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Impact of Economic Growth on Environmental Degradation and Energy Consumption in South Africa: A Cointegration Analysis

Ekonomik Büyümenin Güney Afrika'da Çevresel Bozulma ve Enerji Tüketimine Etkisi: Bir Eşbütünleşme Analizi

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Ö Z

Bu araştırma, 1971 ve 2015 yılları arasında Güney Afrika'da kentleşmenin rolünü ele alarak ekonomik büyümenin çevresel deregülasyon ve enerji kullanımı üzerindeki etki derecesini incelemek üzerine odaklanmaktadır. Bu incelemenin yapılabilmesi için Johansen ve Bounds eşbütünleşme testleri kullanılmıştır ve ortaya konan sonuçlara göre değişkenler arasında uzun dönemli bir ilişkinin varlığı ortaya koyulmuştur. Ayrıca çalışma sonuçlarına göre ARDL sonuçları göstermiştir ki (i) enerji kullanımı ve kentleşmenin çevresel deregülasyon üzerinde olumlu bir etki oluşturmakta; (ii) çevresel deregülasyon ekonomik büyümeyi olumlu yönde etkilemekte; (iii) ekonomik büyüme ve çevresel deregülasyon enerji kullanımı üzerinde olumlu bir etki oluşturmakta; ve son olarak (iv) kentleşme Güney Afrika'da enerji kullanımı üzerinde olumsuz bir etkiye sahip olmaktadır. Hem FMOLS analizi hem de DOLS analizi sonuçları da çalışmada uygulaması olan ARDL'nin bulgularını desteklemektedir. Ayrıca, Granger nedensellik testinin sonuçları da göstermiştir ki, bağımsız değişkenlerden uzun vadede ekonomik büyümeye bir nedensel ilişki bulunduğunu göstermektedir. Yine kısa vadede ekonomik büyümeden enerji kullanımı ve kentleşmeye doğru olan bir nedensellik ilişkisi bulunmuştur.

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A B S T R A C T

The present research focuses on the impact of economic growth on environmental degradation and energy usage by including the role of urbanization in South Africa between 1971 and 2015. By employing the Johansen and Bounds test cointegration approaches for this research, we revealed a long-run linkage among the variables. Also, according to the results of the study the ARDL exposes that (i) energy use and urbanization exert a positive effect on environmental degradation ; (ii) environmental degradation impacts economic growth positively; (iii) economic growth and environmental degradation exert a positive impact on energy usage; and finally (iv) urbanization exerts a negative influence on energy use in South Africa. The outcomes of both FMOLS and DOLS support the findings of the ARDL. In addition, the outcomes of the Granger causality test showed that a one-way causal relationship from all the regressors to economic growth in the long run. Besides, there is a unidirectional causal relationship running from economic growth to energy use and urbanization in the short run.

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1. Introduction

Energy plays a key which contributes to the financial, economic, social, and political growth of both developing and developed countries cannot be emphasized. For instance: to cater and improve the welfare of their citizens, there is a need for an upsurge in the manufacturing of food, production of goods and services, and provision of essential amenities such as housing, health care centers, and security requires the use of energy, in which there is no close substitute causing rising demand of energy. Globally, about 87% of the energy used is supplied by fossil fuels (Lyman, 2016), whereas 92% of the primary energy supply is accounted for by fossil fuel (International Energy Agency, 2019). The increased burning of fossil fuels causes an upsurge in greenhouse gases (GHGs), which have a great impact on environmental degradation (Xu et al., 2022; Kirikkaleli et al. 2022; Asuzu et al. 2022). These are the major challenges of achieving desirable and sustainable economic growth. Developing nations greatly face this problem are both social and economic issues because the countries depend largely on sectors that are climate sensitive, such as agriculture, it is difficult for them to manage the hazards associated with climate change.

South Africa emits about 1% of carbon dioxide (CO2) in the world, making her the largest emitter in the continent of Africa, due to the exploration and mining of her natural resources. South Africa is among the tenth biggest producer of coal and also the fourth largest in terms of exportation of coal. The country also depends on these resources to generate energy. This shows that the nation's economic progress is tied to the dirty industry, which has a negative influence on environmental degradation and climate change (Akadiri et al., 2022; Oladipupo et al., 2022; Kutlay et al., 2022). Although South Africa has made attempts towards minimizing the global warming effects through intergovernmental agreements and international conventions, environmental degradation and pollution continue to be rampant, which is persistent in posing a big challenge to South Africa's economic growth (GDP). For this reason, the country is tasked to achieve these two objectives of higher GDP and lower CO2 emissions. Over the years, some researches have been implemented regarding the connection between urbanization, energy consumption, GDP, and environmental degradation but their main outcomes are mixed. For example, Onifade et al. (2022), Alola et al. (2020), Kirikaleli et al. (2020), Olanrewaju et al. (2021), and Adebayo (2022a) established that energy usage and GDP exert a positive impact on CO2 emissions. Likewise, Nathaniel et al. (2020), Udi et al. (2020) detected an adverse relation between urbanization and GDP, while the study of Zhang et al. (2021), Nathaniel et al. (2019) find a positive association between urbanization and GDP. Due to mixed outcomes in the empirical literature, it is imperative to examine this association.

This contribution of this study tends to plug the gap into existing environmental and energy literature. This study focus on the effect of GDP on environmental degradation and energy usage by including the role of urbanization in the case of South Africa by using several econometric techniques. Furthermore, no study has been able to apply these econometric techniques with regards to this subject based on our knowledge.

