CO_2 EMISSIONS, ENERGY CONSUMPTION AND FINANCIAL DEVELOPMENT NEXUS IN SOUTH AFRICA

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Abstract - In this study, the nexus between carbon emissions, financial development and energy consumption is investigated for South Africa using annual time series data from 1990 to 2021. The mounting pressure on nations to reduce their carbon footprint has motivated this study. The findings of this study will contribute to establishing economic variables that South Africa can take advantage of in the journey to reducing carbon emissions. Two energy consumption proxies were used, namely, total energy consumption and electricity. Employing autoregressive distributed lag approach to cointegration and error correction (ECM)-based Granger causality test, the study found a unidirectional causal flow from carbon emissions to total energy consumption in the short run and the long run, and no causality was found when energy consumption was measured by electricity. The study also found a unidirectional causal flow from carbon emissions to energy consumption and from energy consumption to financial development in the long run and in the short run. The findings of the study reveal conscious decisions South Africans are making to reduce the carbon footprint coupled with the financial sector ability to design instruments that suit the customer requirements. Policy implications are also discussed.

Keywords: South Africa, carbon emissions, financial development, energy consumption, autoregressive distributed lag approach.

1. INTRODUCTION

There has been growing concern on the increase in carbon emissions that now has tangible climatic changes across the globe. The push for sustainable and environmentally friendly production has gained ground. At the same breath, customers are now well informed about the impact of global warming, and with some customers even protesting products produced by countries that have lax environmental policies. According to Saleh (2022) global warming has risen significantly in the recent past with world ocean surface temperature getting 0,98 degrees warmer in the 20^{th} century. Africa alone has a cumulative carbon emissions of 48 billion metric tons between 1884 and 2020 Saleh (2022). The amount of carbon emissions is a concern and culminated in 198 countries ratifying the United Nations Framework Convention on Climate Change which came into force in 1994 (United Nations, 2023). The overarching objective of Convention is to prevent negative human interface with the climate system (United Nations, 2023). Under the convention, developed and developing countries agreed to support each other in the fight against climate change. South Africa is one of the signatories to the Convention and is working towards reduction and ultimately elimination of carbon emissions. However, one of the major challenges in South Africa is the over reliance on fossil fuels in electricity generation. According to Climate Transparency Report, fossil fuels make up 92% of South Africa energy mix (Climate Transparency, 2022). This has slowed the momentum on reduction in carbon emissions. Currently, the country is having capacity challenges in generation enough power for households and commercial consumption, resorting to load shedding as a way of managing demand for electricity. The objective of this study is to examine the causal relationship between carbon emissions, financial development, and energy consumption in South Africa. The findings from the study would provide insight on which variable should be influenced first to realise a decrease in pollution in the journey towards environmentally friendly activities. The importance of climate change has drawn several researchers who investigated the impact of different economic variables on emissions. Some studies examined the impact or causality between carbon emissions and energy consumption.

South Africa makes an interesting case study because it is among the top African countries on carbon emissions. According to Saleh, (2022) South Africa is the most polluting nation in Africa. In 2021, South Africa emitted close to 436 million metric tons of carbon dioxide, followed by Egypt with 250 million metric tons (Saleh, 2022). South Africa and Libya have the highest CO2 emissions per capita among African countries (Saleh, 2022). Given the level of emissions the country is currently grappling with, on one hand, and the ratification of the Convention on the other hand, the findings of this study shed some light on ways of reducing carbon emissions. Further, emission is taking place at a time the country is experiencing financial development and high energy demands. The causal flow among these variables will shed light and inform policy makers on which variables to be influenced first to realise a decline in emissions.

The study is structured as follows; Section 2 focuses on literature review; and Section 3 dwells on estimation techniques. Section 4 presents data analysis and discussion of results and Section 5 provides concluding remarks.

2. LITERATURE REVIEW

2.1. Carbon emissions, energy consumption and financial development dynamics

Carbon emissions dynamics

South Africa drafted legislations and regulations to back the government in the implementation of carbon emissions policies. In 2003 the final draft on Joint Implementation Strategy for The Control of Exhaust Emissions from Road-Going Vehicles in The Republic South Africa was gazetted. This was developed on the back of a surge in the emissions from vehicles and the need to regulate the sector (Department of Environmental Affairs and Tourism and Department of Minerals and Energy, 2003). Another piece of legislation is the Air Quality Act of 2004 with amendments to the national Greenhouse emissions reporting regulation of 2016 (Department of Environment, Forestry, and Fisheries, 2020). The Integrated Pollution and Waste Management White Paper which addresses waste minimisation, pollution minimisation, integration of government departments and all spheres of government, involvement of all sectors in the economy (South African Government, 2023). The main objective of the policy is to lay a foundation on how to minimise pollution and waste in a way that is environmentally friendly (South African Government, 2023). South Africa has drafted several white papers in an endeavour to put legal framework on the push to a clean environment. Some of the White papers include White Paper on Environmental Management Policy of 1998; National Climate Change Response White Paper of 2011; White paper on Conservation and Sustainable Use of Biodiversity of 1997; White Paper on Marine Fisheries Policy of 1997, among others (Department of Forestry, Fisheries, and the Environment, 2023). Although South Africa has developed a strong legal framework on carbon emissions, the effort has not yet reflected in the figures on carbon emissions as expected. Implying this is a slow process, for example, larger part of electricity generated in South Africa comes from coal. This source of energy generation contributes to carbon emissions (Bp, 2023). Retirement of the coal plants is a gradual process, and the government is working toward moving to clean energy sources. Evidence of government's effort is seen on the most recent steps taken such as, the Climate Change Bill passed in Parliament in February 2022, the Just Energy Transition Partnership, aimed at accelerating the phasing out of coal use in energy generation (Climate Transparency, 2022).

