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RESEARCH ARTICLE

Carbon emission effect of renewable energy utilization, fiscal development, and foreign direct investment in South Africa

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Abstract

In recent times, the persistent global environmental challenges have paved the way for the underpinning of climate change within the perspective of financial performance. Given this motivation, the current study further examines the interaction of foreign direct investment, fiscal development, renewable energy usage, economic growth, and CO_2 outrush of South Africa (1970 to 2014). The unit root test of Zivot-Andrews and augmented Dickey-Fuller (ADF), vector autoregressive (VAR), and Pesaran ARDL (autoregressive distributed lag bounds) approach were employed in the data analysis. The existence of a statistically significant correlation among the series was detected by the Johansen multivariate cointegration in long term and subsequently by the long run coefficient of the vector error correction model test result. Furthermore, in the long run, significant positive correlation existed among renewable energy, GDP (economic growth), development in finance (FD), and CO_2 outrush. While in the short run, GDP and development in finance have a statistically positive correlation with outrush of CO_2; renewable energy consumption exerts a negative relationship on CO_2 in the short run. The Granger causality results show overall causality among the series; proof of bidirectional stimulus running from renewable energy to economic growth; foreign direct investment to trade; and also one causality direction running among the other variables. The policy twist is that the implementation of energy efficiency programs currently pursued by the South African government to enhance renewable energy consumption should be facilitated with more determination. In addition, the government and policymakers should thrive to align these energy efficiency programs with other macroeconomic and financial variables such as foreign direct investment (FDI), fiscal development, and trade openness to achieve minimum CO_2 outrush level in South Africa, thus yielding environmental sustainability.

Keywords Carbon emissions · Foreign direct investment, Fiscal development, Renewable energy · South Africa

Introduction

Government across the globe entrenched goals such as to enhance the volume of development and growth of their country economically. The government constructs different policies which are geared towards increasing the level of investment to actualize some of these goals, as it is believed that adequate financial development enhances economic growth. Financial institutions through the provision of credit facilities to the public in general with pliant policies increase investment; thus, they work as an accessory of government. The financial crisis is seen as a main economic issue. In this present age, pollution and energy usage are presumed to be among the vital disquiet environmentally; hence, a further examination of the correlation among foreign direct investment, fiscal development, energy consumption, and outrush of CO_2 is paramount. Fiscal development and FDI (foreign direct investment) play an enormous role in goods and service manufacturing. FDI

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and fiscal development (FD) is imperative for an economy as it offers investment and capital opportunities. Furthermore, in addition to capital and labor, energy is an essential factor of production. According to Mohammed et al. (2019), financial development enhances the consumption of energy and hence accelerating growth in the economy. In addition, FDI through productivity gains and transmission of technology promotes economic growth as it provides alluring investment opportunities which offer direct funding capital (Lee 2013; Sinha and Sen 2016). Unavoidably, the deliberation about outrush of CO_2 reduction has continued to be a major concern, the bane of sustainable development and a global hindrance towards achieving a greener environment (Alola and Alola 2018; Alola 2019a, b; Bekun et al. 2019; Saint Akadiri et al. 2019). However, one of the first things that should be done in the construction of a more sustainable and greener environment is the reduction of the emissions of CO_2.

There is numerous literature on the impact of CO_2 emissions on the ecosystem's health and the factors played by macroeconomic and microeconomic factors in their determination. According to the study of Auffhammer and Carson (2008) on the emissions of CO_2 in China on a provincial level, emissions of CO_2 have increased drastically over the past 5 years. CO_2 emissions affect human health in addition to the damage to the ecosystem (Chen et al. 2017). Outrush of carbon is concurrently increased by enhanced production rate and growth in the economy. Thus, the use of energy, fiscal development, and FDI contribute to degradation in the environment through carbon outrush by increasing the level of production and growth of the economy. The degree of the correlation between outrush of CO_2 and economic growth in a nation is determined by numerous factors; however, in theory, fiscal development, openness in trade, usage of energy, and FDI are the major ones that are discussed (Al-Mulali et al. 2015; Shahbaz et al. 2019; Raheem et al. 2020). Recent empirical works examining the linkages between financial development and outrush of CO_2 discovered that there is a changing (dynamic) correlation between CO_2 outrush and fiscal development (Khan et al. 2021; Pata 2018). According to the study of Pata (2018), there seems to be an improvement in urbanization when there is financial development in a nation, and consequently more consumption of energy.

Additionally, CO_2 emissions increase directly or indirectly in a country with increase financial development and trade because countries improve in their export with higher financial development and R&D (research and development) (Balsalobre et al. 2015; Farhani and Ozturk 2015; Huang and Zhao 2018). It is essential for nations to have a formal and congenital plan for energy, fiscal development, urbanization, and FDI, to assimilate the outrush effects. There is an introduction of new debates and technologies such as climate and energy finance that have emerged resulting from the notion of fiscal development and its impact on the climate. They provide explanations on the reasons why a nation's finance should be connected to its energy policies and strategies (La Rovere et al. 2018).

This research assessed the correlation among FDI, clean energy utilization, CO_2, and fiscal development on outrush of carbon in South Africa for a period of 44 years (1970 to 2014) and associating causality association among outrush of CO_2, fiscal development, FDI, and growth in the economy. Five major hypotheses of Granger causality were tested; first, to determine the direction and how FDI and GDP contribute to each other. Secondly, investigation of causality direction between GDP and outrush of CO_2 using Granger causality test. Thirdly, to examine the causality relations between FDI and outrush of CO_2. Fourthly, the causality association between financial development and GDP was investigated to ascertain in which direction do financial development contributes to GDP. Finally, to examine the causality link between outrush of CO_2 and fiscal development, which in literature has been rarely considered.

