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Examining the Effect of Government Expenditure, Urbanization and Green Finance on Carbon Emission: New Insight from the Southern African Development Community

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Abstract: ***The role of how southern African development communities (SADC countries) can substantially mitigate carbon dioxide emission (CO_2) remains fathomless. In consideration of this, this research explored the correlation between government expenditure (GEXP), urbanization (URB), green finance (GFN), human capital (HC), economic growth (GDP), information and communication technology (ICT), natural resource rent (NRR), and carbon emission (CO_2) using panel data from 1996 to 2020. In order to estimate the interaction between the variables, this work combined the augmented mean group (AMG) s, and common correlated effect means group estimator (CC - MG) model approaches. The result of this study reveals a positive and significant association between government expenditure, urbanization, economic growth, natural resource rent, and carbon emission. In contrast, human capital and information commutation technology extensively decrease carbon emissions, while green finance shows insignificantly positive in the SADC economies. Moreover, the outcome of the Granger causality test indicates that government expenditure and urbanization have a bidirectional association with CO_2. On the other hand, government expenditure and urbanization also have a bidirectional relationship with green finance. The Granger causality test revealed a unidirectional causality between economic growth, green finance, human capital, information and communication technology, natural resource rent, and carbon emission. Finally, this research has implications for policymakers in the SADC countries.***

Keywords: Carbon emission, Government Expenditure, Urbanization, Green Finance Natural Resources Rents

1. Introduction

The world is currently experiencing serious environmental problems related to climate change and greenhouse gases (GHG) (Doğan, Driha, Balsalobre Lorente, & Shahzad, 2021) . Concerns about climate change and warming brought on by carbon dioxide (CO_2) emissions have grown as a result of environmental hazards (Shen et al., 2021) . According to some academics, human activities like urbanization, deforestation, and the need to provide for food security as the global population grows are what contribute to these carbon emissions (Osobajo, Otitoju, Otitoju, & Oke, 2020) .

The question of whether or not the government should contribute to the reduction of greenhouse gases has always been significant. Environmental finance can help prevent environmental harm, improve environmental quality, and directly contribute to reducing carbon dioxide emissions (Basoglu & Uzar, 2019) . The reduction of CO_2 emissions may also be positively impacted by fiscal expenditures that are not related to the environment. Spending on education can increase locals' understanding of energy conservation, which indirectly encourages CO_2 reduction, while spending on science and technology can encourage the development of energy conservation technology (M. Li & Wang, 2017; Misra & Verma, 2015) . Prior research, however, did not take into account how regional socioeconomic variations influence the mechanisms through which fiscal policy has an impact on CO_2 emissions.

As the social structure has developed over time, cities have taken up residence. Urban areas contribute roughly 70% of global GDP, consume more than 75% of energy, and generate 72% of carbon emissions (Solomon Prince Nathaniel, Alam, Murshed, Mahmood, & Ahmad, 2021) . The impact of urbanization on economic development and environmental sustainability is significant. Some empirical studies show that unreasonable development and extraction of resources in the process of urbanization cause environmental damage and cause air, noise, and water pollution (I. Khan, Hou, Le, & Ali, 2021) .

The application of green financing (GFN) for economic growth is another novel idea in environmental sustainability. Now, green finance and environmental quality have taken center stage in environmental research and policy. Some academics have supported the thought of "green financing" as a way to enhance environmental quality. Similar to this, it was suggested by (Huang, Huang, Chen, & Sohail, 2022) that green finance encourages businesses to invest in technology that improves environmental quality, such as (non - fossil innovation investment), thereby helping to lessen environmental deterioration. Yet, research on how carbon emissions and green finance interact is still under progress. In the top ten economies with the largest GFN investment, (Saeed Meo & Karim, 2021) looked into how green finance affected carbon dioxide emissions.

Considering the preceding discussion, the current study investigated the dynamic interplay of government expenditure, urbanization, green finance, economic growth, information and communication technology, and natural resource rent on carbon dioxide emissions. The critical question to be addressed in this study is how developing economies, such as the Southern African Development Community (SADC), can maintain environmental sustainability while also advancing economic development. The practical contribution of this research is as follows; (1) Understanding the intricate relationships between the variables that affect carbon emission can help stakeholders and the government build policies and strategies to deal with these problems. (2) Empirical data are essential for assisting legislators, citizens, and other stakeholders in the SADC in better comprehending methods for achieving environmental sustainability. (3) The results of this study will give emerging economies a framework for economic growth and enhanced environmental protection.

2. Literature Review

This section of the research delves into the specifics of previous literature on the relationship between government expenditure, urbanization, green finance, economic growth, human capital, information and communication technology, natural resource rent, and carbon dioxide emissions.

2.1 Empirical review of Government expenditure and Carbon Emission

Governments are essential to the preservation of the environment, according to prior studies, the government's spending has a significant impact on reducing carbon dioxide emissions (Le & Ozturk, 2020) ; in addition, expenditure on areas other than the environment may have a favorable impact on CO_2 emissions reduction. Spending on education can increase locals' understanding of energy conservation and environmental preservation, which indirectly promotes CO_2 mitigation, but spending on science and technology can enhance energy conservation technology, which also indirectly promotes CO_2 mitigation (Misra & Verma, 2015) . Prior research, however, did not take into account how socioeconomic disparities between areas influence the mechanisms by which fiscal spending affects CO_2 emissions. According to (Carlsson & Lundström, 2001) , the larger the scale of government expenditures, the greater the degree of intervention in the market economy, which is likely to lead to a decline in energy efficiency and an increase in environmental damage. (Halkos & Paizanos, 2013) investigated the direct and indirect effects of government spending on CO_2emissions, their findings revealed that the direct effects of government spending on CO_2 emissions are not obvious. Based on data from Chinese cities, (Hua, Xie, & Su, 2018) investigated whether education and R&D expenditures would affect emissions through the accumulation of human capital and the development of clean technology, respectively. The results revealed that these expenditures had a minor impact on environmental governance. Environmental protection expenditures, are primarily used for energy conservation, pollution reduction, and environmental protection as a special expenditure of the Chinese government.

