Government Expenditure, Gross Fixed Capital Formation and Carbon Dioxide Emissions within Climate Change Context in South Africa

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Abstract

The purpose of this study was to evaluate the effectiveness of government expenditure and investment in attaining low carbon emissions in South Africa. Particular attention is paid to differential effectiveness of government expenditure on research and development (R&D) and gross fixed capital formation (GFCF) on lowering carbon dioxide emissions. By 2030 South Africa is aspiring to be a climate-change resilient economy and low carbon-economy. The National Development Plan identified zero carbon-emission building standards, less carbon-intensive electricity production and economy wide carbon price as critical in efforts to achieve inclusive, low-carbon and resource-efficient economy. This study evaluated the effectiveness of government expenditure on research and development (R&D) and gross fixed capital formation on reducing carbon dioxide emissions. The study applied the autoregressive distributed lag (ARDL) bound test for cointegration, fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares(DOLS). The research used time series data from 1990-2022. The ARDL estimation results showed that gross fixed capital formation increases carbon dioxide emissions in both the short and long run. FMOLS and DOLS models confirm that GFCF promote carbon emissions in the long run though with different magnitudes. This outcome suggested that infrastructure development aimed to build an economy might lead to excessive depletion of natural resources, disruption of eco-systems and threat to climate change. Regarding, outcomes obtained from ARDL, FMOLS and DOLS indicate that government expenditure on research and development emerged as influential in lowering carbon dioxide emissions. South Africa faces challenges to balancing economic growth with carbon dioxide emissions. The findings of this research have implications to government providing insights to spend more on research and development.

INTRODUCTION

South African is aspiring to transition to environmentally sustainable, climate change resilient and low-carbon economy. Hence, the long term development policy document placed greater emphasis on decreasing carbon dioxide emissions, the National Development Plan (NDP): Vision 2030. The NDP recognise lower carbon emission as critical to sustainable economic growth, alleviation of poverty and job creation (National Planning Commission, 2011). As noted by Nosheen, Iqbal and Khan (2021) that carbon dioxide emission not only have adverse effect on health but harmful to global environment as well as sustainable growth.

Realising the detrimental effect of carbon dioxide emissions, South African authorities targeted zero carbon–emission building standards, less carbon-intensive electricity production and economy wide carbon price by 2030 (National Planning Commission, 2011). South Africa is the 27th largest economy in the world and one of the top 20 global emitters, with a high dependency on fossil fuels (Department of Environmental Affairs, 2020). The country embrace green economy through lower carbon dioxide emission as a result the government is commitment to ultimately moving towards net zero carbon emissions by 2050 and achieve Paris Climate Change Agreement. Furthermore, the government of South Africa took up a responsive to drive actions to combat climate change and its impacts, to achieve Sustainable Development Goal 13 (Department of Environmental Affairs, 2020).

Zubair, Samad and Dankumo (2020) compared per GDP and territorial carbon dioxide emissions considering 10 key economies in Africa in 2018. The researchers discovered that South Africa and Libya are the highest greenhouse gas emitters in Africa, which may be linked to industrialization and oil production, respectively. According to Espoir, Sunge and Bannor, (2023), South Africa is responsible for 38 % of continental total CO2 emissions from fuels and cement manufacturing while Morocco, Libya, Nigeria, Egypt and Algeria together are responsible for 46 %. From these studies, South Africa seems to be dominant in environmental degradation in Africa.

Clearly, South Africa is struggling to contain carbon emissions, supported by the Green Growth Index (GGI) score of around 50, suggesting that the country is not performing well in all four dimensions of the index. Factors undermining carbon emission efforts in the country is high dependence on coal for energy (International Monetary Fund, 2022). High reliance on non-renewable energy as source power impede the country's efforts to curb and adapt to the devastating impacts of climate change. Transition to green economy and decarbonisation require green investment in critical infrastructure. Investing in green technology and innovation will provide solid foundation for climate change resilient economy. It is against this background that this study seeks to evaluate the effectiveness of government expenditure and investment in attaining low carbon emissions in South Africa. Particular attention is paid to differential effectiveness of government expenditure on research and development (R&D) and gross fixed capital formation (GFCF) on lowering carbon dioxide emissions.