2. Literature Review

Numerous studies have been done regarding the empirical research on GDP, energy usage, urbanization, and the CO2 emissions relationship. Consumption of energy is vital to GDP, as the use of energy is crucial for production. Misuse or misappropriation of resources of energy, nonetheless, produces a high level of environmental deterioration mirrored in CO2. The first strand of literature emphasizes the interaction between economic growth and environmental pollutants (Rjoub et al., 2022; Fareed et al., 2022; Miao et al., 2022; Ojekemi et al., 2022; Ayobamiji & Kalmaz, 2020; Xulu et al., 2022; Kirikkaleli, 2020; He et al., 2021; AbdulKareem et al., 2022; Umar et al. 2022). Although, the outcome of these studies had been inconsistent with the inverted U-shaped relationship. The second strand of literature to be reviewed in this study focuses primarily on research that probes into the causal link between energy use and GDP (Erol & Yu, 1987; Akarca & Long, 1980; and Soytas & Sari, 2003; Kalmaz & Kirikkaleli, 2019). Several authors examined the interconnection amongst economic growth, energy use, and environmental degradation , and findings proved the existence of a connection amongst them (Cai et al. 2018; Heidari et al. 2015). This finding complies with the study carried out in Turkey in regards to the link between environmental degradation and energy use by Halicioglu (2009). In Brazil, the interaction between environmental degradation , energy usage, and GDP was examined by Pao and Tsai (2011), and the authors finding complies with the study of Halicioglu (2009). In the USA, the linkages between GDP growth, trade, urbanization, CO2 emissions, and energy usage were investigated by Dogan and Turkekul (2016). Based on their result, a bidirectional causality was evident between GDP and environmental degradation and also between energy consumption and environmental degradation .

Moreover, using the MINT bloc, Dogan et al. (2019) analyzed the interconnection between GDP and environmental degradation and energy usage. Contrary to his earlier result on the USA, findings from this study support the EKC hypothesis. Using 23 nations, Moutinho et al. (2018) studied the linkages between environmental degradation and renewable energy. Findings revealed a positive link between environmental degradation and renewable energy. Some research have included urbanization in their model as one of the variables influencing CO2 emission (Kirikkaleli & Kalmaz 2020; Khoshnevis Yazdi & Dariani, 2019; and Nondo & Kahsai, 2020). The research of Koengkan et al. (2019) investigated the relationship amongst energy, GDP, and environmental degradation in 5-South-America countries. Finding from the study revealed feedback causality between non-renewable energy, renewable energy, and energy usage on environmental degradation . Also, unidirectional causality was establish from renewable energy to urbanization. The findings of Wang et al. (2020), Nondo & Kahsai, (2020), and Rahman & Vu, (2020) established a positive linakge between environmental degradation , energy usage, and urbanization. Recently, Kirikkaleli & Kalmaz (2020) studied the moderating role of urbanization on the EKC in Turkey. The authors revealed that the EKC hypothesis is evident for Turkey and the urbanization moderate the association between environmental degradation and energy use. The table below highlights the summary of associated work.

Table 1: Summary of Studies

Investigator (s)	Time-frame	Nation (s)	Methods (s)	Result(s)
Solarin & Shahbaz (2013)	1971–2009	Angola	ARDL, VECM	ECC↔ GDPG ECC↔ URB
Sbia et al. (2017).	1975–2011	United Arab Emirates	ARDL, VECM	URB → ECC (+) FD → ECC (+) \ EN↔ FD
Wang, (2014).	1980-2011	China	time-series analysis	GDPG → URB (+) TI → GDPG(-) URB → GDPG (+)
Zhang et al. (2021)	1960 - 2018	Malaysia	Wavelet Coherence, ARDL, Fourier Toda-Yamamoto	GDPG → CO_2E (+) URB → CO_2E (+) URB → CO_2E (+) TO → CO_2E (-)
Koengkan et al. (2020)	1980–2014	Five Latin countries	Panel VECM	URB→ CO_2E
Khoshnevis Yazdi, & Golestani Dariani, (2019)	1980–2014	116 countries	PMG, Panel Causality	CO_2 →GDPG (+) CO_2E ↔ GDP CO_2E ↔ URB
Wang, et al. (2020).	1990-2014	APEC countries	DSUR	URB→ CO_2E
Olanrewaju et al. (2021)	1980–2016	Thailand	ARDL	GDPG → CO_2E (+) FD → CO_2E (+) ECC → CO_2E (+)
Ayobamiji & Demet (2020)	1971–2015.	Nigeria	ARDL and Wavelet Coherence	CO_2→ GDPG (+) GDPG → CO_2E (+) FD → CO_2E (+) ECC → CO_2E (+)
Kirikkaleli and Sowah (2020)	1950 - 2014	Global	wavelet coherence technique	URB → CO_2E

Note: ECC: Energy Consumption, GDPG: Economic Growth, CO_2E: Carbon Emission, URB: Urbanization. The directions of the causalities are reported by arrows.

3. Data, Methodology and Procedure for Estimation

The study's objective is to focus on the effect of GDP on environmental degradation and energy usage by including the role of urbanization in the context of South Africa for the period of 1971-2015 . The statistics of the variables used were been summarized, which was shown in Table 2. All the variables used were obtained from World Bank. To reduce the deviation of the variable used, the present study used the time series variables in their logarithmic form in the estimated models.