Carbon emissions has been on an upward trend during the study period with an average of 292315 kt between 1990 and 2005 and 424553.8kt between 2006 and 2021(World Bank, 2023). The average for the second half of the study period almost double, showing increasing carbon emissions. This is not surprising given an increase in population and economic activities in South Africa coupled with renewable energy use still at the nascent stage in the country. The upward trajectory is likely to slow down with the increasing pressure from the international community to reduce carbon footprint.

Energy consumption dynamics

Energy consumption in South Africa varies among households, depending on whether a household has electricity connection or not. Many households with electricity connection use electricity for lighting and cooking (Climate Transparency, 2022). However, some households use gas, wood for the same purpose. According to the Climate Transparency Report (2022) households with electricity connection also use gas most. South Africa production include fossil – coal used in the production of electricity, oil, gas, renewable energy biased towards wind energy, hydro power and nuclear, though there has been a gradual increase in support for solar energy. Several legislation and regulations have been put in place as far as energy generation and consumption is concerned. At the end of Apartheid, government launched the Energy Policy White Paper in 1994, which was later revised in 1998 after wide consultations. The objective of the energy policy includes improved governance, economic development, increase access to affordable energy, build supply through diversity and managing any health and environmental impact related to energy production and consumption (Department of Minerals and Energy, 1998).

The current Integrated Resource Plan (IRP) 2019 lays out a plan of decommissioning 11.5 gigawatts (GW) of old coal-fired power plant and replace with plants fired by wind and solar and self-generated electricity by households (Yelland, 2020). On coal, the National Coal Strategy for South Africa released in 2018, focuses on what must be done given the traction in decarbonising of the economy (Yelland, 2002). Energy related to gas and renewable energy are guided by Gas Utilisation Master Plan and the new IRP 2019, respectively (Yelland, 2020). Energy consumption has generally been increasing when measured from electricity consumption or total energy consumption. Total energy consumption averaged 104,37Mtoe between 1990 and 2005, while the period between 2006 and 2021 registered 134.2 Mtoe (Enerdata, 2023). The same trend was recorded on electricity consumption with an average of 174 TWh between 1990 and 2005, and 208,5 TWh between 2006 and 2021 (Enerdata, 2023). Although it is important to note that between 2020 and 2021 energy consumption in general decreased, reflecting COVID-19 lockdown economic restrictions. Figure 1 reports the trends in carbon emissions and energy consumption.

Carbon emissions and energy consumption measured by total energy consumption and electricity consumption took an upward trend during the study period as reported in Figure 1. However, carbon emission is increasing at an increasing rate in comparison to energy consumption. This shows the increasing impact of environmentally unfriendly energy sources. The trends in the three variables suggest a positive relationship between energy consumption measures and carbon emissions.

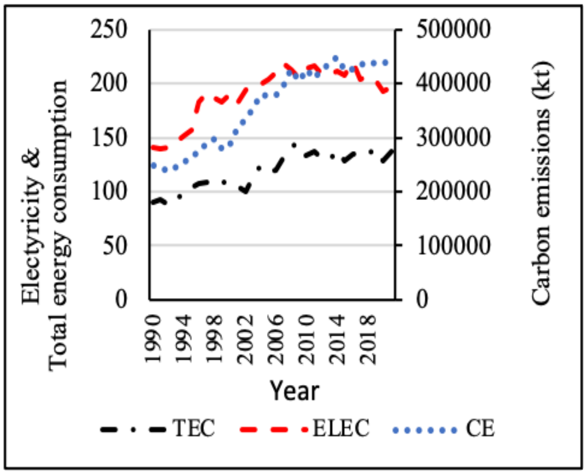

Fig. 1. Carbon Emissions and Energy Consumption Trends 1990 -2021

Source: World Bank (2023) and Enerdata (2023)

Financial development dynamics

South Africa has one of the advanced and sophisticated financial sectors in Africa and compare favourably with other emerging market economies (Financial Sector Conduct Authority, 2022). There are 36 registered banking organisations in South Africa under the joint supervision of the Prudential Authority (PA) and the Financial Sector Conduct Authority (FSCA) (Financial Sector Conduct Authority, 2022). The FSCA started operation in 2018, with a mandate to enhance integrity and efficiency in the financial markets; provide financial education and support financial literacy; and assist in building stability in the financial sector together with other regulatory bodies (Prudential Authority, 2023). The Prudential Authority, processes license application guided by financial sector laws and regulations; public interest, governance; risk management; prudential requirements and information and accounting systems. The Prudential Regulation also rely on the green light from Financial Sector Conduct Authority in providing the outcome of a licence application (Prudential Authority, 2023). Thus, several authorities ensure prudential regulation is thorough as assessment is done by several stakeholders before a licence is awarded and on the regulation of the sector (Prudential Authority, 2023). This strengthens the financial sector and bring stability and resilience. Treating Customers Fairly (TCF) provides a framework that ensure the financial institutions treat customers fairly during financial transactions.

The financial sector is guided by primary and secondary legislation with the primary legislation including the Banks Act 94 of 1990; Financial Sector Regulation Act 9 of 2017; Co-operative Banks Act 40 of 2007; Insurance Act 18 of 2017 and Mutual Banks Act of 1993; among other legislations and regulations in the financial sector (Prudential Authority, 2023). Some of the secondary; legislation include the South African Reserve Bank Act 90 of 1989; the Companies Act 71 of 2008; the National Payments System Act 78 of 1998; and Financial Intelligence Centre Act 38 of 2001; among other secondary legislations. These Acts and regulations lay the foundation on the operations of the financial market players ranging from banks, insurance, and mutual banks (Prudential Authority, 2023).

