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

N. Norouzi, M. Fani*

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

P A P E R I N F O	*A B S T R A C T*
  	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.

NOMENCLATURE

CE	Carbon Emissions	CO_2	Carbon Dioxide
GDP	Gross Domestic Product	ARDL	Autoregressive Distributed Lag
CD	Coal Consumption	DOLS	Dynamic Ordinary Least Squares
FI	Financial Development Index	FMOLS	Fully Modified Least Square

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 pregnable 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

Corresponding Author Email: mfani@aut.ac.ir (M. Fani)

country's economic growth, which is why many countries are reluctant to implement it. Like CO_2 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 CO_2 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 CO_2 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 CO_2 contamination in this investigation [12]. Therefore, it is important to study the role of economic growth, globalization and financial development, and coal consumption in CO_2 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 CO_2 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 CO_2 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
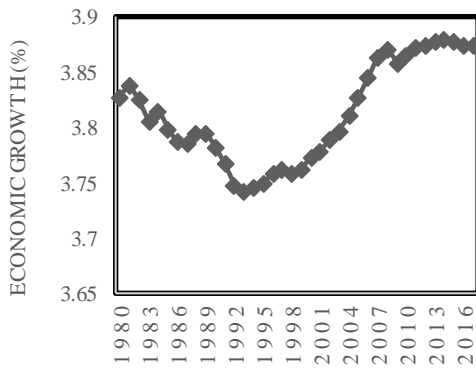
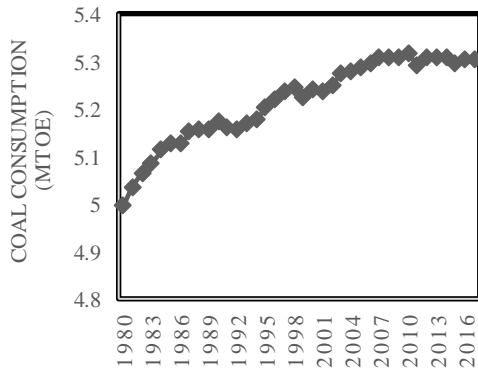**Figure 1.** Economic Growth in South Africa, World Bank (2020)

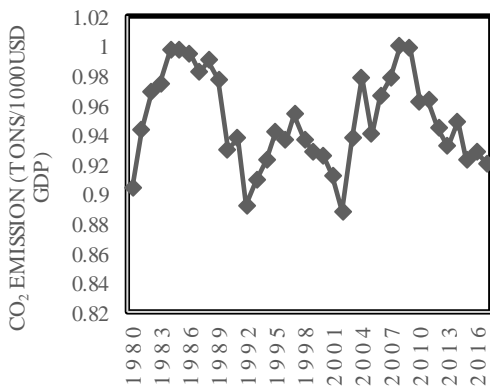**Figure 2.** Coal Consumption in South Africa, World Bank (2020)

Figure 3. Carbon dioxide (CO_2) Emission, World Bank (2020)

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, CO_2 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 CO_2 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 CO_2 emissions in South Africa due to rapid economic growth. Previous studies have also reported that increased economic growth resulted in an increase in CO_2 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 CO_2 in Mexico. In Turkey, Udi et al. [46] studied the relationship between CO_2 emissions and the economy and presented that increasing climate change is associated with increased GDP growth.

Financial development and CO_2 emissions
Over the years, several studies have examined the relationship between financial development and CO_2 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 CO_2 emissions, while energy consumption, trade openness, and urbanization increase CO_2 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 CO_2 emissions. Similarly, it was reported that economic development increases CO_2 emissions [38]. The relationship between financial development, economic growth, trade openness, CO_2 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 CO_2 emissions in South Africa for the period. From 1971 to 2016. The authors report that economic development has a positive effect on CO_2 emissions in South Africa.

Globalization and CO_2 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 CO_2 emissions in the G7 for 1970-2015. Their analysis showed that the Kuznets environment curve hypothesis inversely strongly confirms the relationship between globalization and CO_2 emissions. Besides, increased economic production is associated with a significant increase in CO_2 emissions. The study conducted by Belay Kassa [48] also examines the impact of globalization and trade openness on CO_2 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 CO_2 emissions.