The case of South Africa is considered in this study because on the one hand, the country is one of the very few vast and fast-moving emerging economies. In addition, the peculiarity of the features of its economy and as a major actor in coal energy market is distinct from other African emerging economies. For instance, according to Enerdata (2019), South Africa is the 7th largest emitter of carbon in the world and in Africa, South Africa is the largest carbon emitter making about 45% of the total continent. In 2019, their GDP in absolute value is at $351.4 billion with an estimated GDP growth rate of 0.20% (WDI, 2020). Similarly, according to the 2019 report of UNCTAD, in after Nigeria, South Africa is the second-largest economy with FDI inflow in Africa, and they are the leader of the inflow of FDI to the southern region. "In 2018, the FDI inflows to the southern region experienced an increase by 13% to $32 billion out of which South Africa received the largest share of about $5.3 billion, a sharp increase compared to 2017." Thus, these unique features informed the motivation to investigate the correlation among FDI, clean energy utilization, CO_2, and fiscal development on outrush of carbon of South of Africa.

In novelty, this study is the first study aimed at finding stimulus (causality) relationships among fiscal developments, FDI, and outrush of CO_2 in South Africa. In South Africa, the impact of energy use (consumption) on economic growth and/or energy consumption on CO_2 emission have been examined (see Shahbaz et al. 2013; Kohler 2013; Menyah and Wolde-Rufael 2010) but no study has examined the linkages or correlation among FDI, renewable energy consumption FD (fiscal development), and outrush of CO_2 in South Africa, thus the need to include this idea into research. Furthermore, FDI and fiscal development are very vital to analyze because South Africa as an emerging economy is the number one emitter of carbon in Africa continents because of its heavy reliance on

energy production based on coal. The vector autoregressive method (VAR) is selected because it deviates from the norm of estimation techniques such as ARDL and least squares regression methods employed by previous empirical work. Examination of the impacts of fiscal development and FDI on the CO_2 outrush in the present state of the art is an unconventional contribution to South Africa's energy and environment literature and sub-Saharan Africa as a whole. The deductions from this research will be insightful for policymakers in South Africa as they are presently involved in energy efficiency policies and strategies that are geared towards the reduction of CO_2 outrush. The findings will also be helpful to other Sub-Saharan Africa countries that are yet to put in place a proper and well-established energy plan to accommodate the pressure of financial development and FDI growth.

The arrangement of the study's other sections is as follows: an overview of the extant and related studies is highlighted in section "Review of related literature" while section "Data representation and methodology" presents the data and the empirical methods employed. In section "Empirical results and discussion," the results of the estimations are discussed while section "Concluding remark and policy" concludes by suggesting policy implications and the direction for further study.

Review of related literature

The association among FDI, energy usage, fiscal development, and outrush of CO_2 is reviewed in this section. Theoretically, the association between FDI and economic expansion could be linked to the prior model of neo-classical growth. FDI can promote economic growth according to the model by accelerating the capital stock. Also, according to the new growth model, both long-run and short-run technology changes associated with FDI will result in economic growth. Numerous studies according to the orthodox theories are in agreement with the initial idea that assumed that there are positive impacts of FDI on growth in the economy. Also, evidence of the positive impact of exports and FDI on economic growth was provided by Makki and Somwaru (2004) article who examined the impact using a sample of 66 developing nations. The Granger causality between FDI and GDP was undertaken by Hansen and Rand (2006) employing heterogeneous panel data, and they found that the impact of FDI on economic expansion in the long run is positive. Evidence of the unidirectional effect of FDI on GDP was discovered by the study of Hsiao and Hsiao (2006), both directly and indirectly using the exports of chosen samples of East and Southeast Asian economies.

According to the study of FDI impact on the economic expansion in Nigeria by Ekwueme (2018), the study discovered that there is a positive impact of foreign direct investment on GDP, and therefore recommended formulation of policies by the government which is geared towards the increase of FDI inflow in the nation. A positive correlation in the long run between foreign direct investment (FDI) and GDP was proven by Nosheen (2013) in his work on the FDI impact on the economic growth of Pakistan. Evidence of the positive effect of FDI on economic growth was found by Iamsiraroj and Ulubaşoğlu (2015) with a case of selected 140 countries. However, a significant positive impact of foreign direct investment on GDP was discovered by Carkovic and Levine (2005) in nations that are developing. Also, there is no Granger causal relationship between economic expansion and FDI in the short run was discovered for Tunisia by Belloumi (2014). According to Herzer and Klasen (2008), there could be a negative correlation between FDI and economic expansion.

Additionally, a reverse relationship is postulated by the growth-led FDI hypothesis that economic growth can lead to the creation of new activities in the economy and new markets which will, in turn, leads to the attraction of FDI concentration. Thus, the causality association between economic expansion and FDI is not an essentially one-way direction. Each of them is not excluded by these two directions. A two-way direction (bidirectional) causality linkage between foreign direct investment and economic expansion was discovered by Basu et al. (2003) in a sample of 23 developing nations.

Carbon effect of renewable energy

Kirikkaleli and Adebayo (2020) found that global renewable energy usage has a significant positive impact on environmental sustainability in the long run, which implies that an increase in the usage of clean energy will enhance the quality of the environment and vice versa. Contrarily GDP (economic growth) accelerates global emission of carbon according to their findings. Ji et al. (2020) found that renewable energy and eco-innovations mitigate emissions of carbon, while GDP enhances carbon emissions in their study of the importance of fiscal decentralization in promoting a sustainable environment of Switzerland, Spain, Germany, Canada, Belgium, Austria, and Australia using the non-linear and linear methods. In another dimension, Kirikkaleli et al. (2020) in their study of the role of globalization on the ecological footprint in Turkey while controlling energy consumption, economic growth, and trade openness discovered that GDP has a negative impact on the ecological footprint in both the long run and short run while in the short run, trade openness mitigates ecological footprint. Furthermore, while Saint Akadiri et al. (2020) identified the carbon effect of electricity consumption and economic expansion for the case of Turkey, Ike et al. (2020) also illustrated the environmental quality effect of renewable energy in the panel of G-7 economies.