Global Green Growth Institute Report of 2023, portrays a bright picture about South Africa as leading on the social inclusion dimension and have potential for green economic opportunities (green investment, green trade, green employment and green innovation) in Southern Africa. Thus, the country is expected to have an important role in driving green economy by unlocking its green economic opportunities. It is for this reason that the South African government launched a range of legislation, policies, strategies and plans. In 2020, the government introduced the National Climate Change Adaptation plan, South Africa's Low Emission Development Strategy 2050 (Statistics South Africa, 2023). In an effort to confirm, its commitment to reduce carbon dioxide emissions, in 2021 the government of South Africa submitted its First Nationally Determined Contribution under the Paris Agreement to the United Nations Framework Convention on Climate Change (UNFCCC).

During the study period 1990-2022 South African government pay attention to gross fixed capital formation, industrialisation, achieving inclusive and sustainable growth and attract foreign direct investment. This study established that gross fixed capital formation promote carbon emissions. Hence, there is a need to exert more effort to explore complementary policy interventions to ensure balance between achieving inclusive sustainable growth and low carbon dioxide emissions. Majority of reviewed studies focused on carbon emission effects of government expenditure on education and healthy respectively. From the best of the researcher knowledge there is no study that has investigated the impact of government expenditure on research and development and gross fixed capital formation on lowering carbon dioxide emissions in South Africa. This study is different from reviewed literature and in this respect represent its unique contribution.

The discussion unfolds in a manner that carbon dioxide (CO2) emissions within climate change context is presented in section 2. Section 3 provides literature review, while methodology, data analysis and estimation results are discussed in sections 4 and 5 respectively. Section 6 offers conclusion and policy recommendations.

CO2 EMMISSIONS WITHIN CLIMATE CHANGE CONTEXT

Climate change resulting from rising greenhouse gas emissions from human activity continue to impose and worsen socio-economic challenges around the globe. Greenhouse gas emissions include carbon dioxide from burning of fossil fuels. Developing and emerging economies are characterised by high level of income inequality, unemployment, poverty and low levels of economic growth. In order to address afore mentioned socio-economic challenges governments have an important role to play in achieving sustainable economic, providing law and order and provide public goods. However, there is complicated interdependence between environmental degradation (climate change) and economic growth as highlighted by Espoir, *et al* (2023). In support of this notion, Han and Gao (2024) indicated that human activities aimed at economic growth, mass production together with population growth and urbanization, lead to excessive depletion of natural resources, disruption of eco-systems and threat to climate change. Osobajo *et al* (2020) noted economic growth of any country depend on a number of different factors, which may have detrimental effect on environmental degradation. Meanwhile, Espoir,*et al* (2023) argued that countries with higher economic performances often face several environmental challenges.

Odhiambo (2023) highlighted that energy stimulate economic growth while at the same bringing environmental problems via carbon dioxide emissions and hinder sustainable economic growth. Jong, Soh and Puah (2022) contributed to the climate change and economic growth debate by adding that the climate crisis affected at least 33 million people in parts of east and Southern African region. In the context of South Africa, climate change worsen realities of inequality due to its potential to impede efforts to reduce poverty, unemployment as well as food insecurity Johnston, *et al* (2024).

Furthermore, Venter and Inglesi- Lotz (2023) pointed out that climate change have negative multiplier effect on individual livelihoods and welfare of the entire country. For example, high water temperatures reduce fishing, decreases agricultural output as well as income, while droughts and floods destroy crop yields and displace individuals. It is in this context that, Onofrei, Vatamanu and Cigu (2022) advocated for the implementation of environmental protection policies based on their findings that higher economic growth lead to environmental degradation. Huang *et al* (2022) and Onofrei *et al* (2022) argue that low carbon dioxide emissions is a mechanism in an effort to reduce environmental degradation globally and mitigate adverse impacts of climate change.

Hamilton and Kelly (2017) in Espoir, *et al* (2023) observed that most countries in Africa are developing hence the consumption for fossil energy and carbon dioxide emissions are expected to rise. Espoir,*et al* (2023) supported this view and further ague that emerging economies rapid increase in energy demand may push their emissions in absolute terms above those of industrialised economies. To validate this view, Espoir and Sunge (2021) noted that carbon dioxide emissions are responsible for approximately 70 % of total greenhouse emissions. Even though there are different types of greenhouse gases, CO2 is attracting more attention due to its long-stay in the atmosphere and as major driver of climate change. The key concern in many countries is the reduction of carbon dioxide emissions.