Despite several players in the financial sector, banking is arguably concentrated among few largest banks with over 85% of the deposits in the industry (Financial Sector Conduct Authority, 2022). The coming in of new banks in the recent past has diluted this position with the subsequent reduction in transaction costs. New banks that entered in the banking sector include the Bank Zero, Tyme Bank and Discovery Bank (Financial Sector Conduct Authority, 2022). South Africa has payments system that has enabled 91% of South African to participate in the formal financial system. The growth in innovative digital payments such as, 3D scans, scan to pay chip and pin cards has availed several options to consumers and convenience (Financial Sector Conduct Authority, 2022). The banking sector has experienced growth especially in the use of technology that has increased efficiency, although new risks have been opened. There has been increased use of banking applications to transact, which has brought a lot of convenience to customers. The downside is the increase in cyber security issues and digital banking fraud that are associated with more reliance on internet for almost all banking transactions (Financial Sector Conduct Authority, 2022). Automated Teller machines have also become advanced to provide a wide range of service that were not available some years back, such as, access to statements and deposit of cash. The developments in the financial sectors are evident with an increase in the financial development index over the study period, except 2020 and 2021 (IMF, 2023). The decline during the two years reflects a decrease in the use of the financial markets due to COVID-19 restrictions. The trend on financial development and carbon emissions are reported in Fig. 2.

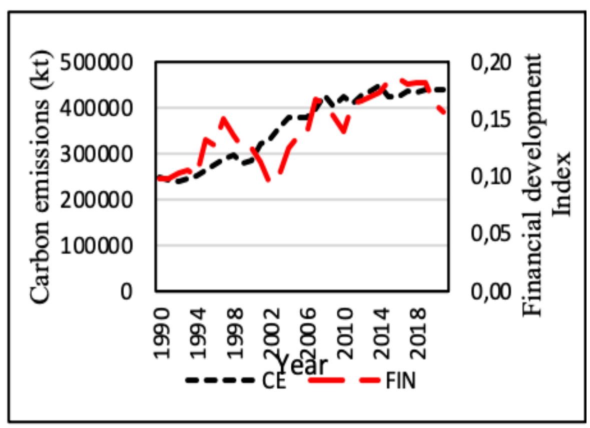

Fig. 2. Carbon Emissions and Financial Development 1990-2021

Sources: World Bank (2023) and IMF (2023)

Figure 2 reports the trends in carbon emissions and financial development during the study period, characterised by an upward trend over the period. A close look at the two graphs shows that, although the two variables are taking an upward trend, financial development is always associated with an opposite movement in carbon emissions. This suggests financial development leads to a reduction in carbon emissions.

2.2. Theoretical Literature

The current literature points to a positive relationship between energy consumption economic growth and carbon emissions. The positive link between carbon emissions and energy consumption comes from the use of fossils or non-renewable sources of energy, where increase in energy consumption leads to an increase in emissions. However, as economies move towards renewable energy sources, the relationship between the two is likely to change. Renewable energy sources, such as solar, wind and hydro reduce carbon emissions and promote sustainability. On the other hand, the role of the financial sector has been well documented in the literature in relation to several macroeconomic variables like economic growth, remittance inflow, energy consumption, carbon emissionss and foreign direct investment among other variables. The financial sector acts as an intermediator between surplus units (savers) and deficit units (borrowers). Financial sector developed can be categorised into bank-based and market-based, depending on the sector that plays a significant role in the economy. In the literature, the interaction of measures of bank-based financial development and those of market-based financial development have provided varied results. The link between financial market development and energy consumption comes from the ability of the financial sector to avail funding for projects related to cleaner energy sources. This consequently reduces carbon emissions. If the financial sector has more accessible financial windows for those who would want to borrow funds for renewable energy sources, this subsequently results in an increase in the consumption of renewable energy sources. This leads to a significant reduction in carbon emissions.

There are limited studies that have examined the causal relationship between carbon emissions, energy consumption and financial development, in this study, the literature on the impact of energy consumption on carbon emissions and causality between the two will be reviewed. Although impact studies are not the same as causality studies, the relationship between the two will shade some light on the nature of the relationship between carbon emissions and energy consumption.

Empirical literature review

Studies on Carbon Emissions and Energy consumption

Gyamerah and Gil-Alana (2023) examined the causality between CO_2 emissions, electricity consumption and economic growth for Western and Central Africa using data from 1970 to 2020. Employing vector error correction model (VECM) the study found electricity consumption to have a positive impact on CO_2 emissions. No causal relationship was found between electricity consumption and CO_2 emissions. Chontanawat (2020) investigated the relationship between energy consumption, CO_2 emissions and economic output for ASEAN counties using data from 1971 to 2015. The study found a bidirectional causality between CO_2 emissions and energy consumption in the long run and a unidirectional causal flow from energy consumption to CO_2 emissions in the short run. Hussain, Javaid and Drake (2012) investigated the relationship between environmental pollution, economic growth and energy consumption for Pakistan using data from 1971 to 2006. The study used per capita carbon emissions (CO_2) as a measure of carbon emissions, commercial use per capita for energy measure. Employing VECM and Granger causality the study found a bidirectional causality between carbon emissions and energy consumption. Alam *et al*. (2011) examined the causality between energy consumption, carbon dioxide emissions and income in India. Using the dynamic approach, the study found a bidirectional causality between energy consumption and carbon dioxide emissions in the long run. Acaravci and Ozturk (2010) examined the causality carbon dioxide emissions, energy consumption and economic growth for 19 European countries using data from 1960 to 2005. Using the autoregressive distributed lag approach, the study found a unidirectional causal flow from energy consumption to carbon emissions per capita for Denmark, Greece, Italy, Portugal, Germany, and Switzerland.