Furthermore, Zhang et al. (2021) utilized the wavelet coherence and gradual shift causality tests, dynamic ordinary

least square (DOLS), fully modified OLS (FMOLS), and auto-regressive distribution lag (ARDL) and investigated the long-run and causal impact of economic growth, financial development, urbanization, and gross capital formation on Malaysia's CO_2 emissions based on the STIRPAT framework. They discovered that there are long-run linkages between the variables and that urbanization, gross capital formation, and economic growth have a positive significant influence on emissions of CO_2. A substantial dependency among urbanization, gross capital formation, economic growth, and emissions of CO_2 has revealed their wavelet coherence test results. In addition, Ahmad et al. (2020) examined the impact of renewable energy on the degradation of the environment of North-western provinces of China from 1995 to 2014 utilizing the nonlinear (ARDL) autoregressive distributed lag bound testing approach. They found that positive shock from renewable energy influences the emissions of carbon in the North-western provinces of China adversely. Additionally, they discovered that in the long run, emissions of carbon increase with a reduction in the consumption of renewable energy. Also, they found that positive shocks from GDP and non-renewable energy increase the degradation of the environment in both the long run and short run.

According to Cowan et al. (2014), there is a causal linkage between CO_2 emissions, electricity consumption, and economic growth in the panel of BRICS countries. The BRICS countries studied are South Africa, Russia, Brazil, China, and India. In India and China, no proof of Granger causality between CO_2 outrush and GDP. They discovered a one-way causal direction running from CO_2 outrush in South Africa and Russia; in Brazil, a converse correlation between CO_2 outrush and GDP was found. Liu (2006) found the existence of a causality association between economic expansion and outrush of CO_2 for Norway. Also, the causality running from economic growth and emissions of CO_2 is bidirectional according to Kim et al. (2010). The non-existence of causal correlation in the short run between economic growth and CO_2 emissions was detected by Saboori et al. (2012) work. On the other hand, he found one-way directional causality in the long run running from economic growth to CO_2 outrush.

According to Leitão (2015), in the long run, energy use and economic growth cause CO_2 emissions; emissions of CO_2 and economic growth cause consumption of energy. An identical outcome was discovered by Wang et al. (2011). The existence of bi-directional stimulus (causality) between GDP (economic growth) and outrush of CO_2 and uni-directional stimulus (causality) from financial development to carbon emission was discovered by Shahbaz et al. (2013). The same relationship was found by Omri (2013) for nations in the MENA region. Bloch et al. (2012) from the point of view of supply-side substantiate the proof of uni-directional causal linkages between coal usage and output in both the long run and short run in his study of the linkages between China's coal consumption and income. Under the demand point of view analysis, they also found in both the long run and short run existence of a uni-directional causal link from income to coal usage. An enormous positive correlation between CO_2 emissions and economic growth in Portugal was found by Leitão (2014). For China, Japan, and the USA, the same finding was proved by Azam et al. (2016), while for India's situation, a significantly negative linkage was found.

Carbon effect of fiscal development and FDI

The study of Khan et al. (2021) investigates the impact of fiscal decentralization on the emission of carbon of 7 (seven) OCED countries starting from 1990 to 2018. They found that fiscal decentralization through various avenues such as human capital and institution indirectly affects the emissions of carbon in addition to its direct impact. Their findings reveal that environmental quality is improved by fiscal decentralization. Similarly, Khan and Ozturk (2020) applying the panel FMOLS (fully modified ordinary least squares) on the data from 17 Asian countries from 1980 to 2014 in their study of causal linkages between environmental pollution by CO_2 emissions and net FDI (foreign direct investment) discovered that environmental pollution increases with increase in inward foreign direct investment and vice versa. Their study supports the pollution Haven hypothesis. Also, bidirectional causality between FDI and carbon emission was revealed by their panel causality results.

Ji et al. (2020) in their study of the importance of fiscal decentralization in promoting a sustainable environment of Switzerland, Spain, Germany, Canada, Belgium, Austria, and Australia using the non-linear and linear methods discovered that fiscal denaturalization by reducing emissions of carbon enhances the environment of these nations. Additionally, they found that renewable energy and eco-innovations mitigate emissions of carbon, while GDP enhances carbon emissions. Kirikkaleli and Adebayo (2020) applying the Bayer and Hanck cointegration, dynamic OLS (DOLS), fully modified OLS (FMOLS), and canonical cointegrating regression (CCR) found that global renewable energy usage and global financial development have a significant positive impact on environmental sustainability in the long run; contrarily, GDP (economic growth) accelerates global emission of carbon. In addition, Baloch et al. (2021) in their study of the linkages among financial development, energy innovation, and environmental quality of OCED (Organization for Economic Cooperation and Development) nations from 1990 to 2017 employing the PMG/ARDL (pooled mean group autoregressive distributed lag) discovered that financial development enhances the quality of the environment. Energy innovations were also found to enhance environmental quality.