Similarly, Asian based article by Khan et al. [26] examined the impact of globalization on CO_2 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 CO_2 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 CO_2 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 CO_2 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:

$$CO_{2t} = f(CD_t, FI_t, GI_t, GDP_t) \tag{1}$$

$$CO_{2t} = \vartheta_0 + \vartheta_1 CD_t + \vartheta_2 FI_t + \vartheta_3 GI_t + \vartheta_4 GDP_t \tag{2}$$

$$CO_{2t} = \vartheta_0 + \vartheta_1 CD_t + \vartheta_2 FI_t + \vartheta_3 GI_t + \vartheta_4 GDP_t + e_t \tag{3}$$

In Equations (1), (2), and (3), CE, CD, FI, GI, and GDP illustrate CO_2 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. $\left(\beta_1 = \frac{\partial CE}{\partial CD} > 0\right)$. Financial development is expected to negatively impact CO_2 emissions [1-3]. Thus, an increase in financial development would also increase environmental sustainability, i.e. $\left(\beta_2 = \frac{\partial CE}{\partial FI} < 0\right)$ otherwise $\left(\beta_2 = \frac{\partial CE}{\partial FI} > 0\right)$. It is anticipated that the interconnection between globalization and CO_2 emissions is negative [22, 26, 27]. Thus, a rise in GLO would improve the environment's quality, i.e., globalization $\left(\beta_3 = \frac{\partial CE}{\partial GI} < 0\right)$ otherwise $\left(\beta_1 = \frac{\partial CE}{\partial GI} > 0\right)$. Economic growth is expected

Table 1. Data description and source

Variable	Description	Units	Sources
CE	Carbon Emissions	Metric tonnes of CO_2	
GDP	Gross Domestic Product	Constant US Dollars, 2010	[52]
CD	Coal Consumption	Million Tonnes of Oil Equivalent (Mtoe).	
FI	Financial Development Index	A broad measure for financial development by taking into account its efficiency, accessibility, and depth	[53]
GI	Economic Globalization Index	Index-Based on FDI, trade, and portfolio investment	[54]

to increase CO_2 emissions [41]. Therefore, the rise in economic growth would deteriorate environmental quality, i.e., $\left(\beta_4 = \dfrac{\partial CE}{\partial GDP} > 0\right)$.

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:

$$EG - JOH = -2[\ln(PEG) + \ln(PJOH)] \tag{4}$$

$$EG - JOH - BO - BD = -2[ln\,(PEG) + ln\,(PJOH) + ln(PBO) + ln(PBDM)] \tag{5}$$

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):

$$\Delta CO_{2t} = \vartheta_0 + \beta_1 CE_{t-1} + \beta_2 CD_{t-1} + \beta_3 FI_{t-1} + \beta_4 GI_{t-1} + \beta_5 GDP_{t-1} \sum_{i=1}^{t}\vartheta_1 \Delta CE_{t-i} + \sum_{i=1}^{t}\vartheta_2 \Delta CD_{t-i} + \sum_{i=1}^{t}\vartheta_3 \Delta FI_{t-i} + \sum_{i=1}^{t}\vartheta_4 \Delta GI_{t-i} + \sum_{i=1}^{t}\vartheta_5 \Delta GDP_{t-i} + \varepsilon_t \tag{6}$$

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
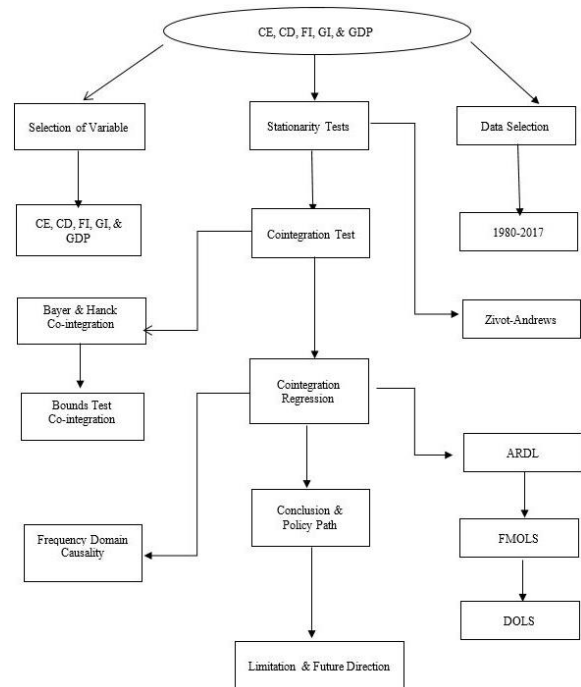

Figure 4. Schema of the model of this study

values. Equations (8) and (9) illustrate the null and alternative hypotheses, correspondingly;

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

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

where H_0 denotes the null hypothesis and H_a illustrates the alternative hypothesis.