2.2 Empirical review of Urbanization and Carbon Emission

The urbanization boosts the urban population, which already have limited resources. As a result, demand for energy, food, transportation, water, housing, commercial buildings, electric appliances, and public utilities, among other things, rises, resulting in increased carbon emissions, over - extraction, and resource depletion (Ahmed, Wang, & Ali, 2019) . Despite its benefits to economic development, innovation, and knowledge, urbanization increases emissions, and has a negative impact on local food production (Winoto & Schultink, 1996) , reduces soil fertility (Ali, Bakhsh, & Yasin, 2019) , and generates massive waste, and contributes to deforestation and environmental degradation. Urban residents consume almost 75 percent of natural resources (Adams & Klobodu, 2017) , more than 66 percent of the world's total energy, and generate about 70 percent of total greenhouse gas (GHG) emissions. For instance, (Al - Mulali, Ozturk, & Lean, 2015) reveal a positive influence of urbanization on emission using FMOL methodology for 23 European Countries. Likewise, several other country - specific and panel studies report that urbanization upsurges energy demand.

2.3 Empirical review of green finance and Carbon Emission

Governments have under pressure to cut carbon emissions as soon as possible and connect their national emission reduction targets to the Paris Agreement (Sampene et al., 2022) . Environmental scientists are therefore discussing how carbon emissions and green financing are interrelated. An investment technique to safeguard the environment is known as "green finance" (Meo & Abd Karim, 2022) . In an effort to make up for inadequate government investment, green financing enables private investors to support environmental projects. There have been few studies that have linked green finance to carbon emissions. Environmental sustainability can be achieved, according to (Wang & Zhi, 2016) , by developing solar energy financing. A similar study conducted by (W. Li & Jia, 2017) , has indicated most effective way to reduce environmental degradation is through sustainable green finance. Sustainable green finance encourages investment in new technologies and innovations, such as renewable energy (Jones, 2015) .

2.4 Empirical review of human capital and Carbon Emission

Human capital, can be classified into three parts; "First general human capital, that includes general education and experience; second firm specific human capital, that is combination of firm associated education, knowledge and skills; third task specific human capital, that include task related knowledge, experience, training and skills" (Layard, 2009) . Mahmood, Wang, & Hassan, (2019) , analyzed the effect of energy use and economic prosperity on CO_2 emission with the consideration of human capital in Pakistan spanning over 1980 - 2014. They reported a decline in emissions resulting from human capital implying that it helps to control pollution. Similarly, (M. Khan, 2020) empirically analyzed the influence of human capital on CO_2 emission using a large sample of 122 economies for 1980 - 2014. The result reveals that for sustainable economic development education is required as it supports a decline in emissions. Wan et al., (2019) investigate the impact of human capital on CO_2 emission using a unique data set of 1870 - 2014 for 20 OECD countries. Their result indicates that nexus among human capital and CO_2 emission switched from positive to negative in the 1950s and this nexus is more consistent afterward. A remarkable contribution to literature comes from (Solomon P Nathaniel, Nwulu, & Bekun, 2021) who find the mixed effects of human capital on environmental quality on 18 LACCs from 1990 - 2017. Human capital reduces emission in 50% of countries and increases emission in the remaining 50% of countries.

2.5 Empirical review of economic growth and Carbon Emission

Analyzing the effects of economic growth on environmental degradation has recently fascinated a number of researchers. An increasing number of empirical studies have been conducted to explain the relationship between economic growth and environmental degradation. It is hypothesized that the negative effects of economic growth on environmental quality will be mitigated by efficient infrastructure and energy - saving technologies (Destek & Sarkodie, 2019; Nasreen, Anwar, & Ozturk, 2017) . Environmental degradation increases with rising per capita income in the early stages of economic development; however, after a certain level of per capita income, environmental degradation decreases (Jalil & Feridun, 2011; Ulucak, İlkay, Özcan, & Gedikli, 2020) . However, the relationship between economic growth and environmental degradation is more complex than monotonic, and the available evidence is mixed and inconclusive. For example, (Apergis, 2016) found mixed results when examining the impact of real GDP growth on per capita CO_2 emissions in 15 countries. The environmental Kuznets curve can be found in the majority of countries. In this regard, a study on 43 developing countries conducted by (Balsalobre - Lorente, Shahbaz, Roubaud, & Farhani, 2018) found that for Middle Eastern and South Asian countries (panels), carbon emissions decreased as income increased. The evidence from other developing economies is mixed. The studies on the US by (Apergis, Christou, & Gupta, 2017) show mixed results and evidence on the EKC hypothesis, which only holds true for some regions and states.

2.6 Empirical review of ICT and Carbon Emission

Information and communication technologies (ICT) have improved people's lives by becoming one of society's most important pillars. Increased progress has been observed in recent decades as a result of the expansion of ICT, This has allowed both households and businesses to increase their productivity, and businesses can now make decisions with minimal costs while significantly increasing output (Faisal, Tursoy, & Pervaiz, 2020) . The convergence of technology and innovation in ICT has enabled firms to achieve higher productivity with greater efficiency and effectiveness, not only at the firm level, but also at the aggregate industrial level. The efficient use of ICT provides the opportunity for developing economies to access resources and knowledge, thereby allowing them to integrate into the rest of the world and increase their competitiveness (Niebel, 2018) . Though the role of ICT in boosting economic growth cannot be overlooked due to its pervasiveness in advanced economies, its role in polluting the environment is debatable (Magazzino, Mele, Morelli, & Schneider, 2021) . As ICT becomes more powerful, energy consumption due to ICT usage has increased at a rate of 7% per year over the last few decades (Z. Wang, Asghar, Zaidi, & Wang, 2019), and by 2012, the world's energy consumption due to ICT - linked products had reached 4.7%, up from 3.9% in 2007. (A. Usman et al., 2021). Accordingly, the total contribution of the ICT sector in global CO_2 emissions has reached 2% by the year 2012 (Adebayo et al., 2022) .