In their study, Jian et al (2019) employing VECM techniques assessed the impact of economic growth, financial

Table 1 Variable summary table

Variables	Proxy	Symbols
Fiscal development	Domestic credit to private (% of GDP)	FD
C02 outrush	Metric per tons per capital	CO_2
Foreign direct investment	FDI net inflows (% of GDP)	FDI
Economic growth	GDP (constant 2010 US $)	GDP
Trade	Trade (percent of GDP)	T
Renewable energy utilization	Renewable energy utilization (share of primary energy consumption)	REC

development, and energy use on China's emissions of CO_2. The empirical results found a cointegrating relationship among the energy use, economic growth, and financial development. Also, the result shows that the effect of energy use and financial development on CO_2 outrush is positively significant. Furthermore, there is one-directional Granger causal nexus of financial development and energy use. Siddique et al. (2020) discovered that energy use and financial development by increasing CO_2 emissions are polluting the environment. A bi-directional causal linkage in both the long run and short run running from CO_2 emissions to energy use was uncovered by their empirical results. The causality link between financial development and CO_2 emissions was further discovered by this study, while there is non-existent causality in the short run. They further buttress that environment-related problem such as CO_2 emissions is created by extensive use of power resources.

Furthermore, Abidin et al. (2015) investigated for selected ASEAN countries the linkages between selected ASEAN countries FDI, energy utilization, T (trade), and FD. The empirical result found the presence of a significant relationship between the entire explanatory variables in the long run after employing appropriate tests of stationarity. In the long run, during the period under study, bi-directional causal correlation was discovered between trade and energy use; trade and FDI; trade and financial development; and energy use and financial development. While in the short run, uni-directional causal links running from energy use to financial development; foreign direct investment and energy use; and energy use to trade were revealed by the Granger causality test results. Moreover, according to Ozturk and Acaravci (2013), there is a long-run nexus of energy utilization per person, financial development, carbon emissions per capita, real per capita, income, and the square of per capita real income, openness. Also, the result indicates that in the long run, the impact of financial development on carbon emissions per capita is not statistically significant. Consumption of energy is explained by enormous literature as a major factor that increases pollution and economic growth. Thus, creativity concerning technology and cogent energy is highly needed.

Tamazian and Bhaskara Rao (2010) discovered that to achieve a better environment, financial developments are vital. Furthermore, according to the study, emissions of CO_2 are increased by trade. Also, Tamazian et al. (2009) found that emission of carbon dioxide is reduced by openness to trade, financial development, and financial liberalization in his study of the association existing among enhanced environment and financial development of the country under study starting from 1992 to 2004 (Brazil, Russia, India, and China). Financial development is suggested to be helpful in reduction of the China's emission rate by Jalil and Feridun (2011)'s research. Their study further suggested that the fundamental causes of emissions of CO_2 are trade and energy use and trade are the major causes of CO_2 emissions and the paper empirical result exposed environmental Kuznets curve (EKC).

In addition, Siddique (2017) employed ADF unit root test and ARDL bound methods. Existence of a long-run relationship among capital, CO_2 emissions, energy consumption, trade, economic growth, and financial development is indicated by the results of the ARDL bound test. The factors increasing the emission of carbon dioxide according to the empirical findings are energy consumption, financial development, economic growth, and trade. The result of the analysis revealed that economic growth can be actualized directly and indirectly using financial development and trade; the role played by financial development, economic growth, and trade is very essential and imperative. However, this result is inconclusive as there is a tendency or possibility of achieving a reduction in energy use using financial development, as cogent energy might be increased by improvement or increase in financial development.

Xiong et al. (2017) using a panel dataset from China assessed the regional differences FMD's effect on emissions

Table 2 Summary of descriptive statistics

Statistics	$LNCO_2$	LNFD	LNFDI	LNGDP	LNT	LNREC
Mean	2.147	4.53	20.25	26.18	3.94	2.84
Median	2.15	4.62	20.36	26.13	3.94	2.83
Maximum	2.30	5.07	23.01	26.74	4.28	2.95
Minimum	1.91	3.98	15.02	25.64	3.62	2.74
Standard deviation	0.10	0.36	2.05	0.30	0.14	0.05