The study utilizes the criteria of Kripfganz and Schneider 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:

$$\Delta CO_{2t} = \vartheta_0 + \sum_{i=1}^{t} \vartheta_1 \Delta CE_{t-i} + \sum_{i=1}^{t} \vartheta_2 \Delta CD_{t-i} +$$
$$\sum_{i=1}^{t} \vartheta_3 \Delta FI_{t-i} + \sum_{i=1}^{t} \vartheta_4 \Delta GI_{t-i} + \qquad (9)$$
$$\sum_{i=1}^{t} \vartheta_5 \Delta GDP_{t-i} + \rho ECT_{t-i} + \varepsilon_t$$

where the speed of adjustment is depicted by ρ 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 CO_2 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; Xt = [H_t, C_t, D_t], where Xt is the 3D vector of the steady parameters noticed at time parameter of t= 1, …, T. X_t is assumed to have a finite-order VAR illustration procedure as:

$$\Theta(L)X_t = \epsilon_t \qquad (10)$$

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

$$X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \Theta(L)\varepsilon_t = \begin{bmatrix} \Theta_{11}(L) & \Theta_{12}(L) \\ \Theta_{21}(L) & \Theta_{22}(L) \\ \Theta_{31}(L) & \Theta_{32}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \varepsilon_t \\ \varepsilon_t \end{bmatrix} \qquad (11)$$

$$X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \Phi(L)\Pi_t = \begin{bmatrix} \Phi_{11}(L) & \Phi_{12}(L) \\ \Phi_{21}(L) & \Phi_{22}(L) \\ \Phi_{31}(L) & \Phi_{32}(L) \end{bmatrix} \begin{bmatrix} \Pi_t \\ \Pi_t \\ \Pi_t \end{bmatrix} \qquad (12)$$

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:

$$f_H(\psi) = \frac{1}{2\pi}\{|\Phi_{11}(e^{-i\varphi})|^2 + |\Phi_{12}(e^{-i\varphi})|^2\} \qquad (13)$$

In Equations (10) and (11), H_t can be defined as the total value of two uncorrelated MA procedures: an integral part guided by previous H_t implementation and an element containing the Ct and Dt variables' predictive ability. The C_t and D_t 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 ψ if the Ht ray's dependent parameter at the frequency ψ is 0. This is the explanation for the estimate of causality proposed by Hosoya and Geweke and described in literature [17, 19]:

$$M_{x \to y}(\psi) = In\left[\frac{2\pi f_y(\psi)}{|\Phi_{11}(e^{-i\varphi})|^2}\right] \tag{14}$$

$$= In\left[+\frac{|\Phi_{12}(e^{-i\varphi})|^2}{|\Phi_{11}(e^{-i\varphi})|^2}\right] \tag{15}$$

The above equations linked to Geweke's estimation would be zero (0) when $|\Phi_{11}(e^{-i\varphi})|^2 = 0$. A simple linear constraint is extended to the VAR Equation (1), as described as follows:

$$CO_{2t} = \theta_1 CC_{t-1} + \theta_\delta CC_{t-\delta} + \gamma_1 FD_{t-1} + \gamma_\delta FD_{t-\delta} + \gamma_2 GLO_{t-1} + \gamma_\delta GLO_{t-\delta} + \gamma_3 GDP_{t-1} + \gamma_\delta GDP_{t-\delta} + \varepsilon_t \tag{16}$$

where the coefficients of the lag polynomials are illustrated by $\theta's$ and $\gamma's$. The null hypothesis $M_{x \to y}(\psi) = 0$ equal to the linear constraint,

$$H_O: R(\psi)\gamma = O \tag{17}$$

where $\gamma = [\gamma_1, \ldots \gamma_\delta]^t$ is the vector coefficient, whereas $R(\psi)$ is explained below:

$$R(\psi) = \begin{bmatrix} \cos(\psi)\cos(2\psi)\ldots\cos(\delta\psi) \\ \sin(\psi)\sin(2\psi)\ldots\sin(\delta\psi) \end{bmatrix} \tag{18}$$

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

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 Jaque-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,

Table 2. Descriptive statistics

	CE	CD	FI	GI	GDP
Mean	0.92904	5.10972	-0.36064	1.68168	3.73576
Median	0.92316	5.1303	-0.33908	1.70324	3.72498
Maximum	0.97902	5.2087	-0.19796	1.81202	3.80142
Minimum	0.87024	4.8951	-0.52234	1.53762	3.66618
Std. Dev.	0.03038	0.08526	0.1078	0.11172	0.04508
Skewness	0.04312	-0.66346	0.04606	-0.09408	0.13426
Kurtosis	2.03546	2.50096	1.37396	1.18188	1.60328
Jarque-Bera	1.34064	3.15854	3.97488	5.04798	3.0037
Probability	0.49588	0.19502	0.12838	0.07448	0.2107
Observations	38	38	38	38	38

Table 3. Unit-root tests (level)

Tests		CE	CD	FI	GI	GDP
ADF		-2.71557	-2.72844	-2.49084	-2.10375	-2.6037
PP		-2.94129	-2.72547	-2.94921	-1.7315*	-1.70775
ZA	K & T	-4.44213	-4.65102	-4.23324	-3.5679*	-3.548**
LS		-5.95881*	-6.936**	-6.8745*	-6.01227	-7.60815