2.7 Empirical review of natural resource rent and Carbon Emission

Natural resources have several distinct effects on the environment. Natural resources are used for production and consumption; however, unsustainable natural resource use, such as farming, deforestation, and mining, has an impact on the country's environment. The extraction of natural resources releases waste and chemicals into the environment's water and air (S. T. Hassan, Xia, Khan, & Shah, 2019) . Furthermore, human activities such as industrialization, deforestation, and mining result in excessive consumption of natural resources, which has an impact on environmental quality. At the same time, natural resources influence environmental quality through economic growth. The accelerating economic growth expedites natural resource extraction that increases carbon emission (S. Hassan, 2022) . Many countries rely on natural resources for a large portion to increase the rate of gross domestic product (GDP) (S. Hassan, 2022) . However, GDP indirectly relates to natural resource consumption (Betz, Partridge, Farren, & Lobao, 2015) . According to the traditional EKC hypothesis, during the scale effect of production, a rise in extraction and production of natural resources generates pollution.

3. Methodology, Data, and Empirical Model

3.1 Data source and unit of measurement.

The SADC countries were chosen for this study for the following reasons: (1) Various stakeholders and governments have expressed concerns about SADC countries' economic growth and environmental resilience. Coordinating the interaction of the environment and the economy, as well as minimizing the impact of global warming, are critical to the SADC countries' international sustainable development. (2) Over the last few decades, the SADC countries have seen rapid increases in urbanization, natural resource rent, and economic growth. Furthermore, due to data availability, the study examined panel data from 1996 to 2020. In this study, environmental pollution is used as a proxy for CO_2, the dependent variable. We measured CO_2 in metric tons, and it encompasses metric tons per capita. Various studies have used this variable in their research work.

Government Expenditure (GEXP), research measures general government final consumption expenditure (current US$) GEXP it has been used in research conducted by quality (Halkos & Paizanos, 2013; Q. Zhang, Zhang, Ding, & Hao, 2017) . It measures the money spent by the public sector on the acquisition of goods and provision of services such as education, healthcare, and social protection to supply goods and services that are not supplied by the private sector, such as defense, roads, and bridges; merit goods such as hospitals and schools, and welfare payment.

Urbanization (URB) determined the percentage of anurban population (% of total population), it has been used in research conducted by (Ahmed, Zafar, & Ali, 2020) . Urbanization varies impact across the countries CO_2 emissions in some countries have positive impact while reduces emissions in others. Likewise, (Behera & Dash, 2017) report mixed effects of urbanization on CO_2 emissions in SSEA countries. The findings reveal a positive role of urbanization in environmental degradation in middle and high - income countries, while no significant role in low - income countries. Using time - series data and the ARDL approach, (Baloch, Mahmood, & Zhang, 2019) find a negative contribution of urbanization in CO_2 emissions. The description of variables, unit measurement, and source of data for all the selected variables are indicated in Table 1.

3.2Descriptive statistical information

Table 2 indicates the statistical descriptive profile of the SADC for the study period from 1996 to 2020. The standard deviations are homogeneous in recognition, and the descriptive statistics of the variables utilized in the study. It is clear from the table that the data follows a normal distribution. The results show that all variables have a positive response of average to carbon emission. GEXP has the value of the mean, and Std. Dev with corresponding values of 21.68507 and 1.351212 respectively as General government final consumption expenditure (current US$). URB has the value of mean and Std. Dev with corresponding values of 3.662316 and 0.360828. We have GNF, GDP, HC, ICT, and NRR with their corresponding values of 3.383120, 3.121415, 2.816414, 0.821062, and -2.085420. The high indicates that it has more effect on carbon emission. Table 2 further provides the correlation matrix assessment information, which shows that all series are modestly associated with environmental pollution.

Table 1: Description Variable

Variable	Symbol	Description	Source
Carbon emission	CO_2	CO_2 emissions (metric tons per capita)	WDI
Government Expenditure	GEXP	General government final consumption expenditure (current US$)	WDI
Urbanization	URB	Urban population (% of the total population)	WDI
Economic growth	GDP	Gross capital formation (% of GDP)	WDI
Natural Resources Rents	NRR	Total natural resources rents (% of GDP)	WDI
Information communication technology	ICT	Fixed broadband subscriptions (per 100 people)	WDI
Green finance	GFN	Access to clean fuels and technologies for cooking urban (% of urban population)	WDI
Human capital	HC	Government expenditure on education, total (% of government expenditure)	WDI