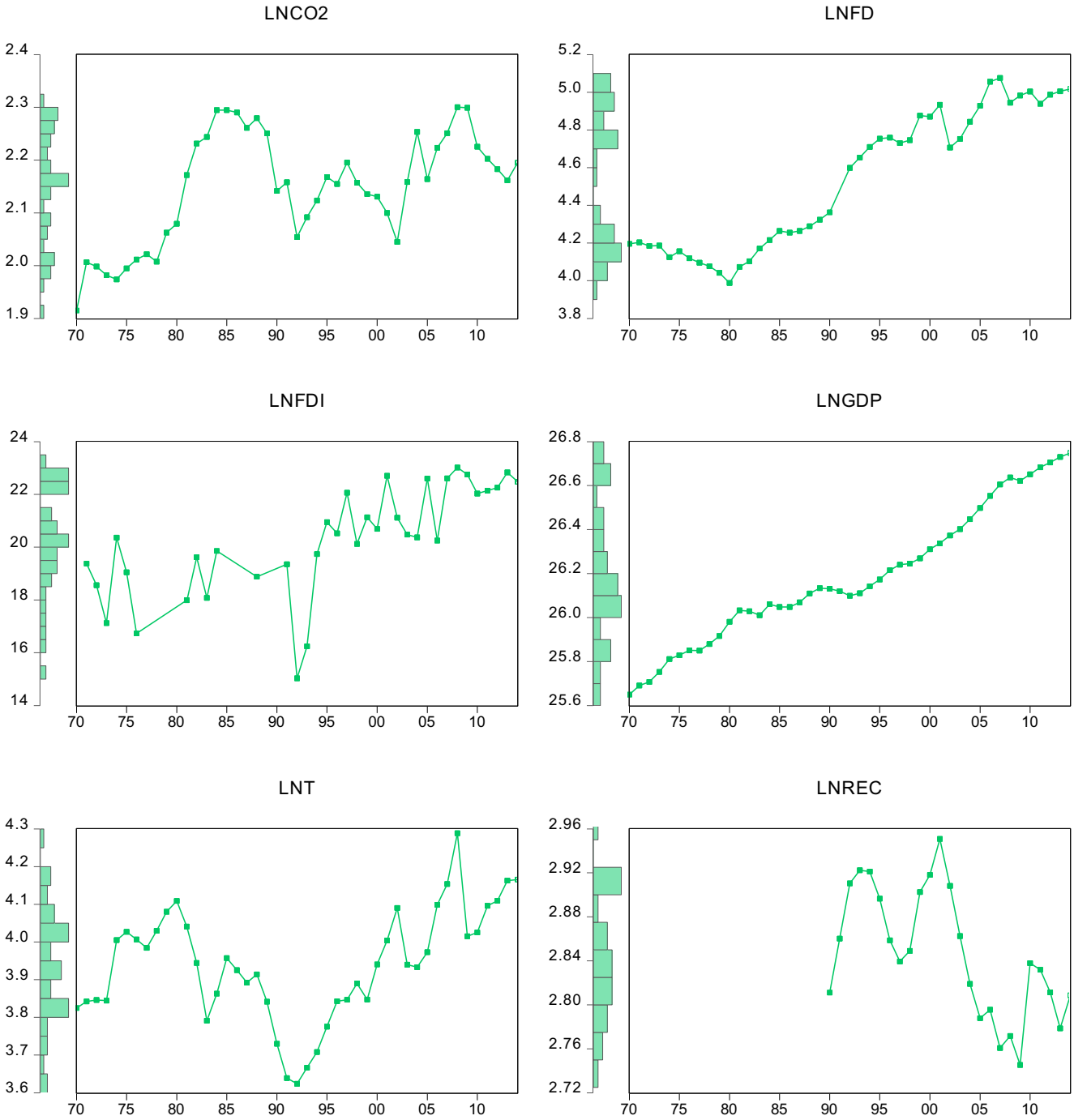

Fig. 1 The FDI and GDP exhibit an upward trend, while CO_2, REC, and T (trade exhibit), a fluctuating movement of an upward and downward trend

considering differences in various regions. The study opined that emissions could be reduced by financial development in China's developed cities thus leading to the abatement of environmental hazards especially in the less developed regions of China. This is because it is stated that bringing of improvements in the environments by financial development can be hindered by institutional constraints and market forces. These five variables (financial development, FDI, energy consumption, economic growth, and CO_2 emissions) have rarely been researched together despite the existence of numerous literature on "FDI-Growth," financial development-Growth," or "CO_2 emissions-Growth" nexuses. Additionally, as far as we know, there is no empirical literature encompassing all the variables used in this study; also, the case of South Africa is unique in this study. Thus, research on the correlation and the Granger causal linkages among financial development, FDI, energy consumption, and economic growth in South Africa is paramount and highly needed, and this is the study's major.

Table 3 Results of correlation coefficient matrix

Correlation	$LNCO_2$	LNFD	LNFDI	LNGDP	LNT	LNREC
$LNCO_2$	1.000					
LNFD	0.6520*	1.000				
LNFDI	0.5677*	0.7358*	1.000			
LNGDP	0.6334*	0.8706*	0.7038*	1.000		
LNT	0.5549*	0.8107*	0.7762*	0.8964*	1.000	
LNREC	−0.8236*	−0.6823*	−0.5494*	−0.7714*	−0.6647*	1.000

Note: "*" means statistical rejection at 0.01% significance level

Data representation and methodology

Data

A time series and yearly dataset from the database of the World Bank Development Indicator from 1970 to 2014 was collected and used for the analysis of this study. The variables comprise foreign direct investment (FDI), FD (fiscal development), trade (T), REC (renewable energy utilization), GDP (economic expansion), and carbon outrush (CO_2). The descriptive statistics and correlation matrix (see Tables 1 and 2) and the series plot which is depicted in Fig. 1 are all presented.

The descriptive statistics of carbon emissions, REC (renewable energy), FD (fiscal development), FDI, T (trade), and economic expansion are shown in Table 1 above. The mean of FD (4.53) is low in contrast to other developed and developing countries. Over time the variation in FD level is much as shown by the maximum and the minimum value which has a value of 5.07 and 3.98 respectively. The mean of FDI (20.25) is low, which implies that for the period under study, the FDI of South Africa on the average is relatively small compared to other African countries. The maximum and the minimum values of FDI are 23.01 and 15.02. A small variability across time is suggested by the mean, maximum, and standard deviation of carbon emissions, trade, GDP, and REC. The correlations among the variables which are consistent with the established economic theory are exhibited in the table of the correlation matrix result above (Table 3), for example, positive correlation between GDP and CO_2 outrush. Also, it is expected that energy use (renewable) should be negatively correlated with CO_2 outrush.

Model specification

This study assessed the relationship among fiscal development, FDI, renewable energy use, economic expansion, and outrush of CO_2 in South Africa. The dependent variable is CO_2 emissions while the independent variables are financial development, FDI, renewable energy consumption, and economic growth. These variables in literature was used by Siddique 2017, Siddique et al. 2020, and Mahmood et al. 2019.

$$CO_2 = f\ (\mathrm{FD}, \mathrm{FDI}, \mathrm{REC}, \mathrm{GDP}, \mathrm{T}) \tag{1}$$

With natural logarithm the functional form of our model is stated below:

$$\mathrm{LNCO_2}t = q_0 + q_1\mathrm{LNFD}t + q_2\mathrm{LNFDI}t + q_3\mathrm{LNREC}t + q_4\mathrm{LNGDP} + q_5\mathrm{LNT}t + t \tag{2}$$

Estimation techniques

Different test methods and tests were employed to scrutinize the correlation among FDI, fiscal development, trade, renewable energy use, economic growth, and CO_2 outrush. The test of the unit root (see Dickey and Fuller 1981) was first performed to ascertain the stationarity of the variables since it is a