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

Table 4. Unit-root tests (first difference)

Tests		CE	CD	FI	GI	GDP
ADF		-6.351**	-6.266**	-5.712***	-4.261*	-4.212**
PP		-6.328**	-6.153**	-5.402***	-3.434***	-4.589*
ZA		-7.793*	-7.753*	-6.276 **	-5.010**	-5.901**
LS	K & T	-6.641**	-7.391*	-6.5773**	-7.297 *	-6.115**

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

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 CO_2 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-Mawlali [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 reservoirs. This high dependence on coal consumption concerning population and the economy's size is an important factor in CO_2 emissions [6]. In South Africa, the coal industry emits 87% CO_2 emissions, 94% nitrogen oxide emissions, and 96% sulfur dioxide (SO_2) emissions in terms of energy emissions [17].

Table 5. Bound test

Model	F-Stat.	T-Stat.	χ2 ARCH	χ2 RESET	χ2 Normality	χ2 LM
	5.91*	-5.45*	1.47(0.29)	2.19(0.14)	0.13(0.93)	1.33(0.10)

Kripfganz and Schneider (2018) critical and P-values

	10%		5%		1%		PV
F-Stat.	2.18196	3.2868	2.58885	3.85209	3.53628	5.0688	0.00
T-Stat.	-2.47005	-3.76002	-2.81457	-4.16493	-3.5046	-4.9779	0.00

Note: * represent a 1% level of significance, and PV denotes probability value both F-stat and T-stat are greater than critical values.
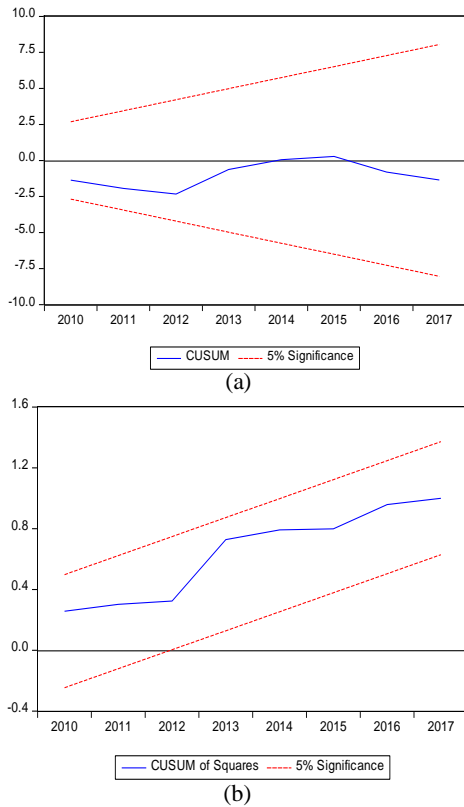
Figure 5. (a) Results of the CUSUM, (b) Results of the CUSUM$_{Sq}$

Table 6. Combined cointegration test

Model Specifications	Fisher Statistics	Fisher Statistics	Co-integration Decision
	EG-JOH	EG-JOH-BAN-BOS	
$CO_2 = f$(CE, FI, GDP, GI)	14.088**	27.795**	Yes
	Critical value	Critical value	
	10.576	20.143	

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

Table 7. ARDL estimations

Long-Run Result			
CO$_2$=f(CD, FI, GI, GDP)			
Regressors	Coefficient	t-statistics	Probability
CE	1.066**	2.289	0.051
FI	-0.974*	-2.488	0.037
GI	0.232	0.566	0.590
GDP	1.451**	2.274	0.052
Short-Run Result			
Regressors	Coefficient	Std. Error	Probability
ECM(-)	-0.542*	-6.641	0.000
CD	1.081*	4.281**	0.002
FI	-0.134	-0.871	0.411
GI	0.237	0.991	0.353
GDP	0.689**	1.851*	0.102
Diagnostic Tests			
R^2		0.961	
Adj. R^2		0.961	

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 8. Robustness check

	FMOLS			DOLS		
Regressors	Coefficient	t-statistics	Prob.	Coefficient	t-statistics	Prob.
CD	1.101*	5.437	0.002	1.099*	3.838	0.003
FI	-0.521*	-4.674	0.009	-0.981*	-4.194	0.002
GI	0.279	1.244	0.267	0.244	0.985	0.356
GDP	1.533*	5.467	0.000	1.451*	3.851	0.003
R^2		0.9712			0.9714	
Adj R^2		0.9619			0.9686	