Table 2: Descriptive statistical information

Series	CO_2	GEXP	URB	GFN	GDP	HC	ICT	NRR
Mean	30.354	21.685	3.662	3.383	3.121	2.816	- 2.085	0.821
Std. Dev	1.455	1.351	0.361	1.491	0.352	0.372	2.306	2.336
Maximum	2.133	25.146	4.261	4.592	4.095	3.273	3.215	4.023
Minimum	- 2.732	19.070	3.039	0.405	2.254	1.564	- 6.857	- 6.749
Jaque - Bera	13.783	37.224	14.829	38.791	1.889	149.535	6.268	168.317
observation	225	225	225	225	225	225	225	225
Correlation Matrix								
$C0_2$	1							
GEXP	0.518***	1						
URB	0.716***	0.724***	1					
GFN	0.783***	0.259***	0.557***	1				
GDP	- 0.136**	0.066***	0.202***	- 0.071***	1			
HC	0.112***	- 0.121**	- 0.184**	0.004	- 0.114***	1		
ICT	0.491**	0.304***	0.389***	- 0.484***	0.075***	0.117	1	
NRR	0.398**	0.251***	- 0.041***	- 0.345***	0.117**	0.303**	- 0.375***	1

Note * (10%), ** (5%) and *** (1%) denotes the level of significance accordingly

Theoretical underpinning

The researchers adopted the IPAT approach (I = PAT) developed by Ehrlich and Holdren (1971) . The model focuses on three main variables influencing pollution in the environment. Thus, environmental pollution (I) is influenced by population (P), affluence (A), and technology impact (T). To identify the interaction among the variable in this model on the CO_2 is to alter one of the variables and keep the others constant. York et al. (2003) developed the extended model of the IPAT to STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology). These two models have been used widely in environmental pollution research. STIRPAT is a new breed of IPAT, which assumes that a "variety of variables affect environmental pollution in the same proportion" (H. Zhang, 2021) . The mathematical function is derived as

$$I_{it} = \alpha P_{it}^{b} \times A_{IT}^{c} \times T_{it}^{d} \times \mu_{it} \qquad \textbf{Eq (1)}$$

In Eq. (1), I represent environmental pollution, population (P), affluence (A), and technological Impact (T). The terms b, c, and d were included in the IPAT equation to eliminate proportionality constraints in the approach. α is the constant in the model, and μ denotes the error it terms. i represents the individual units (countries), and t is the time dimensions. Based on the studies by Koçak and Ulucak (2019), we can formulate Eq. (2) as

$$\ln I_{it} = \alpha i + b\ln P_{it} + c\ln A_{it} + d\ln T_{it} + \mu_{it} \qquad \text{Eq (2)}$$

Therefore, revised Eq. (2) to demonstrate the impact of GEXP, URB, GFN, HC, GDP, ICT, NRR on CO_2.

$$\ln I_{it} = \alpha i + b\ln GEXP_{it} + c\ln URB_{it} + c\ln GFN_{it} + b\ln GDP_{it} + c\ln HC_{it} + b\ln ICT_{it} + c\ln NRR_{it} + \mu_{it} \qquad \text{Eq (3)}$$

In Equation (3), $InCO_2$ (carbon emission metric ton per capita), InGEXP (government expenditure), InURB (Urbanization), InGFN (green finance), InHC (human capital), InGDP (economic growth) lnICT (information communication technology), and lnNRR (Natural resource rent) represent their natural logarithms forms. The terms α – c represents the parameters for elasticity to be estimated in the model, α is the constant in the model, μ denotes the error terms, I represent the individual units' countries, and t is the time dimensions. It is important to note that this investigation did not include dummy variables. This is because it is anticipated that behavior does not change over time.

4. Econometrics Estimation Strategy

4.1 Cross - sectional dependency test

In our study, we found it necessary to start with Cross - sectional dependence before testing the panel unit root test. The reason for starting with CD, was to look for the existence of cross - sectional dependence our panel data. To detect the stationarity of the variables in this study, the author was in enticed to know the residual correlation within the cross - section. Therefore, in this research, we applied the following CSD test: (Breusch & Pagan, 1980; Chudik & Pesaran, 2015) . The mathematical representation is shown in Eq. (4):

$$CSD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N} \varphi i \sum_{m=i+1}^{N} \partial im \text{Eq} \qquad (4)$$

where T indicates the time, N represents the CSD in the panel, and ∂_{ij} denotes the correlation coefficient of i and m units.

Panel Series Stationary Test

We used second generation panel root test, i. e., cross - sectionally augmented Dickey–Fuller (CADF) and augmented cross - sectional Pesaran (2007) for the analysis of the unit root test on the selected variable. The CADF and CIPS test assists in addressing the issues of CSD and also tackles spurious in analyzing regression results. Moreover, both stationarity tests helped the researchers examine the robustness and accuracy of the series heterogeneity and also ignoring the cross - sectional dependence can cause serious invalid results statistically. The mathematical expression for the CADF test is described in Eq.5 Below.

$$\Delta x_{it} = \alpha_{it} + \beta_{it-1} + \delta_I T + \sum_{j=1}^{N} \gamma ij \Delta xit - j + \mu_{it} \text{Eq (5)}$$

where x_{it} indicates the variables analyzed in the study, Δ represents the difference in the variables, and μ_{it} shows the white error term. The Akaike information criteria (AIC) selected the appropriate optimal lag lengths.

The CIPS test is expressed in a mathematical form as in Eq (6):

$$CIPS = \frac{1}{N} \sum_{i=1}^{n} \varphi\, i(N, T) \text{Eq} \qquad (6)$$

where the parameter φ_i (N, T) indicates CADF regression test statistics.