When examining the issue of carbon dioxide emissions, it is importance to look at the Green Growth Index, developed by Global Green Growth Institute with the aim of assessing country's performance in achieving Paris Climate change agreement and meeting SDG 13. The Green Growth Index entails four green growth dimensions, namely efficient and sustainable resources use (ESRU), social inclusion (SI),green economic opportunities (GEO) and natural capital protection (NCP). For comparative purposes this paper looked at green growth index for South Africa, Botswana and Lesotho.

Table 1: Green Growth Index for South Africa, Botswana and Lesotho (2020-2023)

2020					
	ESRU	SI	GEO	CNP	**GGI Score**
SA	39.14	67.88	23.97	62.95	50.70
BOTS	66.96	57.77	11.70	72.41	55.70

LES	51. 82	59.81	8.61	42.68	42.65
2021					
SA	38.59	67.47	23.31	64. 87	50.70
BOTS	69.72	57.24	17.34	72.68	57.90
LES	59.36	54.84	14.22	41.34	45.08
2022					
SA	39.53	69.57	43.64	64.49	52.74
BOTS	73.63	57.56	41.23	64.99	58.11
LES	62.34	53.01	40.13	41.46	48.42

Source: Global Green Growth Institute, technical reports (2021, 2022 & 2023)

Notes: SA – South Africa, Bots- Botswana, Les- Lesotho, GGI- Green Growth Index

ESRU- Efficient and sustainable resources use (efficient and sustainable energy, efficient and sustainable energy, efficient and sustainable water use, sustainable land use and material use efficiency) , SI – Social Inclusion (Access to basic services and resources, gender balance, social equity and social protection), GEO- Green economic opportunity (Green investment, green trade, green employment and green innovation) , NCP – Natural capital protection environmental quality, GHG emission reductions, biodiversity and ecosystem protection and cultural and social value . GGI Score: range from 1 – 100, 1-20 are very low scores requiring significant actions to improve position relative to the target, 20-40 low scores identifying the right policies to align development toward achieving the target, 40-60 are moderate scores finding the right balance to move forward to and avoiding moving away from the target, 60-80 are high scores, taking a strategic position to completely reach the target (Global Green Growth Institute Technical Report, No. 32, 2023).

Table1 reveals that green growth index scores are moderate for these three countries. In 2020, the score on green growth index ranged between 42.65 and 55.70. However, in 2022 a slight improvement was registered with a range of 48.42 to 58.11. Clearly these countries are struggling to find the right policy balance so as to move forward to green economy targets. The table further shows that, Botswana is the best performer in ESRU while South Africa is dominating in the social inclusion dimension. Considering the natural capital protection, a dimension that includes low carbon dioxide emissions, Botswana and South Africa appear to have potential. On the contrary, South Africa is performing very low on efficient and sustainable resource use. On the other hand, Lesotho seems to be struggling to align its development policies to achieve SDG 13.

LITERATURE REVIEW

From theoretical perspective, the connection between environmental degradation and economic growth can be traced back to work of Kuznets. Simon Kuznets (1955) investigated the link between economic growth and natural resources. Kuznets study established an inverted U-shaped association between natural resources and economic expansion. The results suggested that at the initials stages of economic expansion, growth is accompanied by massive environmental degradation. However, as the economy experiences economies of scale, innovation and income increases then the environment improves.

Liu (2017) provided empirical evidence for nonlinear relation between natural resources and economic expansion. Liu (2017) stated that during initial phase of economic expansion, industrial production is driven by fossil-fuel generated energy which in turn emit large volumes of greenhouse gases particularly carbon dioxide. As economic growth advances countries are able to invest in production technologies that reduce carbon dioxide emissions (Onofrei *et al*, 2022). On the same issue, Nosheen, Iqbal and Khan (2021) support Kuznets hypothesis based on their study conducted for the Asian region focusing on tourism and CO_2 emissions. The outcome revealed tourism industry as responsible to increase carbon emissions up to a threshold level beyond which pro-environmental friendly technologies outweigh negative impact of tourism on the environment.