Among the studies that examined the impact of energy consumption on carbon emissions, Akwasi *et al.* (2022) investigated the relationship between renewable energy, non-renewable energy, foreign direct investment, and economic globalisation for E7 countries using data from 1990 to 2016. The study employed panel econometrics test and quantile regression and found that investment in renewable energy led to improvement in environmental quality. Coskuner *et al.* (2020) examined the economic and social determinants of carbon emissions in the Organisation of Petroleum Exporting Countries (OPEC) using data from 1995 to 2016. The social factors used in the study are per capita GDP, fossil fuel energy consumption, urbanisation, and international trade. Employing the Fully Modified Ordinary Least Squares, the study found relationship between carbon emissions and GDP to be non-linear in OPEC countries and follows the inverted U-shaped Kuznets environmental curve. A 1% increase in energy consumption leads to 0,94% rise in carbon emissions. Kwakwa and Alhassan (2018) investigated the effect of urbanisation and energy on carbon emissions in Ghana using data from 1971 to 2013. Using the Fully Modified OLS and the Environmental Kuznets Curve, the study found renewable energy and waste consumption to reduce carbon emissions. The study found the interaction of waste, urbanisation, consumption, and combustible renewables to have a positive impact on carbon emissions. Muhammad and Saad (2018) analysed the relationship among carbon emissions, energy consumption and economic growth in Malaysia using data from 1980 to 2017. Employing the multiple linear regression, the study found energy consumption to have a negative effect on carbon dioxide emissions and gross domestic product had a positive relationship toward carbon dioxide emissions.

Financial development and carbon emissions

Rahman et al. (2020) studied the relationship between carbon emissions, economic growth, financial development, foreign direct investment, and energy consumption for Lithuana using data from 1989 to 2018. Employing autoregressive distributed lag, the study found a unidirectional causal relationship from financial development to carbon emissions. Cetin and Ecevit (2017) in a study on Turkey found the same results as Rahman et al. (2020). Cetin and Ecevit (2017) investigated the impact of financial development on carbon emissions for Turkey using data from 1960 to 2011. Using the autoregressive distributed lag (ARDL) and the vector error correction model (VECM) the study found financial development to have a positive impact on carbon emissions in the long run. Shahbaz et al. (2013a) analysed the relationship between energy consumption, financial development, economic growth, trade openness and carbon emissions using quarterly data from 1975 to 2011 for Indonesia. The study used the ARDL approach to examine the long run relationship and the vector error correction Granger-causality to examine causality among the variables. The findings of the study confirm a positive impact of energy consumption on carbon emissions and financial development was found to reduce carbon emissions. A directional causality was found between energy consumption and carbon emissions and a unidirectional causal flow from financial development to carbon emissions.

Apart from causality studies, Habiba, Xinbang and Ali (2023) examined the relationship between financial development, green technology, renewable energy, and carbon emissions using data from 1990 to 2020. Using the cross-sectional dependence test, Westerlund cointegration test, panel estimator and Panel Granger causality test, the study found financial development to increase carbon emissions. However, financial development was found to have less impact on emissions if used with green technology. In the same vein, Guo (2021) examined the impact of financial risk index, renewable energy electricity output, financial development, human capital development on carbon emissions for China using time series data from 1988 to 2018. Using econometric techniques, the study found increasing renewable energy in electricity output to negatively impact carbon emissions and a negative association between financial development and carbon emissions. Abbasi and Riaz (2016) examined the impact of economic growth and financial development on carbon emissions for Pakistan using a full sample from 1971 to 2011 and a sub-sample from 1988 to 2011. Employing the autoregressive distributed lag and Vector Error Correction Model, the study found financial development to mitigate carbon emissions. Shahbaz, Kumar, and Nasir (2013b) examined the effect of financial development, economic growth, coal consumption and trade openness on carbon emissions for South Africa using data from 1965 to 2008. Employing autoregressive distributed lag, the study found coal consumption to lead to a deterioration of the environment and financial development to have a negative impact on carbon emissions.

The literature reviewed on the causal relation between energy consumption and carbon emissions is tilted more to a bidirectional causality between energy consumption and carbon emissions. Confirming a mutual reinforcing effect between energy consumption and carbon emissions. High energy consumption is associated with high carbon emissions, and this also feeds into more energy consumption. On the causal relationship between financial development and carbon emissions. The relationship has been mixed with some studies confirming a unidirectional causal flow from financial development to carbon emissions and others confirming the opposite flow. Another study for South Africa is important even though Shahbaz, Kumar, and Nasir (2013b) found financial development to reduce carbon emissions. The direction of causality in the study was not explored.

3. ESTIMATION TECHNIQUES

This study uses the autoregressive distributed lag (ARDL) to cointegration and the error correction model (ECM)- based Granger - causality test to investigate the causal relationship between carbon dioxide emissions, energy consumption and financial development. The ARDL approach was selected for this study because of the advantages it has over other methods. For example, the ARDL approach allows results from the study to be tied to short term and long-term times, which give more insight to policy were timeframes are important. Another benefit of using the ARDL approach is that it does not require variables to be integrated of the same order. This allows a mixture of level variables and those integrated of order one in one equation.

Variable definition

Variable of interest in this study are carbon emissions (CE) captured by kiloton (kt); energy consumption is captured by two proxies namely, total energy consumption (TEC) measured by mega tonnes of oil equivalent (Mtoe); and electricity consumption measured by terawatt hour (TWh); and financial development (FIN), captured by the financial development index from International Monetary Fund database. To fully specify the model, human development (HDI) measured by the United Nations Human Capital Development Index, gross domestic product per capita (GDPP) were added to the model to form a multivariate causality framework.

Table 1. Variable definition and sources

Variable	Notation	Description	Source
Carbon emissions	CE	Carbon emissions in kiloton (kt)	WDI
Total energy consumption	TEC	Total energy consumption in mega tonnes of equivalent oil (Mtoe)	Enerdata
Electricity	ELEC	Electricity consumption measure in terawatt hours (TWh)	Enerdata
Financial development	FIN	Financial development Index	IMF database
Gross domestic product per capita	GDPP	GDP per capita	WDI
Human development	HDI	Human Development Index	United Nations database

Source: Author's compilation

Note: WDI= World Development Indicators
IMF=International Monetary Fund

ARDL model specification

The study consists of two models, Model 1, where energy consumption is measured by total energy consumption and Model 2, where electricity is used as a measure of energy consumption. The rest of the variables remain the same in each model.