4.2 Panel Co - integration Test

The study employed two approaches to analyze the long - run association among the variables. First is the Pedroni (2004) co - integration approach, which explores the co - integration association between the series by examining if the residual value component of the equation is steady. The null hypothesis (H0) of this technique is that there exists no co - integration in the series. The cointegration test is expressed mathematically as in Eq. (7):

$$y_{it} + \alpha_i + \psi i^t + \sum_{n=0}^{n} \beta ni, x_{nit} + \mu_{it} \qquad \text{Eq (7)}$$

Where α_i indicates the specific individual effect, $\psi_i = \psi_i$ *and* ψ_{2_i} shows the series trend, and n represents the explanatory variables. Second is the Westerlund (2007) co - integration approach, which analyzes our series CSD and heterogeneity. The null hypothesis (H0) of this technique indicates that there exists no co - integration in the error correction term among the series. The model is mathematically expressed as in Eq. (8):

$$\Delta y_{it} + \psi_i d_t + \alpha_i (y_{it-1} - p x_{it-1}) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{it-1} + \sum_{j=-p_i}^{p_i} \phi_{ij} \Delta x_{i,t-j} + \mu_{it} \text{......Eq (8)}$$

where d_t = (1, t) ′ provides the series trend, elasticity estimates indicate the constant term for all countries series, and i and t indicate all the CSD and period of the study. The test statistics of the two categories of this approach are expressed mathematically as in Eqs. (9) – (12):

$$G_\tau \frac{1}{N} \sum_{I=1}^{N} \frac{\text{ň}_i}{S.E(\text{ň}_i)} \qquad \text{Eq (9)}$$

$$G_\tau = \frac{1}{N} \sum_{i=1}^{N} \frac{T\text{ň}_i}{1 - \sum_{j=1}^{k} (\text{ň}_{ij})} \qquad \text{Eq (10)}$$

The panel co - integration approach statistics is mathematically estimated as

$$P_\tau \frac{\text{ň}_i}{S.E(\text{ň}_i)} \qquad \text{Eq (11)}$$

$$P_\alpha = T\text{ň}_i \qquad \text{Eq (12)}$$

where G_τ and G_τ show the group mean statistics, P_τ and P_α indicate the panel statistics , and ˆň$_i$ indicates the transition from short-run to long-run equilibrium in terms of speed.

4.3 Long - run estimation models

The investigation used the following econometrics methodologies after demonstrating the presence of long - run correlation among the variables: the augmented mean group (AMG), and common correlated effect means group estimator (CCMG), (Eberhardt & Bond, 2009) . The AMG model helps estimate the coefficient of the slope heterogeneity across cross - sections, generating the specific group information or estimation. The AMG technique is based on a two - stage approach and is mathematically expressed as in Eqs. (13) – (14):

Stage one AMG technique:

$$\Delta Y_{it}=\varphi_i + \delta_i \delta x_{it} + \gamma_i \vartheta_t + \sum_{t=2}^{T} \theta_i \Delta D_t + \mu_{it} \quad \textbf{Eq (13)}$$

Stage two of the AMG technique:

$$AMG_{estimator}= N^{-1} \sum_{i=1}^{N} \beta_i \quad \textbf{Eq (14)}$$

Where φ_i represents the intercept, Y_{it} and X_{it} indicate the observed variable, ϑ_t denotes heterogenous variables with unobserved common factors, Δ indicates the initial operator of the variables, time dimension t, and μ_{it} represents the model's stochastic error term.

The next model estimator we employed is the CC - MG approach, as it is consistent and reliable in estimation. The CC - MG considers the serial correlation among the series, the robustness of a non - cointegrated structural flaw, and unexplained common elements (Kapetanios, Pesaran, & Yamagata, 2011) . The CC - MG is expressed mathematically in Eq. (15):

$$Y_{it}=\alpha 1_i+\beta_i X_{it}+\theta_i n_{it}+\mu_{it} \quad \textbf{Eq (15)}$$

where Y_{it} and X_{it} are indicated as observed variables, $\alpha 1_i$ indicate the specific group effect, β_i represents the cross - section estimators' slope, n_i shows the unknown common factor with loading with θ_i heterogenous, and μ_{it} exhibits the model's stochastic error term. The augmented model with a mean cross - section of the explained and unexplained variables can be expressed as in Eq. (16):

$$Y_{it}=\alpha 1_i+\beta_i z_{it}+\varphi_i \bar{Y}_{it}+\bar{z}_{it}+\theta_i n_{it}+\mu_{it} \quad \textbf{Eq (16)}$$

This regression was calculated using the ordinary least square technique for each cross - section. To estimate the country - wise coefficient estimators, Equation 17 offers a robust outcome, and it is mathematically expressed as in Eq. (17):

$$\mathbf{CC-MG}=N^{-1} \sum_{i=1}^{N} \hat{\theta}_i \quad \textbf{Eq (17)}$$

4.4 Causality analysis

The research employed the modern Granger causality test (Dumitrescu & Hurlin, 2012) to analyze the causality relationship from one series to another. This approach helps address the possibility of CSD and whether there is slope variability in our model. The Dumitrescu–Hurlin (D - H) test analyzes the causal relationships between time series data (Lopez & Weber, 2017) . The null hypothesis of the D - H Granger causality test is that the variables have no causal relationship. In contrast, the alternative hypothesis is a causal relationship in the model. The D - H non - causality test is expressed mathematically in Eq. (18):

$$\gamma_{it}=\alpha_i+\sum_{m=1}^{m} \psi_i{}^{m}, \gamma_{i(m-t)}+\sum_{m=1}^{m} \lambda_i{}^{m}, Z_{i(m-t)} \quad \textbf{Eq (18)}$$

5. Empirical results and Discussion

5.1 Cross - sectional dependence test results

This section examined the econometric model by first determining the CSD of the study's variables. Various research work has indicated that ignoring the CSD test can result in inefficiency, inconsistency, unreliability, and bias that result in misleading information (Ibrahim & Ajide, 2021) . Therefore, to overcome the challenges of CSD in our research, we employ four techniques of CSD test in our data set. Furthermore, Hence, we apply three CSD testing methodologies to our data set to address the difficulties of CSD in our findings. The summary of the three CSD used in this study is presented in Table 3. Study, therefore, utilized the second - generation panel unit root test in this study.