There is a number of empirical studies that have been conducted to provide a deeper understanding of interdependence between CO_2 emissions and different macroeconomic indicators. For example, Jong, Soh and Puah (2022) undertook a study, aiming to establish dynamic interaction between climate change and tourism demand using quarterly data from 2010-2019. Estimated result revealed a negative relationship between carbon dioxide emissions and tourism in South Africa. In another study for the same country, Shikwambana, Mhangara and Kganyago (2021) discovered that carbon dioxide emissions are positively correlated with economic growth during 1994-2019. The study applied the Modern-Era Retrospective Analysis for Research and Analysis Version 2, linear regression and the sequential Mann- Kendall test. The study outcome further revealed SO_2 and CO exhibited an N-shape association.

On the same issue, Ekwueme *et al* (2021) recommended alignment of energy efficient foreign direct investments, fiscal development and trade openness in order to reduce CO_2 emissions. This suggestion was based on the study conducted for South Africa exploring interaction between foreign direct investments, fiscal development, renewable energy usage, economic growth and CO_2 outrush in South Africa from 1970 to 2014. In a related study, Alshehry and Belloumi (2024) utilised the Dumitrescu-Hurlin panel causality to assess the symmetric and asymmetric effects of energy consumption and economic growth on environmental sustainability. Focusing on 17 Middle East and North African (MENA) countries the empirical results supported the Kuznets curve. In the long-run economic growth cause environmental degradation whereas energy consumption is responsible for environmental damage both in the long and short -run during 1990-2020. Furthermore, bidirectional causality was observed between economic growth and CO2 emissions and energy consumption and CO2 emissions.

In the proceeding paragraphs, the aim was to shed light that considerable effort has been made to provide contribution on the association between the environment and selected macroeconomic variables. The next section draws attention to empirical work pertinent to the current study.

Effect of Government Expenditure on Carbon Dioxide Emissions

Shobande and Asongu (2021) examined linkage between financial development, human capital development and climate change in the context of 12 East and Southern Africa. The study applied panel VAR/VEC Granger causality model between 2000 and 2018. The study outcome showed that human capital development is vital in reducing carbon dioxide emissions. The scholars concluded that investment in human capital can promote environmental sustainability.

Focusing on Sri Lanka economy, Adikari, Liu, Dissanayake and Ranagalage (2023) examined the role of human capital development in reducing carbon dioxide emission. The researchers relied on time series annual data covering the period of 1978-2019. In their attempt, Adikari, Liu and Ranagalage (2023) regressed CO2 emissions per capita, human capital index, GDP per capita, urban population growth and foreign direct investment net inflows as a percentage of GDP. The autoregressive distributed lag (ARDL) approach reported that a one percent rise in human development reduce carbon dioxide emissions by approximately 1. 63 percent. Based on these findings, the researches recommended that investing in education has a potential to decrease carbon dioxide emissions and drive green economy in the long-run, supporting Shobande and Asongu (2021).

Interested in analysing the direct and indirect impacts of air-related government expenditure on CO2 emissions Oh (2023) applied a two – stage dynamic panel model for the Republic of Korea. For this purpose, the author analysed 16 cities and provincial regions for the period 2008 to 2018. Results indicate that local government expenditure for air quality reduce carbon dioxide emissions, whilst indirectly increases CO2 emissions through regional economic growth. The findings further reveal that the direct effect exceeds the indirect effect resulting into total effect being beneficial in reducing CO2 emissions. Slathia et al (2024) examined the impact of renewable energy, carbon dioxide emissions and economic growth on health care expenditure in 36 Asian countries. Fully Modified Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) estimated results indicate that CO2 emissions rise as a result of private and public health care spending.

With the aid of Fourier ARDL model Li, Chang, Wang and Zhou (2022) determined the nature of relationship between health care expenditure, CO2 emissions and economic growth in four BRICS countries, namely Brazil, India, China and South Africa from 2000 to 2019. Study results found that for India, CO_2 emissions and health care expenditure exhibit a two way negative causal relationship in the short-run. On the contrary, Brazil and China health care expenditure and CO_2 emissions have a positive correlation. However, in the long-run increasing health care expenditure appeared instrumental in CO_2 emissions in Brazil, China and India. In South Africa, results disclosed that the frequency of CO_2 emissions to healthcare expenditure is longer than that of health expenditure to CO_2 emissions. Suggesting that the South African government should spend more on health.

Jin *et al* (2024) analyse effectiveness of nuclear energy research and development in improving environmental quality in the context of Germany using data from 1974-2018. The study applied Augmented ARDL, DOLS and Fourier causality. The results unveil that investment in nuclear energy research and development is instrumental in enhancing ecological quality. Hence, the scholars recommended that government should spend more on research and development.