Table 2: Summary of the Variable Statistics

Variable	Variable Definition	Obs	Mean	Std. Dev.	Median	Max	Min
CO_2PC	CO_2 emissions (metric tons per capita)	44	0.935	0.0431	0.9381	0.9991	0.8572
GDPPCC	GDP per capita (constant 2010, US$)	44	3.481	0.2393	3.4852	3.9034	2.9528
ENU	Energy usage	44	3.39	0.0429	3.3999	3.4698	3.2975
URB	Urban population growth (annual %)	44	0.430	0.0775	0.4271	0.5494	0.3323

The energy usage and CO2 emissions function, which is the basis of this work is stated below:

$$ENU_t = f\,(CO_2PC_t,\ GDPPCC,\ UrB_t) \quad (1)$$

$$CO_{2t} = f\,(ENU_t,\ GDPPCC,\ UrB_t) \quad (2)$$

The empirical model of this study are been specified as follows:

$$ENU_t = \alpha_0 + \alpha_1 \text{GDPPCC}_{t-i} + \alpha_2 CO_{2_{t-i}} + \alpha_2 UrB_{t-i} + \varepsilon_t \quad (3)$$

$$\text{CO2PC}_t = \alpha_0 + \alpha_1 \text{GDPPCC}_{t-i} + \alpha_2 ENU_{t-i} + \alpha_2 UrB_{t-i} + \varepsilon_t \quad (4)$$

where: the subscript t denotes a period of research and ε signifies the stochastic error term.

The unit root test was employed to determine whether the variables' mean and variance are fixed over time i.e. stationary (Gujarati, 2004). The study used the augmented Dickey-Fuller unit root test (ADF) by Said and Dickey (1984), and the Phillip-Perron unit root test (PP) by Phillips & Perron (1988) to carry out the unit root test. South Africa has experienced a lot of uncertainties that affect its economy, caused by factors such as poverty, global shocks, and corruption, etc. During this period, there is a possibility that structural breaks characterize the country's variables. In taking account of the structural break, this research applied the Zivot-Andrews unit root test introduced by Zivot & Andrews (2002), which is used in identifying one structural break in the dataset, and the Lee Strazicich LM unit roots, which is used in detecting two structural breaks were also used.

One of the techniques used in establishing the combined cointegration relationship among the variable is the Johansen cointegration technique. Equation 5 below illustrates the general form of the VEC model.

$$\theta T_t = \alpha_0 + \sum_{i=1}^{k-1} \alpha_1 \theta K_{t-i} + \partial \beta_{i-k}^{iY} + \mu_t \quad (5)$$

Where: the difference operator is epitomized by δ, K_t is (CO_2, Y, EC, URB), θ illustrates the intercept while μ represents the white noise process's vector.

In detecting the presence of cointegration among the variable used, the ARDL becomes invalid, especially when time-series variables with I(2) are introduced but suitable when the variable is stationary either at [I(0) and I(1)], both the long and short-run relationship are presented in a single form, different lengths of lags are accommodated, small sample size and removal of autocorrelation problem. The error correction term (ECT) demonstrates the adjustment rate to a long-run equilibrium from a short-run imbalance. This provides an understanding of how the government's policies in the short run will be effective in the achievement of long-run policy targets. Also, suppose the F-statistic is more than 1(0) but less than I(1). In that case, we say it is inconclusive, and finally, when the F-statistic is more than the upper bound 1(1), reject the null hypothesis, which means there is cointegration that emphasizes the long-run cointegration between the endogenous and the exogenous variables.

Equations (6) and (7) portray the two models:

$$\Delta InENUt = \theta_0 + \sum_{i=1}^{t} \theta_1 \Delta InENU_{t-i} + \sum_{i=1}^{t} \theta_2 \Delta In\text{GDPPCC}_{t-i} + \sum_{i=1}^{t} \theta_3 \Delta In\text{CO2PC}_{t-i} + \sum_{i=1}^{t} \theta_4 \Delta InUrB_{t-i} + \beta_1 InENU_{t-1} + \beta_2 InGDP_{t-1} + \beta_3 InCO_{2_{t-1}} + \beta_4 InUrB_{t-1} + \varepsilon_t \quad (6)$$

$$\Delta In\text{CO2PC}t = \theta_0 + \sum_{i=1}^{t} \theta_1 \Delta InC0_{2_{t-i}} + \sum_{i=1}^{t} \theta_2 \Delta In\text{GDPPCC}_{t-i} + \sum_{i=1}^{t} \theta_3 \Delta InENU_{t-i} + \sum_{i=1}^{t} \theta_4 \Delta InUrB_{t-i} + \beta_1 InCO_{2_{t-1}} + \beta_2 InGDP_{t-1} + \beta_3 InENU_{t-1} + \beta_4 InUrB_{t-1} + \varepsilon_t \quad (7)$$

where: θ_i (i = 1…4) denote the variable's short run dynamic coefficients, β_i (i = 1…4) represents the long-run linkage among parameters, t represents the lags lengths.