Cointegration model specification (CE, EG, FIN, GDPP, HDI)

The ARDL model specification is presented in Equation 1-5

$$\Delta CE_t = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=0}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=0}^{n} \vartheta_{3i} \Delta FIN_{t-i} + \sum_{i=0}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=0}^{n} \vartheta_{5i} \Delta HDI_{t-i} + \beta_1 CE_{t-1} + \beta_2 EG_{mt-1} + \beta_3 FIN_{t-1} + \beta_4 GDPP_{t-1} + \beta_5 HDI_{t-1} + \mu_{1t} \dots\dots\dots (1)$$

$$\Delta EG_{mt} = \vartheta_0 + \sum_{i=0}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=1}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=0}^{n} \vartheta_{3i} \Delta FIN_{t-i} + \sum_{i=0}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=0}^{n} \vartheta_{5i} \Delta HDI_{t-i} + \beta_1 CE_{t-1} + \beta_2 EG_{mt-1} + \beta_3 FIN_{t-1} + \beta_4 GDPP_{t-1} + \beta_5 HDI_{t-1} + \mu_{2t} \dots\dots\dots (2)$$

$$\Delta FIN_t = \vartheta_0 + \sum_{i=0}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=0}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=1}^{n} \vartheta_{3i} \Delta FIN_{t-i} + \sum_{i=0}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=0}^{n} \vartheta_{5i} \Delta HDI_{t-i} + \beta_1 CE_{t-1} + \beta_2 EG_{mt-1} + \beta_3 FIN_{t-1} + \beta_4 GDPP_{t-1} + \beta_5 HDI_{t-1} + \mu_{3t} \dots\dots\dots (3)$$

$$\Delta GDPP_t = \vartheta_0 + \sum_{i=0}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=0}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=0}^{n} \vartheta_{3i} \Delta FIN_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=0}^{n} \vartheta_{5i} \Delta HDI_{t-i} + \beta_1 CE_{t-1} + \beta_2 EG_{mt-1} + \beta_3 FIN_{t-1} + \beta_4 GDPP_{t-1} + \beta_5 HDI_{t-1} + \mu_{4t} \dots\dots\dots (4)$$

$$\Delta HDI_t = \vartheta_0 + \sum_{i=0}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=0}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=0}^{n} \vartheta_{3i} \Delta FIN_{t-i} + \sum_{i=0}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=1}^{n} \vartheta_{5i} \Delta HDI_{t-i} + \beta_1 CE_{t-1} + \beta_2 EG_{mt-1} + \beta_3 FIN_{t-1} + \beta_4 GDPP_{t-1} + \beta_5 HDI_{t-1} + \mu_{5t} \dots\dots\dots (5)$$

Where: Carbon emissions (CE) is captured by carbon emissions in kiloton, energy consumption (EG) is captured by total energy consumption (TEC) and electricity consumption (ELEC); Each of the two energy consumption measures enter into the equation one at a time and the other variables remain the same, Financial development (FIN) is captured by the IMF financial development index; gross domestic product per capita (GDPP) measured by GDP divided by the population; and human development captured by the Human Development Index.

ϑ_0 is a constant.

$\vartheta_1 - \vartheta_5$ and $\beta_1 - \beta_5$ are short-run and long-run coefficients, respectively.

$\mu_1 - \mu_5$ are error terms.

The Error Correction Model for Equation 1- 5 are given in Equation 6 -10.

$$\Delta CE_t = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=1}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta FIN_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta HDI_{t-i} + \rho_1 ECM_{t-1} + \mu_{1t} \dots\dots\dots (6)$$

$$\Delta EG_{mt} = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=1}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta FIN_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta HDI_{t-i} + \rho_2 ECM_{t-1} + \mu_{2t} \dots\dots\dots (7)$$

$$\Delta FIN_t = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=1}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta FIN_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta HDI_{t-i} + \rho_3 ECM_{t-1} + \mu_{3t} \dots\dots\dots (8)$$

$$\Delta GDPP_t = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=1}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta FIN_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta HDI_{t-i} + \rho_4 ECM_{t-1} + \mu_{4t} \dots\dots\dots (9)$$

$$\Delta HDI_t = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i} \Delta CE_{t-i} + \sum_{i=1}^{n} \vartheta_{2i} \Delta EG_{mt-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta FIN_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta GDPP_{t-i} + \sum_{i=1}^{n} \vartheta_{4i} \Delta HDI_{t-i} + \rho_5 ECM_{t-1} + \mu_{5t} \dots\dots\dots (10)$$

ECM = error correction term

$\rho_1 - \rho_5$ are error correction term coefficients.

The rest of the variables remain the same as specified in Equation 1 -5.

Data sources

This study analysed the causal flow between carbon dioxide emissions, energy consumption and financial development using data from 1990 to 2021. Carbon emissions (CE), gross domestic product per capita were extracted from the World Bank Development indicators database; total energy consumption (TEC) and electricity consumption (ELEC) were retrieved from Enerdata; and human development index (HDI) was extracted from the United Nations data base. Financial development index ((FIN) was retrieved from the International Monetary Fund database.