Relationship between Gross Fixed Capital Formation and Carbon Dioxide Emissions

Recent studies that have focused on the relationship between carbon dioxide emissions and gross fixed capital formation include Ekwueme *et al* (2021), Onofrei *et al* (2022), Chidiebere-Mark, *et al* (2022) and Alshehry and Belloumi, (2024). Riti *et al* (2022) empirical investigated the linkage among renewable energy, real GDP, emissions of greenhouse gas and gross fixed capital formation focusing on sub-Saharan Africa. The results of panel regression distributed lag (PARDL) showed that real gross fixed capital formation have an adverse effect on the environment through its association with carbon dioxide emissions. Additionally, the study discovered a bidirectional causal relationship between real GDP, renewable energy and gross fixed capital formation. Dumitrescu and Hurlin Granger causality test further disclose presence of unidirectional causality flowing from renewable energy to CO_2 emissions.

Prakash and Sethi (2023) contributed to the debate on gross fixed capital formation- CO_2 emissions nexus. Focusing on the economy of India during two distinct periods that is before (1971-1990) and after (1991-2021). Results from the ARDL indicated that gross fixed capital formation has no significant influence on carbon dioxide emissions before (1971-1990). However, after trade liberalisation (1991-2021) gross fixed capital formation exert pressure on greenhouse gas emissions particularly carbon dioxide emissions. Zubair, Samad and Dankumo (2020) performed ARDL bounds testing to cointegration and VAR approaches to ascertain that gross domestic income, trade integration, foreign direct investment and gross fixed capital formation reduce CO_2 emissions in Nigeria during 1980-2018. The outcome of this study confirmed that FDI inflows, GDP and gross fixed capital formation have a pull down effect on CO_2 emissions. On the other hand, Granger causality revealed one way causality from gross fixed capital formation to CO_2 emissions.

To explore association between CO_2 emissions and gross fixed capital formation Nur *et al* (2024) applied the ARDL, DOLS and FMOLS models. The scholars discovered that gross fixed capital formation was not an influencing factor on CO_2 emissions during 1991- 2019 in Somalia. Alshammry and Munneer (2023) used decoupling index and VECM to analyse the influence of economic development, gross capital formation and internet use on environmental degradation in Saudi Arabia. Gross capital formation emerged responsible for carbon dioxide emissions in the short-run during 1995-2020.

METHODOLOGY

This section builds upon the previous reviewed literature to explain the framework that is used for analysis in this study.

Data Sources

The study employed time series annual data sourced from the South African Reserve Bank (SARB) online data base and the World Bank Development Indicators. The study analysed data for the period of 1990- 2022. The methodology is focusing on estimating differential linear effect of government expenditure on R&D and gross fixed capital formation (GFCF) on carbon dioxide emissions. The study is working with variables measured in different units, it was appropriate to apply logarithms.

Model Specification

Following Jong *et al* (2022) and Zubair, Samad and Dankumo (2020), the econometric model estimated in this study is specified as follows:

$$LCO_{2t} = \beta_0 + \beta_1 LCO_2 + \beta_2 LRESEARCH_t + \beta_3 LGFCF_t + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where L indicates logarithms, CO_2 stands for carbon dioxide emissions measured in metric tons per capita, while β_(0) is the constant term. Additionally, β_1- β_3, , are coefficients of the respective explanatory variables. Research denotes government expenditure on research and development and GFCF is gross fixed capital formation as percentage of GDP used as a proxy for investment.

This study applied autoregressive distributed lagged (ARDL) a dynamic econometric technique introduced by Pesaran *et al* (2001). The ARDL is applicable irrespective of whether the time series data are integrated of I(0), I(1) or mix of I(0) and I(1) but not I (2) as alluded to by Jong et al, (2022). Additionally, the technique allows for the determination of both short and long –run dynamics in the model (Zubair, Samad and Dankumo ,2020). Hence, the short-run and long-run log transformed model is presented as:

$$\Delta LCO_2 = \delta_0 + \sum_{i=1}^{n} \delta_1 \Delta LCO_{2t-1} + \sum_{i=0}^{n} \delta_2 \Delta LRESEARCH_{t-1} + \sum_{i=0}^{n} \delta_3 \Delta LGFCF_{t-1} + \gamma_1 ECT_{t-1} + \varphi_0 LCO_{2t-1} + \varphi_1 LRESEARCH_{t-1} + \varphi_2 LGFCF_{t1} + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

Variables are describes as in equation (1), t = is the time period, δ_0- δ_(3) represent constant and short-run parameter respectively, whereas φ_0 - φ_2 stand for long-run constant and long-run coefficients, Δ is the difference operator and μ is the disturbance term. Moreover, 〖ECT〗_(t-1) is the one lagged error correction term, with coefficient given by γ_1 is expected to be statistically significant and have a negative sign.