The ECM was incorporated into the ARDL's short-run parameter, which transforms Equation (6) and (7) into Equation (8) and (9) as follows:

$$\Delta InENU_t = \theta_0 + \sum_{i=1}^{l} k_1 \Delta InENU_{t-i} + \sum_{i=1}^{l} k_2 \Delta InCO2_{t-i} + \sum_{i=1}^{l} k_3 \Delta In\text{GDPPCC}_{t-i} + \sum_{i=1}^{l} k_4 \Delta InUrB_{t-i} + xECT_{t-i} + \varepsilon_t \quad (8)$$

$$\Delta In\text{CO2PC}_t = \theta_0 + \sum_{i=1}^{l} k_1 \Delta InCO2_{t-i} + \sum_{i=1}^{l} k_2 \Delta In\text{GDPPCC}_{t-i} + \sum_{i=1}^{l} k_3 \Delta InENU_{t-i} + \sum_{i=1}^{l} k_4 \Delta InUrB_{t-i} + xECT_{t-i}0 + \varepsilon_t \quad (9)$$

where: k_i(i = 1…4) = variables' coefficients in the short run of, ECT_{t-i} = the Error correction term which shows "the speed of adjustment from a short-run shock to the long-run equilibrium. x denotes the ECT's coefficients" (Kalmaz nad Kirikkaleli, 2019). The model was diagnosed using the following: normality test, serial correlation, and Ramsey RESET, heteroscedasticity, CUSUM, and CUSUMSQ.

The existence of cointegration between the endogenous and exogeneous variables in the long-run, indicates a causality relationship that can be either unidirectional or bidirectional. Granger causality-based vector error correction method (VECM) framework will be applied in determining the causality direction of the variable used. Equations below showcase the VECM:

$$\delta\text{CO2PC}_t = \vartheta_0 + \sum_{i=1}^{l} \vartheta_1 \ \delta\text{CO2PC}_{t-1} + \sum_{i=1}^{l} \vartheta_2 \ \delta\text{GDPPCC}_{t-1} + \sum_{i=1}^{l} \vartheta_3 \ \delta ENU_{t-1} + \sum_{i=1}^{l} \vartheta_2 \ \delta UrB_{t-1} + \pi ECT_{t-1} + \mu_{t-i} \quad (10)$$

$$\delta\text{GDPPCC}_t = \vartheta_0 + \sum_{i=1}^{l} \vartheta_1 \delta GDP_{t-1} + \sum_{i=1}^{l} \vartheta_2 \ \delta CO_{2_{t-1}} + \sum_{i=1}^{l} \vartheta_3 \ \delta ENU_{t-1} + \sum_{i=1}^{l} \vartheta_4 \ \delta URB_{t-1} + \pi ECT_{t-1} + \mu_{t-i} \quad (11)$$

$$\delta ENU_t = \vartheta_0 + \sum_{i=1}^{l} \vartheta_1 \ \delta ENU_{t-1} + \sum_{i=1}^{l} \vartheta_2 \ \delta\text{GDPPCC}_{t-1} + \sum_{i=1}^{l} \vartheta_3 \ \delta CO_{2_{t-1}} + \sum_{i=1}^{l} \vartheta_4 \ \delta URB_{t-1} + \pi ECT_{t-1} + \mu_{t-i} \quad (12)$$

$$\delta UrB_t = \vartheta_0 + \sum_{i=1}^{l} \vartheta_1 \ \delta URB_{t-1} + \sum_{i=1}^{l} \vartheta_2 \ \delta\text{GDPPCC}_{t-1} + \sum_{i=1}^{l} \vartheta_3 \ \delta CO_{2_{t-1}} + \sum_{i=1}^{l} \vartheta_4 \ \delta ENU_{t-1} + \pi ECT_{t-1} + \mu_{t-i} \quad (13)$$

where: μ_t(i = 1, 2, 3, 4 & 5) denotes the error term of the model, while the ECT_{t-1} indicates the cointegrating vectors' error correction term, and π illustrates the coefficient of the speed of adjustment (When the coefficient of speed of adjustment is negative and statistically significant, it signifies how fast the variables return to equilibrium. The range of the coefficient must be between 0 and 1).

3. Empirical Results

Table 3 & 4 show the summarized outcome of several stationary tests: ADF, PP, DFGLS, Zivot-Andrew, and Lee Strazicich LM unit root test. The stationarity properties of the variable used are shown to be stationary at I(1), which is suitable for this study to employ both the Johansen cointegration and ARDL cointegration approaches.

Table 3: Unit Root Tests Result at Constant

Unit roots test	Level				1st Difference			
	CO_2PC	ENU	URB	GDPPCC	δ CO_2PC	δENU	δURB	δ GDPPCC
ADF	-1.957	-2.085	-1.359	-1.456	-6.202*	-6.185*	-3.177**	-3.492**
PP	-2.024	-2.087	-1.103	-1.818	-6.206*	-6.188*	-3.144**	-4.705*
DF-GLS	-1.393	-0.798	-1.368	-0.206	-6.249*	-6.135*	-3.187*	-3.444*

Table 4: Unit Root Tests Results with Structural Break (s)

Tests		Level				1st Difference			
Zivot-Andrew	K	-2.91 [1979]	-2.88 [1989]	-3.59 [1995]	-3.73 [1996]	-6.64* [2003]	-6.83* [1985]	-4.43 [1987]	-5.25** [2003]
	K&T	-3.71 [1989]	-4.12 [1989]	-2.90 [1995]	-4.12 [1998]	-6.95* [2003]	-6.97* [2003]	-4.83*** [1987]	-5.27** [2003]
Lee Strazicich LM		-6.06 [1988] {2001}	5.05 [1982] {1991}	-6.20 [1994] {2008}	-4.98 [1992] {2001	-7.18* [1981] {1991}	-6.43* [1986] {2006}	-6.27* [1994] {2008}	-6.20* [1995] {2003}

Note: *, **, & *** signifies 0.01, 0.05, & 0.10 significance level. δ stands for the 1st difference. [], & {} illustrates 1st and 2nd structural break years respectively. For Zivot-Andrew unit root, K, & T, and K signifies constant and trend, and constant respectively.