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

Direction of causality	Long term		Medium-term		Short term	
	$\omega_i = 0.01$	$\omega_i = 0.05$	$\omega_i = 1.00$	$\omega_i = 1.50$	$\omega_i = 2.00$	$\omega_i = 2.50$
CD→CE	< 10.433>	< 10.441>	< 12.577>	< 12.352>	< 12.298>	< 12.211>
	(0.004) **	(0.004) **	(0.001) **	(0.002) **	(0.002) **	(0.002) **
FI→CE	< 5.298>	<5.288>	<0.356>	<4.292>	< 4.677>	<4.698>
	(0.069) *	(0.071) *	(0.837)	(0.114)	(0.091) *	(0.094) *
GDP→CE	< 0.361>	<0.341>	< 1.094>	< 1.229>	< 1.229>	< 1.229>
	(0.834)	(0.833)	(0.578)	(0.540)	(0.540)	(0.540)
GI→CE	< 0.305>	< 0.305>	<0.681>	<0.681>	< 0.681>	<0.681>
	(0.862)	(0.862)	(0.701)	(0.701)	(0.701)	(0.701)

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

consumption and economic growth significantly influence CO_2 emissions, while financial development negatively influences CO_2 emissions. However, no significant interconnection was established between globalization and CO_2 emissions. These results comply with the ARDL long-run estimations (see Figures 5a and 5b). After the long-run effects have been identified, the causal impacts of CD, FI, GI, and GDP on CO_2 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, medium, and long-run because CD Granger causes carbon dioxide contamination. This implies that coal consumption is an important predictor of carbon dioxide contamination in the short-term, medium-term, and long-term South Africa. This result complies with Pata, Shabahz, and Al-mulali [13, 22, 31]. Furthermore, in the short and long-run, financial development Granger cause CO_2 emissions in South-Africa. This indicates that financial development can predict certain variations in CO_2 emissions in South-Africa in the Long and short term (Figure 6). These results correspond to prior studies [51].
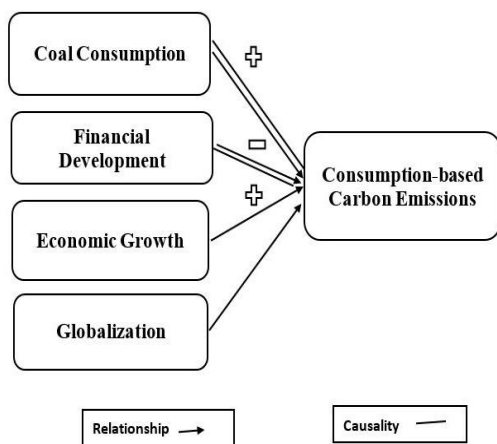

Figure 6. Graphical findings

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 provid 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 CO_2 as an indicator of environmental quality, and other studies should examine these connections using other environmental degradation proxies.

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REFERENCES

1. Adebayo, T. S., amd Odugbesan, J. A. 2020. 'Modeling CO_2 emissions in South Africa: empirical evidence from ARDL based bounds and wavelet coherence techniques', *Environmental Science and Pollution Research*, pp. 1-13. https://doi.org/10.1007/s11356-020-11442-3

2. Adebayo, T. S. 2020. 'Revisiting the EKC hypothesis in an emerging market: An application of ARDL-based bounds and wavelet coherence approaches', *SN Applied Sciences*, 2(12), pp. 1-15. https://doi.org/10.1007/s42452-020-03705-y

3. Adedoyin, F. F., Gumede, M. I., Bekun, F. V., Etokakpan, M. U. and Balsalobre-lorente, D. 2020. 'Modelling coal rent, economic growth and CO_2 emissions: Does regulatory quality matter in BRICS economies?', *Science of the Total Environment*, 710, pp. 136284. https://doi.org/10.1016/j.scitotenv.2019.136284

4. Al-mulali, U. and Che Sab, C. N. B. 2018. 'The impact of coal consumption and CO_2 emission on economic growth', *Energy Sources, Part B: Economics, Planning, and Policy*, 13(4), pp. 218-223. https://doi.org/10.1080/15567249.2012.661027

5. Akinsola, G. D., and Adebayo, T. S. 2021. 'Investigating the Causal Linkage Among Economic Growth, Energy Consumption and CO_2 Emissions In Thailand: An Application of the Wavelet Coherence Approach', *International Journal of Renewable Energy Development*, 10(1). https://doi.org/10.14710/ijred.2021.32233

6. Alola, A. A., Yalçiner, K., Alola, U. V., and Saint Akadiri, S. 2019. 'The role of renewable energy, immigration and real income in environmental sustainability target. Evidence from Europe's largest states', *Science of The Total Environment*, 674, pp. 307-315. https://doi.org/10.1016/j.scitotenv.2019.04.163

7. Attiaoui, I., Toumi, H., Ammouri, B. and Gargouri, I. 2017. 'Causality links among renewable energy consumption, CO_2 emissions, and economic growth in Africa: Evidence from a panel ARDL-PMG approach', *Environmental science and pollution research*, 24(14), pp. 13036-13048. https://doi.org/10.1007/s11356-017-8850-7