Table 4 ADF unit root results

	$LNCO_2$	LNFD	LNFDI	LNGDP	LNT	LNREC
Level	−2.2358	−2.2766	−2.2766	−1.7241	−1.8334	−3.1072
F First difference	−6.5264***	−4.5157***	−3.7733***	−4.6511***	−5.9600***	−3.6995***

"***" means rejection of null hypothesis at 5% level of significance. SIC was used to determine the optimal lag length of ADF

Table 5 Result of Zivot-Andrews unit root test

	Level	First Difference	
			Order of integration
$LNCO_2$	−3.7414	−7.3184**	I (1)
Break year	1984	2002	
LNFD	−2.8161	−7.5376**	I (1)
Break year	1990	2002	
LNT	−4.4677	−64594**	I (1)
Break year	1989	1992	
LNREC	−5.1061	−7.3043	
Break year	2002	2009	

"**" means rejection of null hypothesis at 5% level of significance. The optimal lag length was determined using SIC

time series model. Zivot-Andrews unit root test and ADF2 test was adopted for the unit root test. The SIC (Schwartz selection criteria) was chosen as ascertaining the optimal number of lags in the ADF test. Also to counter autocorrelation, lagged difference was included in the ADF test. This paper made use of the Johansen cointegration test together with a vector error correction model (VECM) analysis to determine the cointegration of time series variables. Afterward, the VECM Granger causality test by Engle and Granger (1987) was applied to determine the causality among FD (fiscal development), REC (renewable energy consumption), and CO_2 outrush. According to Granger (1988), the pertinent technique to appraised the causal link among series if they are 1 (1) series is the VECM. Also, 1 The step-by-step method of the unit root structural breaks is presented by Zivot and Andrews (2002). There is statistical evidence of long-run cointegration relationship among the series such that the employed VECM Granger causality method performed on Eq. 2. However, the step-by-step procedure for the VECM Granger causality is not provided here for lack of space.

Empirical results and discussion

The stationarity of time series data is expected to steer clear of spurious regression and for soundness of result to hold. In addition to the test of ADF unit root, Zivot-Andrews was employed to check the data for stationarity to accommodate structural breaks as also mentioned by Bora et al. (2020) resulting from the change in data utilization of the accustomed test of unit root methods (for example, ADF and PP unit root test) may be biased especially in the rejection of the null hypothesis. Table 4 shows the ADF unit root result while Table 5 shows the test results of the Zivot-Andrews unit root test which was done utilizing both trend and constant terms. Both Table 4 and Table 5 below show that at levels all the variables have a unit root but after the first difference, it was stationary. This implies that the entire variables being studied are integrated order of 1(1); thus, the Johansen cointegration test is performed.

This paper made use of the Johansen cointegration test together to discover the cointegration of time series variables understudy with a vector error correction model (VECM) analysis. The optimal length obtained as seen in Table 6 above is 1 and Table 7 below shows the outcome of the Johansen cointegration test.

Table 7 above suggests the rejection of the null hypothesis of no cointegration among the examined at 5% significance level. The result of trace statistics indicates that at 5% significance level that there is four cointegrating equation. While at 0.05% significance level, two cointegrating equations are shown by the Max-Eigen statistics. Thus, a cointegration exists in the long run among the variables being studied. This is accordant with Leitão (2015) and Siddique et al. (2020). We made use of the vector error correction model (VECM) because the variables are related in the long run. Granger causality test was also employed to ascertain the causality between the variables under study. VECM Granger causality test by Engle and Granger (1987) was applied to determine the causality among foreign direct investments, fiscal development, renewable energy usage, and CO_2 outrush. According to Granger (1988), the pertinent technique to appraised the causal link among series if they are 1 (1) series is the VECM (vector error correction method).

From Table 8 above, it can be seen that FD, GDP, and REC are positively related to CO_2 outrush in the long run, though the impact of FD is insignificant. which implies that a percentage increase in GDP will increase emissions of CO_2 by 0.30%. This in line with the following work: Ekwueme and Zoaka (2020), and Abidin et al. (2015). Ekwueme and Zoaka (2020) found that GDP (economic growth) has a positive impact on the carbon effusion of MENA countries. Abidin et al. (2015) found that for the chosen ASEAN countries that their FD, foreign direct investment, usage of energy, and Carbon outrush are related in the long run.

Additionally, Table 9 below shows the estimated parameters of the VECM. The test result revealed that at a 0.05% significance level a positive and statistically significant error correction term (ECM). This implies that the digression from the equilibrium of South Africa's emission of carbon will

Table 6 VAR lag selection order

Lag	LogL	LR	FPE	AIC	SC	HQ
0	112.80	NA	1.54	−10.17	−9.87	−10.10
1	210.58	130.36*	5.03	−16.05	−13.96	−15.60
2	271.68	46.54	1.38*	−18.44*	−14.56*	−17.60*

"*" is the 1% statistical significant level

Table 7 Results of Johansen cointegration test

Number of cointegrating equation	Trace statistics	5% critical value	Probability value	Maximum Eigen statistics	5% critical value	Probability value
None*	161.1466	95.7536	0.0000	64.9481	40.0775	0.0000
At most 1*	96.1984	69.8188	0.0001	38.9501	33.8768	0.0114
At most 2*	57.2432	47.8561	0.0051	25.9051	27.5843	0.0807
At most 3*	31.3431	29.7970	0.0329	18.2345	21.1316	0.1213

Source: author's computation. The "*" is the 5% statistical significant level

adjust automatically and that exposure of the system to shock will converge in equilibrium in the long-run equilibrium for LNCO2 at a relatively low speed (which is 9%). The adjustment speed is very low considering South Africa too much dependency on coal-based energy usage. Additionally, the results reveal that LNFD (financial development) and LNGDP (economic growth) correlation with CO_2 outrush in the short run is positive and statistically significant. The implication of this is that increasing FD and GDP by 1% will amount to a 0.11% and 0.59% increase in the emission of carbon. Contrarily, LNREC and LNT (trade) have a negative statistical relationship with the emission of carbon in the short run, implying that increasing REC and T by 1% will lead to a 1.17% and 0.08 decrease in carbon emissions in the short run. This is in accordance with Mahmood et al. (2019), Diallo and Masih (2017), and Jian et al. (2019). No significant linkages between FDI and carbon emissions in the short run were revealed by our empirical analysis, and this is consistent with Abidin et al. (2015) who found a relationship that is insignificant between FDI and CO_2 outrush.