A combined cointegration test was done in this study using the Johansen cointegration test because the ADF and PP unit-roots indicate that all parameters are integrated at I(I). The optimal lag selection must be known before carrying out the Johansen cointegration test. Table 5 below showcases the criteria and lag to be selected. This study chooses 2 as the best lag, which is according to the Akaike information criterion (AIC). The result of the Johansen cointegration is shown in Table 6. The table reports that there is a linkage between energy use, CO_2PC, URB, and GDPPCC in South Africa in the long-run.

able 6: Johansen Cointegration Test

Ha	Ho	λmax test	λmax test (0.95)	Trace test	Trace test (0.95)
R=1	R=0	28.415	27.584	65.095	47.856
R=2	R≤1	21.906	21.132	36.679	29.797
R=3	R≤2	14.200	14.265	14.774	15.495
R=4	R≤ 3	0.573	3.841	0.573	3.841

Note: Ho: Null hypothesis, Ha: Alternative hypothesis

Table 5: Criteria Selection Order

Lag	LogL	LR	FPE	AIC	SC	HQ
0	291.42	NA	1.34e-11	-13.686	-13.52	-13.63
1	434.29	251.73	3.19e-14	-19.728	-18.90*	-19.43
2	459.91	40.249*	2.07e-14*	-20.186*	-18.70	-19.64*

Note: * indicates the order of lag chosen by the criterion.

To further investigate the cointegration relationship, the ARDL bounds cointegration test was employed where the CO2 emission, energy use, GDPPCC, and urbanization were deployed as dependent variables. The ARDL cointegration bound test is presented in Table 7. From the result, the presence of cointegration when CO2PC and energy use acts as the endogenous variable. This findings highlights that there are two cointegrating vectors validating the Johansen Cointegration test.

Table 7: ARDL Bounds Cointegration Test

Dependent variable	Optimal Lag	F-statistics	R^2	Adjusted R^2	Cointeg
CO_2PC	1,0,0,0	30.969*	0.941	0.935	Yes
ENU	1,0,0,0	34.329*	0.967	0.964	Yes
GDPPCC	2,0,0,0	1.900	0.939	0.930	No
URB	2,0,0,0	1.374	0.971	0.967	No

Table 8: Diagnostic Test

	χ^2 Normal	χ^2 Serial	χ^2 Hetero.	χ^2 Ramsey
CO_2PC	0.760	0.120	1.649	0.985
	(0.683)	(0.887)	(0.181)	(0.702)
ENU	0.707	1.124	1.804	0.651
	(0.702)	(0.336)	(0.148)	(0.519)

GDPPCC	0.127	4.704	1.858	1.034
	(0.938)	(0.015)	(0.126)	(0.308)
UrB	6.085	1.064	7.280	1.469
	(0.047)	(0.356)	(0.000)	(0.233)

Note: *, **, & *** signifies 0.01, 0.05, & 0.10 significance level. values in parenthesis represents probabilities

We proceed to investigate the effect of GDPPCC and URB on ENU and CO2PC in South Africa. In the CO2PC model, it is evident that GDPPCC positively affects CO2PC, presenting that an upsurge in GDPPCC will lead to a surge in CO2PC. This outcome is supported by the study done by Adebayo et al., (2021) and Shahbaz et al. (2013) for South Africa. Energy consumption positively stimulates CO2PC. South Africa relies heavily on coal in meeting its energy demand because coal mining is cheaper and easier than other energy supplies, making energy use to be the major contributor to the worsening of environment in South Africa compared to other variables. It is believed that the country's reliance on coal consumption will likely not change in the next two decades. This result is in consonance with Farhani et al.'s (2014) findings in Tunisia and Shahbaz et al.'s (2013) findings in South Africa. Furthermore, it was also evident from the result that urbanization positively affects CO2 emissions. This study's discovery is also consistent with the previous study done by Shahbaz et al. (2016), Awosusi et al., (2022), Akinsola et al., (2022)

In the energy consumption model, it was revealed that energy use was positively affected by CO2 emissions at a 1% significance level. This means that if the level of CO2 emissions increases by 1%, will cause the surge in energy use by 0.618%. This finding is consistent with the study done by Rafindadi (2016). Also, the study discovered that the effect of GDPPCC on energy use tends to be positively significant at 1%, which is consistent with Adebayo (2022a), Olanrewaju et al. (2021), Mwamba et al., (202b) and Odugbesan and Adebayo (2022a) findings. Furthermore, urbanization was found to impact energy use positively at a 10% level of significance. Based on our projection, the ECM is statistically significant and have the right signs, which are -0.915 and -0.812 for CO2 emission and energy use model, respectively. This infers that shocks in the short run can be adjusted to the long run by 95% and 81% each year.

The diagnostic tests also report that the models' residuals are normally distributed around their mean, the residuals are not serially correlated, and no problem with heteroscedasticity. The functional form of these two models is well specified as seen from the Ramsey reset results. Fig. 1, 3, and Fig. 2, 4 show the CUSUM and CUSUMsq tests, respectively. It shows that the models used are stable over the period. Therefore, the present model is accurate and reliable enough in developing policies.