Table 3: Cross - sectional Dependence test

Series	Breusch - Pagan LM	Pesaran scaled LM	Bias - corrected scaled LM	Pesaran CD
CO_2	164.924***	15.193***	14.784***	7.755***
GEXP	91.440***	6.533***	6.124***	3.657***
URB	425.047***	45.849***	45.440***	11.675***
GFN	255.321***	25.845***	25.438***	4.007***
GDP	87.835***	6.108***	5.699***	0.3404*
HC	74.269***	4.510***	4.100***	0.497***
ICT	196.989***	18.972***	18.563***	13.053***
NRR	94.398***	6.882***	6.473***	2.158**

Note * (10%), ** (5%) and *** (1%) denotes the level of significance accordingly.

5.2 Panel Stationarity Test

The researchers used panel unit root tests, CADF and CIPS to see if the variables were stationary or not. Table 4shows the results, except for GDP, which has shown to be stationary at level using the CADF and CIPS test, and ICT has also shown stationarity at level all variables become stationary after taking the first difference. Furthermore, the data are good enough to establish long - run cointegration among them. With that, the null hypothesis is rejected.

Table 4: Results of second - generation panel unit root tests (CADF and CIPS)

Series	CIPS		CADF		Order of Integration
	Level	First difference	Level	First difference	Level
CO_2	- 0.985	9.334***	28.2664**	112.448***	1 (1)
GEXP	0.684	133.981***	10.3302	92.005***	1 (1)
URB	2.788*	0.83***	9.08413*	13.813***	1 (1)
GFN	3.215***	4.464***	106.275***	61.174***	1 (1)
GDP	- 0.422	8.525***	17.8926	100.935***	1 (1)
HC	3.234***	373.92***	43.4734***	150.631***	1 (1)
ICT	2.77605	8.154***	8.652	100.999***	1 (1)
NRR	2.0735**	10.309***	29.917**	120.846***	1 (1)

Note: *** (1%) denotes the level of significance

Pedroni cointegration test

To analyze the presence of long - term co - integration interaction among the variables of this research, we applied two co - integration techniques Kao (1999) and Pedroni (2004) . Testing for co - integration between the variables is essential to determine the short - run and long - run coefficients of the variables. Pedroni (2004) and Kao (1999) To determine if there is cointegration or not, the cointegration test was utilized. Applying the test formula for investigation most Pedroni cointegration tests result show that CO_2, GEXP, URB, GFN, GDP, HC, NRR, and ICT have a long - run connection. These findings show that the variables in our research model have a cointegration interaction. Furthermore, Furthermore, Kao's co - integration outcome confirms a long - term co - integration among the selected series.

Table 5: Pedroni and Kao Residual Cointegration Test

	All 9 countries		
	Statistics	prob	sig
Panel v - Statistic	3.131	0.000	***
Panel rho - Statistic	- 1.268	0.1023	
Panel PP - Statistic	- 2.945	0.002	***
Panel ADF - Statistic	- 3.156	0.000	***
Weighted Panel v - Statistic	1.421	0.078	*
Weighted Panel Rho - Statistic	- 0.602	0.274	
Weighted Panel PP - Statistic	- 2.042	0.021	**
Weighted Group ADF - Statistic	- 2.054	0.020	**
Group rho - Statistic	0.275	0.608	
Group PP - Statistic	- 2.159	0.015	**
Group ADF - Statistic	- 2.269	0.012	**
Kao	- 2.496	0.006	***

Note: *** (1%) denotes the level of significance

5.3 Long - run elasticity estimate

After the confirmation of long - term co - integration interaction in the series of this research, the authors estimate the magnitude of this short and long - term association by employing the novel techniques, Random Panel Effect Estimation, This estimate demonstrates that government expenditure, economic growth, urbanization and natural resource rent have a negative impact in explaining variations in carbon emission with a standardized coefficient of 0.118, 0.080, 0.371, and 0.013 using the random effect model. Again GFN, HC, and ICT will result in a negative rise in the CO_2 with standardized coefficients of 0.527, 0.062, 0.0121, and 0.013, respectively. R^2 is used to calculate the percentage of variation in the dependent variable (CO_2) due to variation in the independent variables (GEXP, URB, GFN, GDP, HC, ICT, and NNR), with a model F - statistics value of 48.86 and significance at 1 percent. Again, to check the robustness of the model, we rerun the GLS model to support the random fixed effect estimation method. At the same government expenditure, economic growth and natural resource rent have revealed a positive effect on CO_2; this revised estimation demonstrates that all other factors have a negative impact at a 1% and 5% level of significant in explaining variance in CO_2. According to table 6, most of the variables have somewhat doesn't change the direction when employing pooled estimate compared to GLS estimation results which will support the robustness of the investigation. According to the GLS estimate, a change of 1 standard deviation in GFN, HC, and ICT will have a negative influence with CO_2 of 0.516, 0.061, and 0.012 standard deviations. The result is indicated in Table 6

Table 6: Pooled OLS, Panel Effects & Generalized Least Square Estimates

Random & Generalized Least Square Estimates – A Comparison		
Coefficients	**RE**	**GLS**
GEXP	0.337 (0.004)	0.337 (0.003)
URB	0.718 (0.053)	0.719 (0.047)
GFN	0.520 (0.315)	0.520 (0.304)
GDP	0.394 (0.000)	0.394 (0.000)
HC	- 0.530 (0.000)	- 0.530 (0.000)
ICT	- 0.041 (0.001)	- 0.041 (0.000)
NRR	0.131 (0.000)	0.131 (0.000)
GEXP*GFN	- 0.005 (0.056)	- 0.005 (0.000)
URB*GFN	- 0.370 (0.000)	- 0.370 (0.000)
C	- 7.791 (0.0001)	- 7.791 (0.000)
Standardized Coefficients		
GEXO	0.118	0.115
URB	0.371	0.362
GFN	0.527	0.516
GDP	0.080	0.079
HC	0.062	0.061
ICT	0.012	0.012
NRR	0.013	0.012
GEXP*GFN	0.020	0.029
URB*GFN	0.093	0.091
C	2.125	2.077
	Random Panel Effect Estimation	**Generalized Least Square**
	Re	**GLS**
Model Specification	Waldchi^2 (9) =4799.27 Prob. = 0.000	Waldx^2 = 5022.50 Prob. = 0.000