4. EMPIRICAL RESULTS

Table 2. Unit Root Test Results

Augmented Dickey-Fuller (DF)				
Variable	Stationarity in Levels		Stationarity First Difference	
	Without Trend	With Trend	Without Trend	With Trend
CE	-0.013	-1.337	-6.177***	-6.26182***
ELEC	-2.183	-1.148	-5.796***	-6.687***
TEC	-1.242	-2.579	-2.895*	-6.075***
GDPP	-0.700	-0.984	-4.107***	-4.119***
HDI	-1.740	-2.455	-2.979*	-3.874***
FIN	-1.722	-2.221	-5.224***	-5.218***
Phillip-Perron (PP) Test				
Variable	Stationarity in Levels		Stationarity in First Difference	
	Without Trend	With Trend	Without Trend	With Trend
CE	-0.1223	-1.550	-5.688***	-6.232***
TEC	-0.040	2.661	-2.730*	2.951*
ELEC	-1.097	-1.261	-5.841***	-6.551***
GDPP	-0.316	-1.087	-3.657***	-3.863***
HDI	-1.773	-1.656	-3.097***	-3.919***
FIN	-1.246	-2.435	-5.316***	-5.411***

Note: *, ** and *** denote stationarity at 10%, 5% and 1% significance levels, respectively.

Results reported in Table 2 confirm that variables in this study are stationary at first difference. The level of integration is acceptable when using the ARDL method, the next step is a test for a long run relationship among functions in Model 1 – total energy as a measure of energy consumption and Model 2 – electricity as a measure of energy consumption. Cointegration results are presented in Table 3.

The results reported in Table 3 confirm cointegration in all the functions in Model 1- where total energy is used as a measure of energy consumption and three functions under Model 2 – where electricity consumption is used as a measure of energy consumption namely, the F(GDPP|CE, ELEC, HDI, FIN), F(HDI|CE, ELEC, GDPP, FIN) and F (FIN|CE, ELEC, GDPP, HDI).

Table 3. Cointegration Results

Dependent Variable	Function	F-Statistic	Cointegration Status
Model 1: Energy consumption measured by TEC			
CE	F (CE|TEC, GDPP, HDI, FIN)	5.477**	Cointegrated
TEC	F (TEC|CE, GDPP, HDI, FIN)	4.848**	Cointegrated
GDPP	F (GDPP|CE, TEC, HDI, FIN)	5.137**	Cointegrated
HDI	F (HDI|CE, TEC, GDPP, FIN)	7.011***	Cointegrated
FIN	F (FIN|CE, TEC, GDPP, HDI)	4.472*	Cointegrated
Model 2: Energy consumption measured by ELEC			
CE	F (CE|ELEC, GDPP, HDI, FIN)	2.203	Not Cointegrated
ELEC	F (ELEC|CE, GDPP, HDI, FIN)	2.036	Not Cointegrated
GDPP	F (GDPP|CE, ELEC, HDI, FIN)	8.921***	Cointegrated
HDI	F (HDI|CE, ELEC, GDPP, FIN)	8.782***	Cointegrated
FIN	F (FIN|CE, ELEC, GDPP, HDI)	4.718*	Cointegrated

Note: *, ** and *** denote stationarity at 10%, 5% and 1% significance levels, respectively.

To proceed with the estimation, where cointegration has been confirmed, an estimation of short and long run relationship will be done, whilst those models where no long run relationship was confirmed, only short run causality estimation is done. The ECM-based causality results for Model 1 are reported in Table 4.

Results presented in Table 4, Model 1 where total energy consumption was used as a measure of energy consumption, a unidirectional causal flow from carbon emissions to total energy consumption in the short run and the long run was confirmed. This finding confirms that carbon emissions influences energy consumption in South Africa.

Table 4. Granger-causality Results – Total Energy Consumption as a Measure of Energy Consumption.

Panel 1	Model 1: Total energy consumption					
	ECM t-statistics					ECM (t-stat)
	ΔCE	ΔTEC	ΔGDPP	ΔHDI	ΔFIN	
ΔCE	-	7.151** [0.013]	8.610*** [0.001]	1.872 [0.182]	1.872 [0.182]	-0.769*** [-4.001]
ΔTEC	3.665* [0.067]	-	0.020 [0.890]	3.874* [0.060]	6.827** [0.015]	-0.760 [-4.077]
ΔGDPP	6.433*** [0.006]	0.501 [0.613]	-	-4.148** [0.030]	2.472 [0.109]	-0.657*** [-5.059]
ΔHDI	8.665*** [0.001]	0.032 [0.861]	8.155** [0.001]	-	1.438 [0.241]	-0.029*** [-8.327]
ΔFIN	4.144** [0.053]	5.126** [0.033]	3.128** [0.089]	-	-	-0.729*** [-3.698]

Source: Author's compilation
Note: *, ** and *** denote stationarity at 10%, 5% and 1% significance levels, respectively.

This finding points to the growing consciousness among South African on the negative and positive impact of different energy sources on the environment. Suggesting that South Africans now make conscious decision based on the consequences of the energy sources available. This is also evident at national level where government has put in place a plan to reduce carbon footprint, especially in generation of electricity using coal. These results are not unique to South Africa alone (see, for example, Rahman et al., 2020, Cetin and Ecevit, 2017; Shahbaz et al., 2013a; Acaravci and Ozturk, 2010). The study also found a unidirectional causal flow from carbon emissions to financial development in the short run and the long run. The findings collaborate the causality between carbon emissions and energy consumption. The level of carbon emissions and increasing awareness of global warming has an influence on the financial tools developed to finance clean energy sources – green financial development. A bidirectional causality between total energy consumption and financial development was found in the short run and the long run. This confirms the mutual reinforcing effect of high energy consumption and resulting increase in demand for financial resources. Thus, South Africans fund energy consumption through the financial system.

Other results reported in Table 4 confirmed the following: i) a bidirectional causality between HDI and carbon emissions in the short run and in the long run; ii) bidirectional causality between economic growth and carbon emissions; iii) bidirectional causality between total energy consumption and human development; iv) no causality was found between total energy consumption and economic growth; v) unidirectional causal flow from human development to financial development in the short run and in the long run; vi) unidirectional casual flow from gross domestic product per capita to financial development; and vii) bidirectional causality between gross domestic product per capita and human development in the short run and in the long run. Table 5 reports causality results for Model 2.