Table 9: Short and Long-run Elasticities

Variable	Dependent variable: CO_2 emission		Dependent variable: ENU	
	Coefficient	T-stat.	Coefficient	T-stat.
Constant	2.916	-9.764	2.052	11.079
CO_2	-	-	0.618	10.515*
ENU	1.170	10.225*	-	-
GDPPCC	0.054	4.138*	0.041	4.308*
URB	0.051	1.803***	0.034	1.735***
ECM(-1)	-0.951	11.561*	-0.812	-12.172*

Note: *, **, & *** signifies 0.01, 0.05, & 0.10 significance level, respectively.

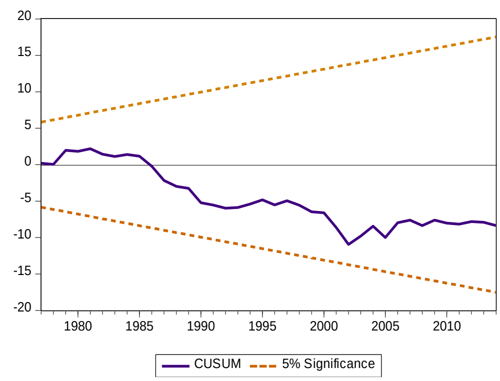


Fig 1: CUSUM for CO_2PC model

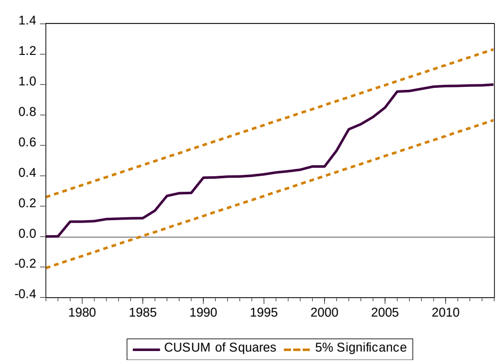


Fig 2: CUSUMSQ for CO_2PC model

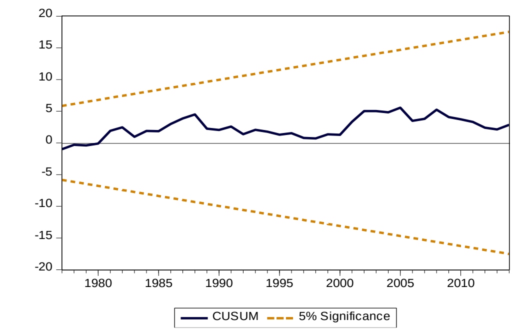


Fig 3: CUSUM for ENU model

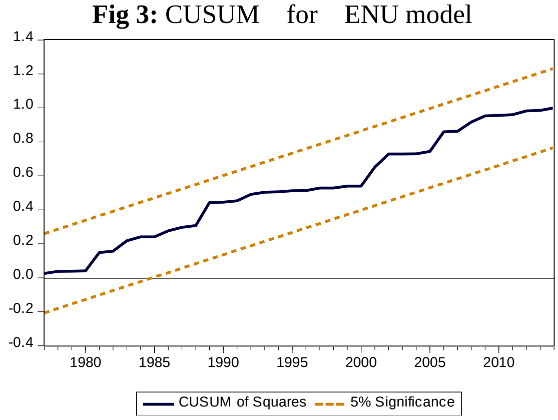


Fig 4: function CUSUMSQ for ENU model

The present study employed the FMOLS and DOLS to act as a robustness check coefficients of the ARDLin the long-run. The long-run coefficients for DOLS and FMOLS models are shown in Table 10. The outcome exhibits that ENU and urbanization were positively affected CO2PC while economic growth significantly impacted CO2PC positively. With respect to, GDPPCC and CO2PC is positively affected energy use, and urbanization has a positive effect on energy use in South Africa. The outcome of the FMOLS and DOLS support the ARDL log-run estimations.

Table 10: FMOLS and DOLS

Regressors	Dependent variable: CO_2 emission		Dependent variable: ENU	
FMOLS				
	Coefficient	T-stat	Coefficient	T-stat
Constant	-2.878	-13.922	2.023	14.553
CO_2	-	-	0.621	14.156*
CO_2(-1)	0.044	0.748	-	-
ENU	1.115	14.744*	-	-
ENU(-1)	-	-	0.200	3.675*
GDPPCC	-0.049	-5.684*	0.036	5.053*
URB	0.056	2.948*	0.038	2.570*
DOLS				
Constant	-2.916	-9.569	2.052	13.295*
CO_2	-	-	0.618	12.618*
ENU	1.170	10.020*	-	-
GDPPCC	0.054	4.055*	0.041	5.170*
URB	0.051	1.767***	0.034	2.082**

Note: *, **, & *** signifies 0.01, 0.05, & 0.10 significance level.

Since the cointegration is evident, the direction of causality among the variable used can be known. Table 10 depicts the results of the VECM framework. The results show a one-way causal interaction from URB, ENU, and CO2PC to GDPPCC in the long-run, while there is proof of one-way causality from GDPPCC to ENU and URB in the short run.