Figure 2 above suggests that the stability condition of the VECM is satisfied. The VECM application for the test of Granger causality was conducted to ascertain the causal association among the variables (see Table 10).

The block exogeneity Granger causality test results are presented in Table 10 above. The null hypothesis of no causal association between the variables was rejected; the implication of this is that there is a causal association between the variables running from independent to the dependent variable. There is causality running from trade, renewable energy to FDI (T, REC → FDI); from CO_2 outrush, fiscal development, trade, renewable energy to economic growth (CO_2, FD, T, →GDP); from CO_2 outrush fiscal development, FDI (foreign direct investment) to trade (CO_2, FD, FDI→), and (GDP →REC). Hence, we can conclude from the above results that there is bi-directional Granger causality from REC to GDP and from FDI to trade, while the rest are uni-directional causality.

Additional estimation techniques were employed to check the robustness of VECM estimation output in Tables 8 and 9. The autoregressive distributed lag model (ARDL) bound testing to cointegration formulated by Pesaran et al. (2001) was utilized in ascertaining the robustness of the VECM test results. This technique was adopted because of its dynamic applicability despite the nature of the integration of the series. It also has the advantage of carrying dual computation by first estimating the long-run and the short-run association between the variables and then examines the causal effect existing among the variables. The estimation output of the long-run and the short-run ARDL is presented in Table 11 below, while the ARDL bound test results to cointegration are presented in Table 12 below.

From Table 11 above, the output is similar to the output of the VECM output in Table 8 and Table 9 above. GDP has a

Table 8 Cointegrating equation of VEC model

Cointegrating equation	Coint EQL	STD errors	*t*-statistic
$LNCO_2(-1)$	1.000		
LNFD(−1)	0.4731	0.1069	0.4422
NFDI(−1)	−0.0546	0.0046	−11.6682
LNGDP(−1)	0.3079	0.0567	5.4261
LNT(−1)	−0.0554	0.0971	−0.5707
LNREC(−1)	1.5567	0.1090	14.27

Table 9 Estimation results of VECM

Variable	Coefficient	Std. errors	*t*-statistics
C	0.1248	0.0051	2.4418
ECM(−1)	0.0950	0.0355	2.6784
DLNFD(−1)	0.1137	0.0308	3.6856
DLNFDI(−1)	−0.0014	0.0014	−0.0043
DLNGDP(−1)	0.5998	0.1840	3.2583
DLNT(−1)	−0.0820	0.0346	−2.0362
DREC(−1)	−1.1792	0.0802	−2.2330
R-squared 0.785			
Adj *R*-squared 0.669			
Loglikehood 73.77			
AIC −6.26			
SIC −5.86			

Table 10 Results of block exogeneity Granger causality

Dependent variable	X^2 statistics (P-value)						
	Δ 2	Δ	Δ	Δ	Δ	Δ	Overall X^2
Δ 2	_	−0.93 (0.3223)	0.04 (0.8385)	1.74 (0.1871)	0.15 (0.6893)	1.05 (0.6893)	5.09 (0.4047)
Δ	0.18 (0.6621)	_	1.20 (0.2732)	0.11 (0.7352)	0.003 (0.953)	2.43 (0.1187)	4.27 (0.5103)
Δ	0.08 (0.7643)	2.30 (0.1293)	_	0.26 (0.6052)	3.46 (0.0625)***	4.81 (0.0283)**	9.27 (0.0984)
Δ	9.15 (0.0025)*	13.58 (0.0002)*	0.98 (0.3200)	_	5.60 (0.0179)*	4.98 (0.0255)**	36.64 (0.0000)*
Δ	6.22 (0.0126)*	16.42 (0.0001)*	4.07 (0.0436)**	3.46 (0.0627)	_	0.60(0.4371)	42.60 (0.0000)*
Δ	0.36 (0.5449)	0.94 (0.3303)	0.48 (0.6635)	2.99 (0.0833)***	0.08 (0.7649)	_	9.78 (0.0817)***

Note: "***," "**," and "*" represent null hypothesis was rejected at 10%, 5%, and 1% respectively

significant positive relationship with carbon emission in both the long run and the short run. This implies that 0.165 of carbon outrush in South Africa in both the long run and short run is caused by the process of growth in South Africa. REC (renewable energy) has a significant negative relationship with carbon emission in both the long run and the short run. This implies renewable energy will reduce the emission of carbon in South Africa substantially by 0.61% and 0.52% in both the long run and the short run respectively. The FD and FDI have an insignificant positive relationship with carbon emission in both the long run and the short run. The study further includes several diagnostic tests, and the findings revealed that the model does not suffer from serial correlation and there is no heteroscedasticity. Similarly, in Table 12 below, the ARDL bound test from the t-statistics rejected the null hypothesis of no cointegration at 1% and 2.5%. The error correction term (ECT) shows that the series converges quickly in the long run with an enormous adjustment speed of 86%. This suggests that disturbances in the short run could be corrected in the long run.

The fully modified ordinary least square (FMOLS) was also estimated. The result is presented in Table 13 below.