Table 5. Granger-Causality Results - Electricity as A Measure of Energy Consumption.

Panel 1		Model 2: Electricity consumption				
	ECM t-statistics					ECM (t-stat)
	ΔCE	ΔELEC	ΔGDPP	ΔHDI	ΔFIN	
ΔCE	-	0.290 [0.596]	3.887* [0.062]	0.078 [0.783]	1.569 [0.224]	-
ΔELEC	0.903 [0.351]	-	0.056 [0.814]	4.743** [0.039]	2.135 [0.157]	-
ΔGDPP	8.486*** [0.001]	2.996* [0.096]	-	4.339** [0.025]	0.978 [0.333]	0.510*** [-5.072]
ΔHDI	6.477** [0.018]	7.892** [0.010]	8.161*** [0.001]	-	0.051 [0.824]	-0.140*** [-8.759]
ΔFIN	4.658** [0.041]	5.904** [0.023]	3.498* [0.073]	-	7.132*** [0.013]	-0.791*** [-4.291]

Author's compilation
Note: *, ** and *** denote stationarity at 10%, 5% and 1% significance levels, respectively.

Results reported in Table 5, where energy consumption is measured by electricity consumption, confirmed no causal relationship between electricity consumption and carbon emissions in the short run. This could be explained by a gradual increase in energy generation from renewable sources. Gyamerah and Gil-Alana (2023) also found the same results in Western and Central Africa. A unidirectional causal flow from carbon emissions to financial development was found in the short run and the long run. The results suggest the influence of carbon emissions on the financial products offered in the financial sector. A unidirectional causal flow from electricity consumption to financial development in the short run and the long run. The availability of electricity influences the demand for financial services. This reflect accessibility to financial services when electricity is available, for instance, the use of cellular phones and other electronic devices.

Other results reported in Table 5 confirmed the following: i) a unidirectional causal flow from carbon emissions to human development in the short run and the long run; ii) a bidirectional causality between carbon emissions and GDP per capita in the short run and a unidirectional causal flow from carbon emissions to GDP per capita in the long run; iii) bidirectional causality between human development and electricity consumption in the short run and a unidirectional causal flow from electricity consumption to human development in the long run; iv) unidirectional causal flow from electricity consumption to GDP per capita in the short run and the long run; v) a unidirectional causal flow from human development to financial development in the short run and the long run; vi) a unidirectional causal flow from GDP per capita to financial development in the short run and the long run; and vii) a bidirectional causality between human development and GDP per capita in the short run and long run.

Based on the results reported in Table 4 and 5, when total energy consumption was used as a measure of energy consumption, carbon emissions was found to influence energy consumption. This finding points to conscious decisions among South Africans when consuming energy. Carbon emissions and energy consumption influence financial development in South Africa as evidenced by the results across the two measures of energy consumption. When electricity was used as a measure of energy consumption, no causal relationship found between electricity consumption and carbon emissions. This could reflect a gradual increase in the use of cleaner energy sources to generate electricity.

5. CONCLUSION

This study examined the causal relationship between carbon emissions, energy consumption and financial development for South Africa using annual time series data from 1990 to 2021. The increasing pressure for developed and developing countries to reduce their carbon footprint motivated this study. Can South Africa harness financial development and energy consumption in a move to reduce carbon emissions? Two proxies of energy consumption were used namely, total energy consumption and electricity consumption. To fully specify the model, gross domestic product per capita, human development and financial development were added to the model to form a multivariate framework. The results from the analysis confirmed a unidirectional causal flow from carbon emissions to energy consumption only when total energy was used as a measure of energy consumption. No causality was found when energy consumption was measured by electricity consumption. Carbon emissions and energy consumption cause financial development irrespective of the measure of energy consumption used. Based on these results, it can be concluded that financial sector offerings in South Africa are informed by the demands from consumers guided by impact of energy sources selection on the environment. It is recommended that policy makers in South Africa continue to educate the population on the importance of clean energy sources and establish a dialogue with the financial sectors to design borrowing options that cater for low income and high-income households, formal and informal business. This implies fostering government and financial sector partnership is important in achieve green energy consumption.

Nomenclature

CE - carbon emissions
TEC – total energy consumption.
GDPP – gross domestic product per capita.
HDI – Human Development Index.
FIN – Financial Development Index.
ELEC – electricity consumption.

REFERENCES

[1]. Abbasi, F., and Riaz, K. - CO_2 emissions and financial development in an emerging economy: An augmented VAR approach. Energy Policy, vol. 90, 2016, pg.102-114.

[2]. Acaravci, A., and Ozturk, I. - On the relationship between energy consumption, CO2 emission and economic growth in Europe. Energy, vol. 35,2010, pg. 5412-5420.

[3]. Akwasi, GB., Murad, B., Ntom, UE., Victor, BF. - Renewable energy, economic globalisation, and foreign direct investment linkage for sustainable development in the E7 economies: revisiting the pollution haven hypothesis. International Social Science Journal, vol. 72, no.24, 2022, pg. 91-110.

[4]. Alam, MJ., Begum, IA., Byysse, J., Rahman, S., and Van Huylenbrorck, G. - Dynamic modelling of causal relationship between energy consumption, CO2 emission and economic growth in India. Renewable and Sustainable Energy Reviews, vol.15, no.6, 2011, pg. 3243-3251.

[5]. Bp, - Statistical Review of World Energy, 2023, Retrieved on June 22, Available online, https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

[6]. Cetin, M., and Ecevit, E. - The impact of financial development on carbon emission under the structural breaks: Empirical evidence from Turkish economy. International Journal of Economic Perspectives, vol. 11, no. 1, 2017, pg. 64-78.