Table 11: Long and Short Causality Test

Dependent variable	Short-run				Long-run
	$\Sigma\delta CO_2$	$\Sigma\delta$ GDPPCC	$\Sigma\delta$ENU	$\Sigma\delta$URB	ECTt−1
$\Sigma\delta CO_2$	-	0.99	0.126	0.566	-1.271
$\Sigma\delta$ GDPPCC	1.588	-	-2.05**	-1.82***	0.727***
$\Sigma\delta$ENU	0.255	1.586	-	0.749	0.220
$\Sigma\delta$URB	-0.186	0.345	0.019	-	0.654

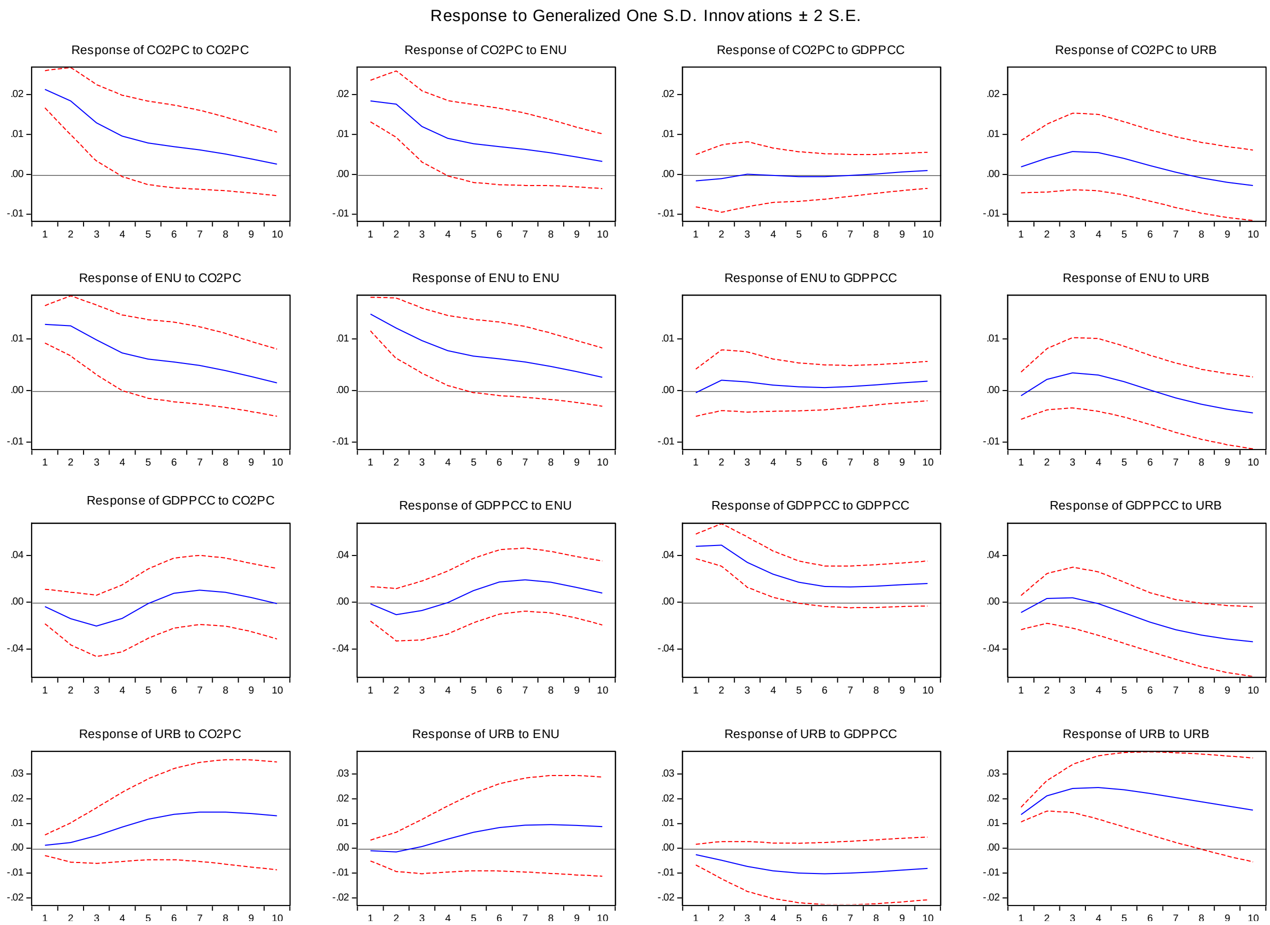
Note: *, **, & *** signifies 0.01, 0.05, & 0.10 significance level, respectively.

This research employed the variance decomposition, which is deployed for measuring the percentage of a particular parameters' forecast error variance caused by a shock from a variable for a given period of time beyond the study's sample period. Table 11 reports the variance decomposition analysis result. From this report, all variables will tend to affect each other in the future. CO2 emissions variance decomposition result shows 2.73%, 0.43%, and 7.16% of the forecast error variance of CO2 emissions is caused by a one standard deviation shock in urbanization, economic growth, and energy use after the 10-year horizon. The remaining percentage of 89.66% of the forecast error variance of CO2 emissions is self-explanatory after 10 periods. After the 10 years period, the energy use variance decomposition finding shows 14.93% of energy use is explained by its shocks. A one variation shock in CO2 emissions contributes to energy use by 73.64%, whereas 3.45%, and 7.97% of energy use is contributed by economic growth, and urbanization respectively. Results for variance decomposition for urbanization exhibit only 65.43% of the variation in urbanization is self-explanatory. CO2 emissions contribution is 23.36% of the forecast error variance. The remaining percentages were accounted for by other variables: energy use (7.60%), and urbanization (3.59%). Variance decomposition outcome for economic growth shows that only 48.26% of the one standard deviation in economic growth is self-explanatory. Energy use explains 23.02% of the forecast error variance after 10 periods while the other variables were accounted for the remaining percentages: CO2 emission (7.39%), and urbanization (21.32%).