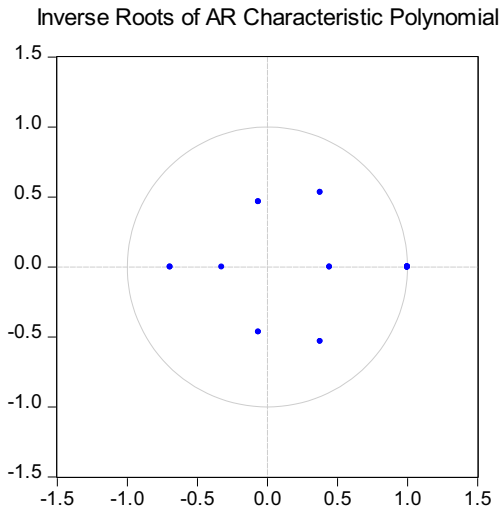

Fig. 2 Showing the stability condition

The FMOLS output is similar to the ARDL long-run result in Table 11; the result shows that GDP has a significant positive impact on carbon emission in the long run, while REC (renewable energy) has a significant negative impact on carbon emission in the long run.

Concluding remark and policy

In the outrush of carbon emissions in South Africa and the world large, patently the gravity of foreign direct investment (FDI), fiscal development (FD), and usage of energy can be

Table 11 Estimation output of the long-run and short-run ARDL (1, 0, 0, 0, 0, 0)

Variable	Coefficient	Standard error	t-statistic	P-value
Long run				
LNFD	0.0455	0.1636	0.2784	0.7840
LNFD1	0.0083	0.0091	0.9110	0.3750
LNGDP	0.1631*	0.0478	3.4103	0.0033
LNREC	−0.6113**	0.2158	−2.8314	0.0115
LNT	−0.2005	0.1361	−1.4737	0.1588
Short run				
LNFD	0.0393	0.1427	0.2757	0.7861
LNFD1	0.0072	0.0081	0.8901	0.3858
LNGDP	0.1409**	0.0509	2.7670	0.0132
LNREC	−0.5282**	0.2124	−2.4864	0.0236
LNT	−0.1733	0.1270	−1.3641	0.1903
ECT	−0.8641*	0.2139	−4.0381	0.0009
Diagnostic tests				
Tests	f-statistics	Probability value		
χ^2 white	1.3527	0.3567		
χ^2 serial	0.3303	0.7235		

"*" and "**"denote significant at 0.01% and 0.05% respectively. The number in parentheses is the standard error. Model: $LNCO_2 = f$ (LNFD, LNFDI, LNGDP, NREC, LNT)

Table 12 ARDL bound test results to cointegration

Test statistic	Value	Sig.	1(0)	1(1)
f-bound test	H_O: no level relationship			
f-statistics	2.8331	10%	1.81	2.93
k	5	5%	2.14	3.34
		2.5%	2.44	3.71
		1%	2.82	4.21
t-bound test	H_O: no level relationship			
t-statistic	−4.0381	10%	−1.61	−3.49
		5%	−1.95	−3.83
		2.5%	−2.24	−4.12
		1%	−2.58	−4.44

overlooked considering the hazardous consequences on global warming, economy, and human lives. Hence, this study scrutinized the correlation among foreign direct investment, renewable energy use, fiscal development (FD), and carbon emissions in South Africa. The study intends to assess the contribution of increment in foreign direct investment (FDI) level, development financially, and increased renewable energy usage to outrush of carbon in South Africa. A suitable test of stationarity was followed by the study and from the result at level, all the series under study have unit root and became stationary after the first difference. The existence of a statistically significant correlation in the long run among the variables under study was disclosed in the Johansen multivariate cointegration test. Furthermore, the result of the Johansen and the VECM cointegration analysis results reveal that fiscal development (FD), economic growth (GDP), renewable energy (REC), and outrush of CO_2 are related in the long run, and digression from the equilibrium of South Africa's outrush of carbon will adjust automatically, though at a small speed considering South Africa too much reliance on coal-based energy consumption. Development in finance and growth economically have a statistically positive relationship with outrush of CO_2 in the short run, while renewable energy use has a negative statistical linkage with the emission of carbon in both the long run and short run. The implication is that renewable energy is good for South Africa as it will help to reduce outrush of CO_2. The Granger causality results show overall causality among the series, however proof of bi-directional causal association running from renewable clean energy to economic expansion; FDI to trade, and one causality direction running among the other variables{ (trade, renewable energy → FDI), (CO_2, fiscal development, trade, renewable energy→GDP (economic growth)), (CO_2, fiscal development, FDI→trade), and (economic growth→renewable energy)}.

The policy implication of this study is that the implementation of energy efficiency programs currently pursued by the South African government to enhance renewable energy consumption should be facilitated with more determination since it is evident from our study that renewable energy usage promotes growth economically and reduces carbon emissions outrush in South Africa. Also, the government and policymakers should thrive to align these energy efficiency programs with other macroeconomic and financial variables such as foreign direct investment (FDI), fiscal development, and trade openness to achieve minimum CO_2 outrush level in South Africa, thus yielding environmental sustainability.

Table 13 FMOLS outcomes

Variable	Coefficient	*t*-statistics	Prob.
LNFD	0.0564	0.3793	0.7091
LNFD1	0.0087	0.8670	0.3980
LNGDP	0.1696	3.8190	0.0014*
LNREC	−0.6185	−3.1193	0.0062*
LNT	−0.2543	−2.0468	0.0565**

"*" and "**" denote significant at 0.05% and 0.10%

Author contribution Andrew Adewale ALOLA: Formal analysis, investigation, methodology, and corresponding.

Daberechı Chıkezıe EKWUEME: Writing—original draft, data curation, and analysis, review.

Joshua Dzankar ZOAKA: Conceptualization.

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Declarations

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