8. Awosusi, A. A., Adeshola, I., and Adebayo, T. S. 2020. 'Determinants of CO_2 Emissions in Emerging Markets: An Empirical Evidence from MINT Economies', *International Journal of Renewable Energy Development*, 9(3). https://doi.org/10.14710/ijred.2020.31321

9. Bekun, F. V., Emir, F., and Sarkodie, S. A. 2019. 'Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa'. *Science of the Total Environment*, 655, pp. 759-765. https://doi.org/10.1016/j.scitotenv.2018.11.271

10. Belaid, F. and Youssef, M. 2017. 'Environmental degradation, renewable and non-renewable electricity consumption, and economic growth: Assessing the evidence from Algeria'. *Energy Policy*, 102, pp.277-287. https://doi.org/10.1016/j.enpol.2016.12.012

11. Bento, J. P. C., and Moutinho, V. 2016. 'CO_2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy'. *Renewable and Sustainable Energy Reviews*, 55, 142-155. https://doi.org/10.1016/j.rser.2015.10.151

12. Bildirici, E. M., and Bakirtas, T. 2016. 'The relationship among oil and coal consumption, carbon dioxide emissions, and economic growth in BRICTS countries', *Journal of Renewable and Sustainable Energy*, 8(4), pp. 045903. https://doi.org/10.1063/1.4955090

13. Charfeddine L, Kahia M. 2019. 'Impact of renewable energy consumption and financial development on CO_2 emissions and economic growth in the MENA region: a panel vector autoregressive (PVAR) analysis'. *Renewable Energy*, 139, pp. 198–213. https://doi.org/10.1016/j.renene.2019.01.010

14. Charfeddine, L., and Khediri, K. B. 2016. 'Financial development and environmental quality in UAE: Cointegration with structural breaks'. *Renewable and Sustainable Energy Reviews*, 55, pp. 1322-1335. https://doi.org/10.1016/j.rser.2015.07.059

15. Destek, M. A., and Sarkodie, S. A. 2019. 'Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development', *Science of the Total Environment*, 650, pp. 2483-2489. https://doi.org/10.1016/j.scitotenv.2018.10.017

16. Di Gianfrancesco, A. 2017. 'Worldwide overview and trend for clean and efficient use of coal. In Materials for Ultra-Supercritical and Advanced Ultra-Supercritical Power Plants', Woodhead Publishing, pp.643-687. https://doi.org/10.1016/C2014-0-04826-5

17. Dogan, E. and Ozturk, I. 2017. 'The influence of renewable and non-renewable energy consumption and real income on CO_2 emissions in the USA: evidence from structural break tests'. *Environmental Science and Pollution Research*, 24(11), pp. 10846-10854. https://doi.org/10.1007/s11356-017-8786-y

18. Fei, L., Dong, S., Xue, L., Liang, Q. and Yang, W. 2011. 'Energy consumption-economic growth relationship and carbon dioxide emissions in China', *Energy policy*, 39(2), pp. 568-574. https://doi.org/10.1016/S2212-5671(13)00067-1

19. Frankel, J. A. and Romer, D. H. 1999. 'Does trade cause growth?' *American economic review*, 89(3), pp. 379-399. https://doi.org/10.1257/aer.89.3.379

20. Inglesi-Lotz, R. and Dogan, E. 2018. 'The role of renewable versus non-renewable energy to the level of CO_2 emissions a panel analysis of sub-Saharan Africa's Big 10 electricity generators', *Renewable Energy*, 123, pp. 36-43. https://doi.org/10.1016/j.renene.2018.02.041

21. Jian J, Fan X, He P, Xiong H, Shen H 2019. 'The effects of energy consumption, economic growth and financial development on CO_2 emissions in China: a VECM Approach', *Sustainability*, 11(18), pp. 4850. https://doi.org/10.3390/su11184850

22. Joshua, U. and Bekun, F. V. 2020. 'The path to achieving environmental sustainability in South Africa: the role of coal consumption, economic expansion, pollutant emission, and total natural resources rent', *Environmental Science and Pollution Research*, pp. 1-9. https://doi.org/10.1007/s11356-020-08145-0

23. Joshua, U., Bekun, F. V. and Sarkodie, S. A. 2020. 'New insight into the causal linkage between economic expansion, FDI, coal consumption, pollutant emissions and urbanization in South Africa', *Environmental Science and Pollution Research*, 1-12. https://doi.org/10.1007/s11356-020-08145-0

24. Kalmaz, D. B. and Kirikkaleli, D. 2019. 'Modeling CO_2 emissions in an emerging market: empirical finding from ARDL-based bounds and wavelet coherence approaches', *Environmental Science and Pollution Research*, 26(5), pp. 5210-5220. https://doi.org/10.1007/s11356-018-3920-z.