Note: *** (1%) denotes the level of significance

As indicated in Table 6, the AMG and CC - MG estimator is consistent with the random and Generalized Least Square outcome. Also, the signs for all the selected series are identical, which confirms the results from the random and Generalized Least Square used for the analysis were robust. Augmented Mean Group Panel Estimator (AMG) and Common Correlated Effects Mean Group (CCEMG) for robustness testing to assess the reliability of the results. To estimate long - run coefficients, two methods have been used: the CCEMG (Pesaran & Smith, 1995) and the AMG estimator (Eberhardt and Bond, 2009; Eberhardt and Teal, 2010). We selected these two estimation approaches because they provide efficient, reliable, and consistent outcomes in the presence of CSD and heterogeneity of slope the analysis of the long - run association indicates that each variable reflected in this model affects CO_2 in the southern countries.

As shown in Table 6, the empirical findings from the AMG estimate show that GEXP, URB, GDP, and NRR are positively and significantly impacts the level of CO_2. On the other - hand, HC, and ICT has negative and significant effect of CO_2 in the SADC economies. As a result, our findings imply that a 1% increase in government expenditure, urbanization, economic growth and natural resource rent will result in a 0.23.8, 0.146, 0.071 and 0.026 (percent) respectively, increase in carbon emission. According to their findings, a green government policy can help minimize CO_2 ceteris paribus. The findings from the AMG approach indicate a positive and significant impact of economic growth, government expenditure, natural resource rent and urbanization on environmental pollution. The implication is that a 1% influence on these variables will increase 0.099% CO_2 in the SADC regions. The possible reason behind this outcome is that this region economic expansion increases with lot of energy consumption, stimulating CO_2 in the SADC countries. More importantly, the empirical outcome of this research indicates the presence of the EKC curve in the selected countries. The presence of the EKC curve indicates that early - stage economic growth raises carbon emission, and the curve begins to drop after reaching a specific threshold.

Moreover, the empirical analysis from the AMG estimate indicates the effect of GFN on CO_2 is positive and insignificant. Therefore, the findings imply that a 1% increase in GFN will result in a 1.700% increase in CO_2. The main intuition behind this result is that, positive environmental impact emanates from the inverse shock of green finance in dissipating CO_2 (Xiong, Sun, & Research, 2022) indicated that the effect of technology and innovation on environmental impacts takes a lot of time to correct itself. This result suggests that the nature of GFN strategies adopted by the SADC economies has higher possibilities of dissipating CO_2. This might be the intuition behind why GFN is positive but insignificant. The positive relationship between green innovation and environmental pollution is justifiable because GFN is a significant initiative to consider and implement sustainable development in the SADC countries. In addition, GFN helps promote carbon neutrality, a low - carbon environment, and achieving energy efficiency. (Sharif, Saqib, Dong, & Khan, 2022) reported in their research that energy innovation and green finance helps in mitigating both carbon emission CO_2.

Table 7: Robustness tests

Variables	AMG			CCEMG		
	Coefficient	t - Stat	P - value	Coefficient	t - Stat	P - value
LNGEXP	0.238	0.55	0.009	0.243	0.30	0.000
LNURB	0.146	1.92	0.654	0.169	- 0.79	0.001
LNGFN	1.700	1.54	0.504	4.390	0.89	0.207
LNGDP	0.071	1.27	0.000	0.155	0.87	0.006
LNHC	- 0.004	- 0.05	0.008	- 0.158	- 0.57	0.070
LNICT	- 0.013	- 1.18	0.001	- 0.060	- 1.21	0.000
LNNRR	0.026	0.53	0.000	0.044	- 0.47	0.006
LNGEXP*LNGFN	- 1.541	- 0.49	0.025	- 0.916	- 0.17	0.008
LNURB*LNGFN	- 26.097	- 1.87	0.061	- 14.161	- 0.78	0.000

The test role of green finance as the moderator variable between the government expenditure and urbanization to evaluate carbon emission performance, the outcome result shows their indirect relationship between the moderator (green finance) and the dependent variables (government expenditure and urbanization). According to Table 5.9, the empirical findings from the AMG estimate show that GEXP*GFN, and URB*GFN are negatively and significantly impacts the level of CO_2. The result implies that a 1% increase in government expenditure, urbanization, will result in a - 1.541 and - 26.097 percent reduction respectively.

5.4 Dumitrescu and Hurlin causality test

The AMG, and CC - MG techniques only provide long - run linkage estimates between the variables. In panel data, these approaches, on the other hand, do not reveal the causal association between series. As a result of slope heterogeneity among cross - sectional series, the research utilized a novel approach proposed by (Dumitrescu & Hurlin, 2012) . The D - H technique is a new version of the Granger causality test that incorporates cross sectional data CSD and slope of heterogeneity. This technique provides the W - bar and Z - bar statistics. Table 7 shows the results of the D - H non - causality test. The outcome of the Granger causality test indicates that government expenditure and urbanization have a bidirectional association with CO_2. The Granger causality test further revealed a unidirectional causality between green finance, economic growth, human capital, information communication technology, and natural resource rent with the carbon emission. The findings indicate that policy targeting CO_2, GEXP and URB, shall has an alternating approach since a bidirectional Granger causality effect exists on each other. The implication is that any radical changes in GEXP, and URB, will increase CO_2 and vice versa. Due to the relative one - way causation, any policy measures focused on these variables will impact the environmental policies of the SADC countries.