Robustness Determination with FMOLS and DOLS

Motivated by Jin *et al* (2024) and Nur *et al* (2024) to ascertain strength of the ARDL long-run results, the study used the fully modified ordinary least squares (FMOLS) developed by Kao and Chiang (2000) and the dynamic ordinary least squares (DOLS) approach. Rehman, Noman and Ding (2020) argued that FMOLS procedure is robust in dealing with problem of heteroscedasticity, while DOLS estimator has an ability to address serial correlation (Nur et al (2024).

RESULTS AND DICUSSION

This section provides discussion of empirical findings.

Unit root test results

The stationarity properties of the variables were analysed using the augmented Dickey-Fuller (ADF) and Phillips-Perron stationarity tests, results are presented in Table 1 for both level and first difference. The unit root tests were performed in the form of intercept, intercept with trend and none.

Table 1: Unit root test results

ADF at level				**PP at level**		
Variables	**Intercept**	**Trend & Intercept**	**None**	**Intercept**	**Trend& Intercept**	**None**
LCO2	-1.5772	-1.9655	-0.5906	-1.3779	-1.7968	-0.7730
LRESEARCH	-1.0051	-0.6967	2.5258	-1.2769	-0.4795	3.5400

LGFCF	-2.0301	-1.7536	-1.0458	-1.7359	-1.6887	-1.0458
First difference						
LCO2	-7.3036**	---	---	-7.5111**	---	---
LRESEARCH	-4.6584***	---	---	-4.6989***	---	---
LGFCF	-3.4690**	---	---	-3.3762	-3.1832	-3.3634**

Source: Author's computation based on E-views 12. Note: ***, ** and * denote significance at 1%, 5% and 10% respectively, ---indicate that variable became stationary at first difference under intercept form

The ADF and PP test results indicate that all the variables are nonstationary at level and become stationary when differences once, implying that the variables are integrated of order one or I (1) from both ADF and PP stationarity tests. The outcome support the application of ARDL estimator.

Testing for co-integration

Having established that the series is integrated, the conducted ARDL bounds test for co-integration to determine long-run relationship between government expenditure on research and development, gross fixed capital formation and carbon dioxide emissions. The selected ARDL model (1,1,0) is based on the Akaike Information Criterion(AIC).

Table 2: ARDL Bounds test

Test Statistic	**Value**	k
F-statistic	4.7214	2
Critical Value Bounds		
Significance	**I(0) Bound**	**I(1) Bound**
10%	2.17	3.19
5%	2.72	3.83
2.5%	3.22	4.3
1%	3.88	5.3

Source:Author's computation based on E-views 12.

Table 2 indicates that the F-statistics value is greater than the upper critical limit value of 3.83 at a 5% level of significant, confirming presence of long-run relationship between the model variables. The results suggest that government expenditure on R & D and GFCF move together in the long-run.

ARDL Short-Run and Long-Run Results

Results in Table 3, unveil that in the long-run previous period CO2 emissions increases the current CO2 emissions. To be specific a one percentage increase in the previous CO2 emissions lead to an approximately 71 percent rise in current CO2 emissions.

Table 3: ARDL long and short-run results

Variables	ARDL Model(1,1,0)		
	Coefficients	t-statistic	P-value
LCO2(-1)	0.708805**	5.041646	0.0000
LRESEARCH	-0.339251**	2.580617	0.0154
LGFCF	0.264971*	1.930889	0.0637
D(LRESEARCH)	0.339251**	2.937088	0.0066
ECT(-1)	-0.291195	-2.957585	0.0062
R-squared: 0.6485 Adjusted R-squared: 0.6108 Durbin-Watson stat: 2.2817			

Source:Author's computation based on E-views 12, Note: ***, ** and * denote significance at 1%, 5% and 10% respectively