25. Kalayci, C. 2019. 'The impact of economic globalization on CO_2 emissions: the case of NAFTA countries', *International Journal of Energy Economics and Policy*, 9(1), pp. 356. https://doi.org/10.32479/ijeep.7233

26. Khan, M. K., Teng, J. Z. and Khan, M. I. 2019. 'Effect of energy consumption and economic growth on carbon dioxide emissions in Pakistan with dynamic ARDL simulations approach', *Environmental Science and Pollution Research*, 26(23), pp. 23480-23490. https://doi.org/10.1007/s11356-019-05640-x

27. Khan, M. K., Teng, J. Z., Khan, M. I. and Khan, M. O. 2019. 'Impact of globalization, economic factors and energy consumption on CO_2 emissions in Pakistan', *Science of the total environment*, 688, pp. 424-436. https://doi.org/10.1016/j.scitotenv.2019.06.065

28. Kirikkaleli, D. and Kalmaz, D. B. 2020. 'Testing the moderating role of urbanization on the environmental Kuznets curve: empirical evidence from an emerging market', *Environmental Science and Pollution Research*, 27(30), pp. 38169-38180. https://doi.org/10.1007/s11356-020-09870-2

29. Kirikkaleli, D., Adebayo, T. S., Khan, Z. and Ali, S. 2020. 'Does globalization matter for ecological footprint in Turkey? Evidence from dual adjustment approach', *Environmental Science and Pollution Research*, pp. 1-9. https://doi.org/10.1007/s11356-020-11654-7

30. Liu, M., Ren, X., Cheng, C. and Wang, Z. 2020. 'The role of globalization in CO_2 emissions: A semi-parametric panel data analysis for G7', *Science of The Total Environment*, 718, pp. 137379. https://doi.org/10.1016/j.scitotenv.2020.137379

31. Magazzino, C., Bekun, F. V., Etokakpan, M. U. and Uzuner, G. 2020. 'Modeling the dynamic Nexus among coal consumption, pollutant emissions and real income: empirical evidence from South Africa', *Environmental Science and Pollution Research*, 27(8), pp. 8772-8782. https://doi.org/10.1007/s11356-019-07345-7

32. Nathaniel, S., Nwodo, O., Adediran, A., Sharma, G., Shah, M. and Adeleye, N. 2019. 'Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded', *Environmental Science and Pollution Research*, 26(26), pp. 27168-27179. https://doi.org/10.1007/s11356-019-05924-2

33. Nguyen, T. and Le, Q. 2020. 'Impact of globalization on CO_2 emissions in Vietnam: An autoregressive distributed lag approach', *Decision Science Letters*, 9(2), pp. 257-270. https://doi.org/10.5267/j.dsl.2019.10.001

34. Odhiambo, N. M. 2016. 'Coal consumption and economic growth in South Africa: An empirical investigation', *Energy & Environment*, 27(2), pp. 215-226. https://doi.org/10.1177/0958305X15627535

35. Odugbesan, J. A. and Adebayo, T. S. 2020. 'The symmetrical and asymmetrical effects of foreign direct investment and financial development on carbon emission: evidence from Nigeria', *SN Applied Sciences*, 2(12), pp. 1-15. https://doi.org/10.21203/rs.3.rs-164276/v1

36. Onyibor, K. and Akinsola, G. D. and Adebayo, T. S. 2020. The impact of major macroeconomic variables on foreign direct investment in Nigeria: evidence from a wavelet coherence technique', *SN Business & Economics*, 1(1), pp. 1-24. https://doi.org/10.1007/s43546-020-00018-5

37. Ozatac, N., Gokmenoglu, K. K. and Taspinar, N. 2017. 'Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: the case of Turkey', *Environmental Science and Pollution Research*, 24(20), pp. 16690-16701. https://doi.org/10.1007/s11356-017-9317-6

38. Pata, U. K. 2018a. 'The effect of urbanization and industrialization on carbon emissions in Turkey: evidence from ARDL bounds testing procedure', *Environmental Science and Pollution Research*, 25(8), pp. 7740-7747. https://doi.org/10.1007/s11356-017-1088-6

39. Pata, U. K. 2018b. 'The influence of coal and non carbohydrate energy consumption on CO_2 emissions: revisiting the environmental Kuznets curve hypothesis for Turkey', *Energy*, 160, pp. 1115-1123. https://doi.org/10.1016/j.energy.2018.07.095

40. Pata, U. K. 2018. 'Renewable energy consumption, urbanization, financial development, income and CO_2 emissions in Turkey: testing EKC hypothesis with structural breaks', *Journal of Cleaner Production*, 187, pp. 770-779. https://doi.org/10.1016/j.jclepro.2018.03.236