Table 8: Granger causality test: carbon emission

Null hypothesis	W - stat	Z - bar Stat	Prob	Conclusion
LNGEXP LNCO$_2$ LNCO$_2$ LNGEXP	5.32520 3.94655	3.61609 1.99496	0.000 0.046	$CO_2 \rightarrow$ GEXP
LNURB LNCO$_2$ LNCO$_2$ LNURB	6.22071 5.98040	4.66912 4.38653	0.000 0.000	$CO_2 \rightarrow$ URB
LNGFN LNCO$_2$ LNCO$_2$ LNGFN	2.98552 9.12615	0.86489 8.08559	0.387 0.000	$CO_2 \rightarrow$ GFN
LNGDP LNCO$_2$ LNCO$_2$ LNGDP	2.36361 3.44322	0.13360 1.40310	0.894 0.061	$CO_2 \rightarrow$ GDP
LNHC LNCO$_2$ LNCO$_2$ LNHC	1.54313 5.12439	- 0.83121 3.37997	0.406 0.001	$CO_2 \rightarrow$ HC
LNICT LNCO$_2$ LNCO$_2$ LNICT	2.56335 4.51082	0.36846 2.65848	0.713 0.008	$CO_2 \rightarrow$ ICT
LNNRR LNCO2 LNCO$_2$ LNNRR	3.10164 2.77982	1.00143 0.62301	0.317 0.033	$CO_2 \rightarrow$ NRR
LNURB LNGEXP LNGEXP LNURB	9.32608 9.10995	8.32069 8.06655	0.000 0.000	URB$\rightarrow$ GEXP

6. Conclusion, Theoretical Implication, and Policy Implications

6.1 Conclusion

The SADC nations are currently growing and are now ranked among the best - performing nations in Sub - Saharan

Africa. With this economic growth also comes a significant amount of environmental damage. Government spending, urbanization, green financing, economic growth, human capital, information and communication technology, and resource rent are among the primary factors that have an impact on CO_2. Thus, this study used panel data from 1996 to 2020 to examine how these parameters affected CO_2 in the SADC countries. We first tested cointegration by analyzing the CSD throughout the cross - section of the data in order to quantify the interaction between these factors. This study employed the AMG and CC - MG techniques to evaluate the variables' long - run interaction after validating the co - integration relationship between the series. The results of this study can be summarized as follows: (1) We discovered a positive and significant correlation between government expenditures, urbanization, economic growth, rent from natural resources, and the environment. (2) In contrast, human capital and information and communication technologies in the SADC economies having negative impact and decrease CO_2. (3) Yet, when used as a moderator between urbanization and government spending, green finance's impact is negative and substantial while being positive elsewhere. (4) The Granger causality test result shows that urbanization and government spending have a two - way relationship with CO_2. (5) The D - H finding showed a unidirectional causality between environmental pollution, human capital, ICT, natural resource rent, and economic growth as a proxy (CO_2).

6.2 Theoretical implication

The STIRPAT approach was used to develop an extended model of carbon emissions by incorporating new variables such as government expenditures, urbanization, green finance, economic growth, human capital, information and communication technology, and natural resource rent. The IPAT and STIRPAT approaches provide a comprehensive understanding of the mechanism by which human activities affect CO2. The STIRPAT's goal is to provide a conceptual framework as well as a statistical strategy for testing the relationship between human actions and their impact on the natural environment. The underlying concept is to identify the fundamental variables that contribute to environmental pollution and mitigate these factors to aid in environmental conservation. Therefore, we are very optimistic that the STIRPAT approach will contribute to the primary understanding of the interaction between government expenditure, urbanization and green finance and the safeguarding of the carbon emission.

6.3 Recommendation

This research is based on empirical findings to aid in the improvement of environmental quality and sustainability. Firstly, our research found a negative relationship between government expenditure and CO_2. Based on this finding, the authors propose that SADC countries discourage more green investments and rely less on coal mining. Secondly, to offset the positive effect of economic growth on CO_2, the study suggests that policymakers focus their efforts on domestic consumption, particularly in sectors of economic development that use less traditional methods of production to produce goods and services. As a result, environmental legislation, regulations, and reforms should control industrial processes that emit less CO_2. Thirdly, we proposed that, in order to reduce the effect of NRR on CO_2, SADC policymakers outline effective plans for maintaining optimal utilization of their natural resources. Fourth, given the positive impact of green finance on pollution, there is a need to raise awareness of the concept of GFN among various stakeholders and policymakers. Likewise, enterprises, entrepreneurs, and businesses should be encouraged to invest in green securities, green credit, and green investment, as well as to promote green business. Fifth, the contribution of information and communication technology to environmental pollution remediation suggests that SADC decision - makers can rely on it as a critical tool for reducing greenhouse gas emissions. Finally, we suggest that stakeholders and urban planners in SADC countries address harmful emissions issues from urbanization by adopting appropriate land procurement to offset the positive effect of URB on CO_2.

6.4 Limitations and Suggestions for Further Study

This study has some limitations, which allows for future research to address these issues. First, our study model did not account for other relevant factors such as good governance and its indicators, such as the rule of law, regulatory quality, and government spending on research and development, all of which can influence environmental pollution. In the future, the researchers will broaden the scope of this study by incorporating these variables and employing other environmental theories such as the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model. Interaction variables such as globalization could also be included to examine the impact of these variables on environmental pollution in other jurisdictions.

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