[8]. Chontanawat, J. - Relationship between energy consumption, CO2 emission and economic growth in

ASEAN: cointegration and causality model. Energy Reports, vol. 6, no.1,2020, pg. 660-665.
[9]. Climate Transparency, - Climate Transparency Report 2022, 222, Retrieved on April 21, Available online, https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-South-Africa-Web.pdf.
[10]. Coskuner, C., Paskeh, M., Olasehinge-Williams, G., and Akadiri, SS. - Economic and social determinants of carbon emission: Evidence from organisation of petroleum exporting countries. Journal of Public Affairs, vol. 20, no. 3, 2020, pg. 1-15.
[11]. Department of Environmental Affairs and Tourism and Department of Minerals and Energy, 2003. Joint implementation strategy for the control of exhaust emission from road-going vehicles in the republic South Africa, 2003, Retrieved on April 20, Available online: https://www.gov.za/sites/default/files/gcis_document/201409/257410.pdf.
[12]. Department of Forestry, Fisheries, and the Environment, - White papers, 2023, Retrieved on April 20, Available online: https://www.dffe.gov.za/legislation/whitepapers.
[13]. Department of Minerals and Energy, - White Paper on the Energy Policy of the Republic of South Africa, 1998, Retrieved on April 21, Available online: https://www.energy.gov.za/files/policies/whitepaper_energypolicy_1998.pdf.
[14]. Enerdata, 2023. World Energy and Climate Statistics – Yearbook 2022, 2023, Retrieved on April 20, Available online: https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html.
[15]. Financial Sector Conduct Authority, 2022. Financial Sector Outlook Study. 2022, Retrieved on June 20, Available online: https://www.fsca.co.za/Documents/FSCA%20Financial%20Sector%20Outlook%20Study%202022.pdf
[16]. Guo, Y. - Financial development and carbon emission: Analysing the role of financial risk, renewable energy electricity, and human capital for China. Discrete Dynamics in Nature and Society, vol.1-8, 2021. ID 1025669. https://doi.org/10.1155/2021/1025669.
[17]. Gyamerah SA. and Gil-Alana, LA. - A multivariate causality analysis of CO2 emission, electricity consumption, and economic growth: Evidence from Western and Central Africa. Heliyon, vol. 9, no. 1, 2023, doi: 10.1016/j.heliyon. 2023.e12858.
[18]. Habiba, U., Xinbang, C., and Ali, S. 2023. On Carbon emission: Does the use of renewable energy and green technology really contribute to achieving low-carbon economies? Gondwana Research, vol. 121, 2023, pg. 472-485. https://doi.org/10.1016/j.gr.2023.05.013.
[19]. Hussain, M., Javaid, MI., Drake, PR. - An econometric study of carbon dioxide (CO2) emission, energy consumption, and economic growth of Pakistan. International Journal of Energy Sector Management, vol. 6, no.4,2012, pg. 518-533.
[20]. IMF, - IMF data: Financial. 2023, Retrieved on May 18, Available online: https://data.world/imf/financial-development-fd.
[21]. Kwakwa, PA., and Alhassan, H. - The effect of energy and urbanisation on carbon dioxide emissions: evidence from OPEC. Energy Review, vol. 42, no. 4, 2018, pg. 301-330. DOI: 10.1111/opec.12133.
[22]. Muhammad, FLB., Saad, NBM. 2018. Carbon emission and energy consumption. The relationship among carbon dioxide, energy consumption and economic growth in Malaysia. Global Business and Management Research, vol. 10, no. 3, 2018, pg 307-314.
[23]. Prudential Authority. 2023. Licensing. 2023, Retrieved on June 20, Available online: https://www.resbank.co.za/en/home/what-we-do/Prudentialregulation/functions-of-the-prudential-authority.
[24]. Rahman, H., Ghazali, A., Bjhatti, GA., Khan, SU - Role of economic growth, financial development, trade, energy and FDI in environmental Kuznets curve for Lithuania; Evidence from ARDL bounds testing approach. Engineering Economics., vol. 31, no. 1, 2020, pg. 39-49.
[25]. Saleh, M. - CO2 Emission in Africa 2021 by Country, 2022, Retrieved on April 20, Available online: https://www.statista.com/statistics/1268395/production-based-co2-emissions-in-africa-by-country/#:~:text=South%20Africa%20was%20the%20most,Algeria%2C%20Nigeria%2C%20and%20Libya.
[26]. Shahbaz, M., Hye, QMA., Tiwari, AK., and Leitao, NC. Economic growth, energy consumption, financial development, international trade, and CO2 emission in Indonesia. Renewable and Sustainable Energy Reviews, vol. 25, 2012a, pg. 109-121.
[27]. Shahbaz, M., Kumar, A., and Nasir, M. 2013b. The effects of financial development, economic growth, coal consumption and trade openness on COP2 emission in South Africa. Energy Policy, vol. 61, no. C, pg. 1452-1459. DOI: 10.1016/j.enpol.2013.07.006.
[28]. South African Government, - Integrated Pollution and Waste Management White Paper: Draft, 2023, Retrieved on April 20, Available online: https://www.gov.za/documents/integrated-pollution-and-waste-management-white-paper-draft.
[29]. United Nations, - What is the United Nations Framework Convention on Climate Change? 2023, Retrieved on April 20, Available online: https://unfccc.int/process-and-meetings/what-is-the-united-nations-framework-convention-on-climate-change.
[30]. World Bank, - World Development Indicators, 2023, Retrieved on May 18, Available online: https://databank.worldbank.org/source/world-development-indicators.
[31]. Yelland, C. - South Africa's Energy Policies: Are changes finally coming? French Institute of International Relations, 2020, Retrieved on April 21, Available online: https://www.ifri.org/en/publications/editoriaux-de-lifri/edito-energie/south-africas-energy-policies-are-changes-finally.