41. Raza, M. Y. and Shah, M. T. S. 2019. 'Analysis of coal-related energy consumption in Pakistan: an alternative energy resource to fuel economic development', *Environment, Development and Sustainability*, pp. 1-22. https://doi.org/10.1007/s10668-019-00468-4

42. Saidi K, Mbarek M. B. 2017. 'The impact of income, trade, urbanization, and financial development on CO_2 emissions in 19 emerging economies', *Environmental Science and Pollution Research*, 24(14), pp. 12748–12757. https://doi.org/10.1007/s11356-016-6303-3

43. Sarkodie, S. A. and Adams, S. 2018. 'Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa', *Science of the total environment*, 643, pp. 1590-1601. https://doi.org/10.1016/j.scitotenv.2018.06.320

44. Shahbaz, M., Tiwari, A. K. and Nasir, M. 2013. 'The effects of financial development, economic growth, coal consumption and trade openness on CO_2 emissions in South Africa', *Energy Policy*, 61, pp. 1452-1459. https://doi.org/10.1016/j.enpol.2013.07.006

45. Stock, J. H. and Watson, M. W. 1993. 'A simple estimator of cointegrating vectors in higher order integrated systems', *Econometrica: Journal of the Econometric Society*, pp. 783-820. https://doi.org/10.2307/2951763

46. Udi, J., Bekun, F. V. and Adedoyin, F. F. 2020. 'Modeling the nexus between coal consumption, FDI inflow and economic expansion: does industrialization matter in South Africa', *Environmental Science and Pollution Research*, pp. 1-12. https://doi.org/10.1007/s11356-020-07691- x

47. Umar M, Ji X, Kirikkale DR, Xu Q 2020. 'COP21 Roadmap: Do innovation, financial development, and transportation infrastructure matter for environmental sustainability in China', *Journal of Environmental Management*, 271, pp. 111026. https://doi.org/10.1016/j.jenvman.2020.111026

48. Belay Kassa, A. 2019. 'Current Status, Future Potential and Barriers for Renewable Energy Development in Ethiopia (Short Communication)', *Iranian (Iranica) Journal of Energy and Environment*, 10(4), pp. 269-274. https://doi.org/10.5829/ijee.2019.10.04.07

49. Mirzaei Darian, M., Ghorreshi, A., Hajatzadeh, M. 2020. 'Evaluation of Photovoltaic System Performance: A Case Study in East Azerbaijan, Iran', *Iranian (Iranica) Journal of Energy & Environment*, 11(1), pp. 75-78. https://doi.org/10.5829/ijee.2020.11.01.12

50. Tamoor, M., Sagir, M., Abbas, G., Ans Zaka, M., ZakaUllah, P. 2020. 'Design, Construction and Production of Small Scale Energy Generation Plant using Indigenous Resources', *Iranian (Iranica) Journal of Energy & Environment*, 11(4), pp. 308-319. https://doi.org/10.5829/ijee.2020.11.04.09

51. Mohammad Alinezhad, F. 2019. 'Passive Cooling in Shavadoon of Traditional Buildings of Dezful City: Cooling Through Renewable Energy Sources', *Iranian (Iranica) Journal of Energy and Environment*, 10(2), pp. 115-120. https://doi.org/10.5829/ijee.2019.10.02

52. Word Development Indicators, WDI, 2020. https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions

53. International Monetary Fund, 2019. https://data.imf.org/?sk=1C28EBFB-62B3-4B0C-AED3-048EEEBB684F

54. Gygli, S., Haelg, F., Potrafke, N. and Sturm, J.E., 2019. 'The KOF globalisation index—revisited'. *The Review of International Organizations*, 14(3), pp.543-574. https://doi.org/10.1007/s11558-019-09344-2

Persian Abstract

چکیده

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 مجموعه داده های ۱۹۸۰ تا ۲۰۱۷ است. بر اساس دامنه این مقاله ، ARDL Bounds، Bavaria و ترکیب Hank، FMOLS، از آزمون‌های علیت و دامنه فرکانس از آزمون علیت استفاده می‌شود. آزمون‌های ادغام Bayer و Hank و محدودیت‌های ARDL (با تقریب‌های Kripfganz و Schneider) یکپارچگی مشترک بین این مجموعه را نشان می‌دهد. یافته‌های مبتنی بر برآوردهای کوتاه مدت و بلند مدت ARDL نشان می‌دهد که توسعه اقتصادی باعث حفظ محیط زیست می‌شود، در حالی که رشد اقتصادی و مصرف ذغال سنگ تخریب محیط زیست را افزایش می‌دهد. نتایج آزمون علیت حوزه فرکانس نشان داد که مصرف ذغال سنگ و توسعه مالی به طور قابل توجهی ثبات محیط را در فرکانس های مختلف تعیین می‌کنند.