Regarding expenditure on research and development (LRESEARCH) the outcome disclose negative association with CO2 emissions both in the short and long –run. Specifically, a 1 percent rise in government expenditure on research and development reduce carbon emissions by around 0.33 percent in the long term. This outcome support the findings of Jin et al (2024). Aghion and Howitt (1992) in Li et al (2022) argue that research and development (R&D) efforts give rise to technological innovation. Increasing expenditure in the energy conservation (R&D) lead to low CO2 emissions. It is important for government to take into consideration in investment decisions R &D green technology innovation discoveries. Whereas in the short-run LRESEARCH is increasing CO_2 emissions by 0.34. Investment in gross fixed capital formation (LGFCF) is detrimental to environmental quality, the positive carbon emissions effect GFCF indicate that government embarked on emission-intensive investment during 1990-2022. The results indicate that 1 percent increase in capital formation lead to approximately 26 % carbon emissions, this outcome is aligned with the findings of Alshammry and Munneer (2023), Prakash and Sethi (2023) and Riti et al (2022).

Robustness check

For intensive purposes, FMOLS and DOLS results enhance ARDL long run results. However, with different magnitudes expenditure on R & D is capable of reducing CO_2 emissions, by 0.06 % and 0.08 % respectively. Whereas, investment in fixed capital damages environmental quality through CO_2 emissions, 1 percentage change in GFCF is associated with approximately 0.94 % of carbon emissions as presented in table 4.

Table 4: FMOLS and DOLS result

FMOLS				DOLS		
Variables	Coefficient	t-statistics	Prob	Coefficient	t-statistic	Prob
LRESEARCH	-0.0641**	-2.1095	0.0434	-0.0800**	-2.3918	0.0258
LGFCF	0.9414	9.3445	0.0000	0.9873**	8.6377	0.0000
R-squared	0.1107			0.5396		
Adjusted R-squared	0.0811			0.3931		

Source: Author's computation based on E-views 12, Note: ***, ** and * denote significance at 1%, 5% and 10% respectively

To move towards net zero carbon emissions by 2050 and achieve Paris Climate Change Agreement and SDG 13, the government of South Africa should invest on green infrastructure.

Post-estimation diagnostic test results

Post-estimation tests are vital to validate the coefficients of the results achieved by the model.

Table 5: Diagnostic tests

Test	Null Hypothesis	Test statistics	Probability	Decision

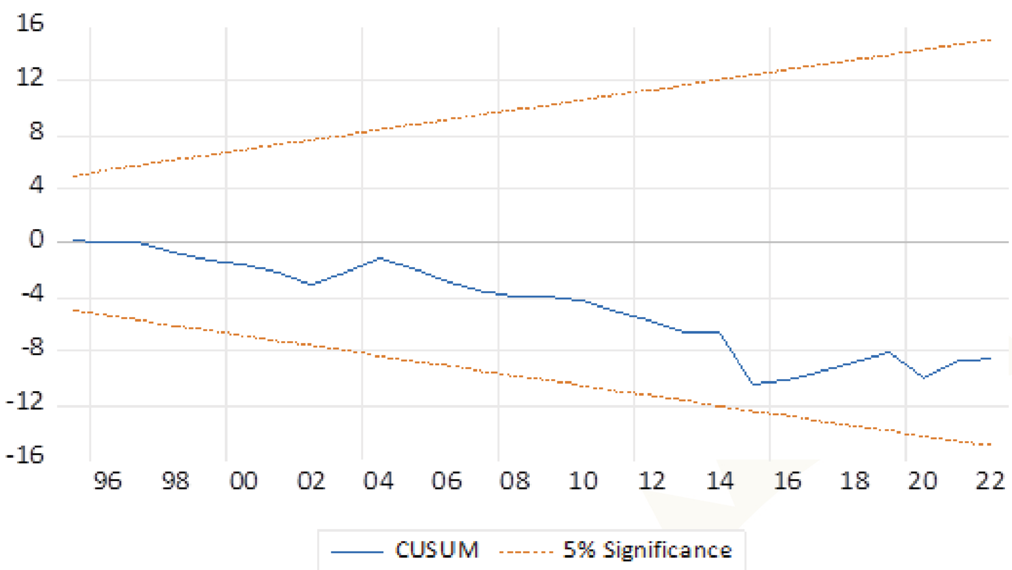
Breusch- Godfrey Serial Correlation –LM test	There is no correlation in residuals	Obs*Rsquared=1.977801	0.3720	There is no autocorrelation
Breusch-Pagan-Godfrey	Residuals are homoskedasticity	Obs*Rsquared=2.130090	0.7118	There is no heteroscedasticity

Source: Author's computation based on Eviews 12

The model was tested for serial correlation results indicate absence of serial correlation with a test statistics of 1.9778 and p-value of 0.3720 and the model does not suffer from heteroscedasticity confirmed by t-statistics of 2.130090 associated with a p-value of 0.7118.