Table 12: Variance Decomposition

Period	S.E.	CO2	ENU	URB	GDPPC
Variance Decomposition of CO_2 emission					
1	0.021	100.000	0.000	0.000	0.000
2	0.029	97.056	1.381	1.510	0.053
3	0.032	94.335	1.377	3.943	0.344
4	0.034	92.192	1.430	5.935	0.443
5	0.035	91.111	1.611	6.840	0.438
6	0.036	90.844	1.813	6.921	0.422
7	0.036	90.839	2.027	6.725	0.409
8	0.037	90.716	2.256	6.624	0.404
9	0.037	90.328	2.496	6.767	0.410
10	0.037	89.666	2.738	7.164	0.432
Variance Decomposition of ENU					
1	0.015	74.473	25.527	0.000	0.000
2	0.020	80.835	15.837	0.880	2.448
3	0.023	80.478	13.205	2.898	3.419
4	0.024	79.107	12.890	4.379	3.624
5	0.025	78.667	13.038	4.684	3.611
6	0.026	78.676	13.358	4.442	3.524
7	0.027	78.380	13.757	4.419	3.443
8	0.027	77.419	14.173	5.006	3.401
9	0.028	75.778	14.577	6.238	3.407
10	0.028	73.640	14.934	7.970	3.455
Variance Decomposition of UrB					
1	0.014	0.799	8.165	91.036	0.000
2	0.025	1.073	9.662	89.132	0.132
3	0.035	2.667	9.332	87.316	0.685
4	0.044	5.642	8.897	84.053	1.407
5	0.051	9.501	8.551	79.877	2.071
6	0.057	13.429	8.257	75.719	2.595
7	0.062	16.865	8.019	72.137	2.978
8	0.066	19.626	7.839	69.284	3.252
9	0.070	21.752	7.705	67.092	3.451
10	0.073	23.362	7.609	65.431	3.599
Variance Decomposition of GDPPCC					
1	0.048	0.572	0.558	2.670	96.200
2	0.071	4.175	0.393	1.842	93.590
3	0.084	8.743	6.357	3.360	81.540
4	0.092	9.690	11.712	3.416	75.181
5	0.096	8.945	16.008	3.234	71.812
6	0.100	8.847	19.309	4.474	67.369
7	0.104	9.059	21.332	7.546	62.063
8	0.110	8.812	22.417	11.850	56.921
9	0.115	8.118	22.923	16.631	52.329
10	0.121	7.394	23.021	21.322	48.263

The impulse response is used to determine the dependent variables' reaction arising from shock from the independent variables for a given period of time beyond the study's sample period. It can be said to be the mirror of the variance decomposition approach. Fig 5 shows the impulse response function for CO2, energy use, GDPPCC, and URB, which is explained as follows: CO2 emissions' responses to forecast error in energy use tend to be positive while it responds to forecast error in urbanization tends to be positive in the first 7th time horizon but the responses after 7th-time horizon show to be negative and finally, the CO2 emissions' response to forecast error in economic growth seems to shows no significant direction. The response of energy use to forecast error in CO2 emissions and economic growth shows to be positive since it's above the 0 lines, but the response of energy use to forecast error in urbanization tends to be negative at the early start and then responds positively before 6th-time horizon and start to decrease after 6th-time horizon. The response of economic growth to forecast error in CO2 emissions shows to be negative until after the 6th horizon is shows to be positive, response to forecast error in energy use shows the similar result which is negative before 4th-time horizon and start to rise after 4th-time horizon. Economic growth response to forecast error in urbanization tends to fluctuate until the 3rd time horizon, then the response changes to be negative. Urbanization responds positively and negatively to forecast error in CO2 emissions and economic growth, respectively, while its responses to forecast error in energy use fluctuate until the 2nd time horizon, then change the response to be positive.



4. Conclusion and Policy Path

This research focuses on the influence of economic growth on CO2 emissions and energy consumption by including the role of urbanization in South Africa between 1971 and 2015. This study employed the Johansen and Bounds cointegration tests, which revealed long-run interaction among the variables. Likewise, the outcomes of the ARDL test reports that (i) energy use and urbanization exert a positive effect on CO2 emissions; (ii) economic growth negatively effect the quality of the environment; (iii) energy use in South Africa is accelerated by economic growth and environmental degradation ; and (iv) urbanization has a positive impact on energy use in South Africa. The outcomes of the DOLS and FMOLS support the ARDL long-run outcomes. Moreover, the VECM Granger causality test outcomes show one-way causality from all the regressors to GDPPCC in the long run. In addition, in the short run, there is a unidirectional causality running from GDPPCC to ENU and URB.

Based on this study's outcome, we recommend the following policies: (i) Given that coal energy use is unavoidable for south African industrial production, measures to limit its improper use/abuse must be adopted to mitigate its devastating consequences on the environment as well as human and animals. Policymakers in South Africa should develop a policy establishing a limit on coal usage. For instance, energy/environmental policy that prohibit the emission-increasing impacts of coal usage should be adopted and strictly enforced in order to improve energy-saving technology or minimise the extensive utilization of coal usage. (ii) We insist that increasing investment in renewable energy such as solar, hydro, wind and geothermal energy sources or the implementation of environmental regulations that stimulate the use of this sustainable energy sources by households as well as locally and internationally industries that depend on energy for manufacturing. (iii) Appropriate planning and organized efforts need to make towards urban cities. Future studies should consider and employ other form of environmemental degradation such as green house gases, ecological footprints and load capacity factor

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