این مقاله بررسی مصرف ذغال سنگ و پایداری محیط زیست در آفریقای جنوبی با بررسی نقش توسعه مالی و جهانی سازی در استفاده از مجمعه‌های 1980 تا 2017 است. بر اساس دامنه این مقاله، ARDL Bounds، Bavaria و ترکیب Hank، FMOLS و ARDL (با تقريب‌های Kripfganz و Schneider) از آزمون‌های علت و دامنه استفاده می‌شود. نتایج آزمون‌های ادغام Bayer و Hank و محدودیت‌های ARDL (با تقرب‌های Kripfganz و Schneider) یکپارچگی مشترک بین این مجموعه را نشان می‌دهد. یافته‌هایی که بر اساس آزمون‌های کوتاه مدت و بلند مدت ARDL تهیه شده‌اند نشان می‌دهد که توسعه اقتصادی باعث حفظ محیط زیست می‌شود. نتایج آزمون علت حوزه‌های فرکانس نشان داد که مصرف ذغال سنگ و توسعه مالی به طور قابل توجهی نتیجه‌ای از تکمیل حفظ محیط زیست دارد.