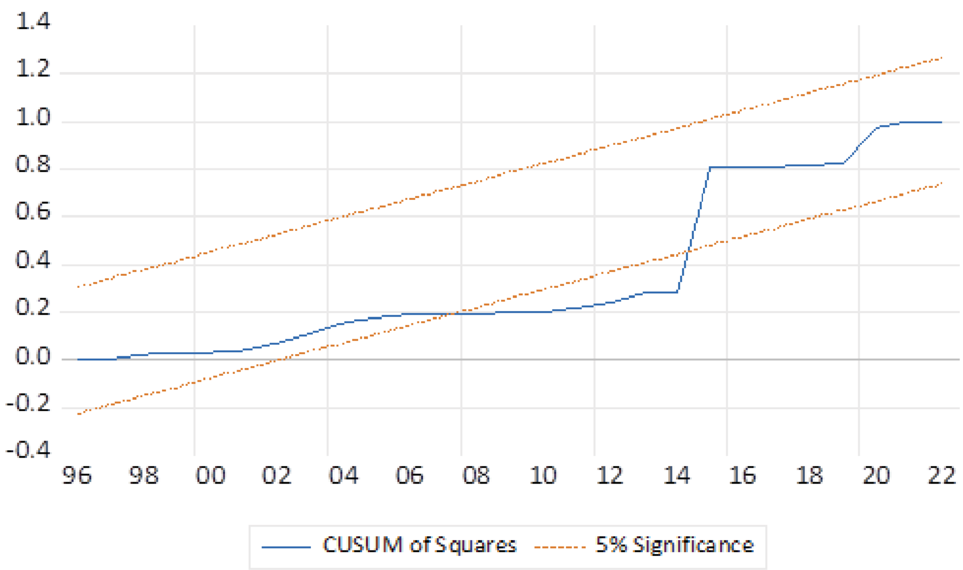
The stability of the estimated model was determined by using the cumulative sum of the recursive residual (CUSUM) together with the cumulative sum of squares of the recursive residual (CUSMSQ) tests.

Figure 1: CUSUM



Source: Author's computation based on Eviews 12

Figure 2: CUSMSQ



Source: Author's computation based on Eviews 12

Results on Figures 1 indicate that the plot of the CUSUM statistics lies inside the critical band of 5 % level of significance confirming parameter stability. However, CUSUMSQ shows that there was instability around 2008 to 2014 as can be seen on Figure 2. Overall, the estimated results are reliable for policy recommendations.

CONCLUSIONS, POLICY RECOMMENDATIONS AND LIMITATIONS

Moving towards net zero CO2 emissions by 2050, meeting SDG 13 and achieving targets of Paris Climate Change Agreement are daunting challenges facing South African economy. It is in this context that this study aimed to unravel the effect of government expenditure on R&D and GFCF on lowering CO2 emissions from 1990-2022. The study outcomes disclosed that expenditure on R&D are effective in reducing CO2 emissions in the long term as confirmed by estimations results obtained from ARDL, FMOLS and DOLS models. While GFCF is detrimental to environmental quality through its association with CO2 emissions. It is therefore, recommended that government should attract foreign investors who may invest in clean energy and R&D projects. The government should also increase expenditure on green infrastructure. South Africa's continuous emissions of carbon dioxide have spill over effects to other countries. Therefore, the study recommend engagements with international and regional collaborations so as learn from their successes and assimilate their carbon emission reduction strategies. The government should priorities reduction of carbon emissions as climate emergence. It is also important to highlight that this paper has limitations that warrant further investigation. The study evaluated differential effectiveness of government expenditure on research and development (R&D) gross fixed capital formation (GFCF) on lowering carbon dioxide emission, refrain to include other macroeconomic variables for more comprehensive understanding. Further studies may benefit from considering research and development as mediator of the relationship between gross fixed capital formation and carbon emissions.

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