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RESEARCH ARTICLE

Assessing South African's Economic Growth and Foreign Direct Investment: Implications for Environmental Sustainability

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ABSTRACT

Environmental sustainability is an essential element of global focus based on 26th UN climate change conference, 2021. Essentially, recent rapid economic growth in South Africa (SA) has created verifying environmental sustainability. Sequel to this, this study assesses SA economic growth and Foreign Direct Investment, implications for environmental sustainability span over 1986-2022. Environmental Kuznet Hypothesis is the framework adopted for the study using ARDL techniques to assess the long-run connection amid the variables. The findings signify that rises in economic growth creates more carbon emissions, then begins to fall at a particular level, thereby confirming Environmental Kuznet Hypothesis for SA. The causality approach signifies that Foreign Direct Investment, urban population and economic growth contribute significantly to carbon emission threshold in SA. Essentially, future researchers may choose to adapt the study to Sub-Saharan Africa and incorporate one or more control variables.

INTRODUCTION

Recent rapid economic growth in South Africa has created an environment that is favorable to both the urban population's (URBP) development and foreign direct investment (ForDI). However, despite its benefits, ForDI has significantly increased the strain on natural quality that is the sustainability of the environment. The effects on South Africa's ecological quality became increasingly apparent in the mid-2000s, when burden to increase per capita income (PCI) and the influence of foreign direct investment(ForDI) truly applied a key effect on economic expansion. Nevertheless, a number of noteworthy environmental problems in recent years have brought institutions, organizations, and citizens to recognize the need of climate protection and environmental sustainability. Carbon emissions (CE) play a major function in the ecological degradation of South Africa, increasing the amount of FDI inflows [1, 2, 38]

The environmental sustainability is well explained by Environmental Kuznets Curve hypothesis (EKC), especially its intricate connection amid environmental deterioration and economic growth is illustrated by the EKC. The EKC evaluates the connection amid environmental harm and economic growth, drawing inspiration from [3], who used an inverted U – shaped curve to show the connection amid environmental degradation and economic growth. Through the early cycle of expansion, ecological pollution primarily rises in step whilst rising GDP per capita. Later in development, as per capita income rises and ecological contamination levels decline, this tendency reverses. Several empirical endeavors carried out in the past support or refute this hypothesized relationship. The presence or absence of cogent variables that could influence this connection, as well as variations in methodological techniques and time periods, can all affect the results of different studies. ***Despite*** *problems with EKC research, identifying the bias due to missing variables in the growth-CE link needs to be done.*

Furthermore, renewable energy helps reduce greenhouse gas (GHG) emissions as stated by European-Environment Agency (EEA, 2014). [4] as first scholars to includes renewable energy (RENE)

consumption in modelling EKC study. [5] and [6] claim that RENE minimized GHG emissions in Asia [7], [8] and [9] all assert that the urban population is a key determinant of CE.[10], [11], [12] and [2] all mentioned ForDI as a critical component that might have a big impact on emissions. Few studies examine how ForDI, URBP, and RENE impact environmental changes in South Africa using the EKC hypothesis. Given this, by investigating the causal relationships between South Africa's urban population, GrDP, CE, RENE and ForDI, Essentially, this piece of work will add to empirical stance in climate change. The aims of this paper are to evaluate the correctness of EKC hypothesis possibilities in SA from 1986 to 2022. It is essential to ascertain "whether the using of RENE and ForDI have an effect on environment sustainability and if any causality exist between RENE and ForDI at both short and long run in South Africa. Additionally, using data gathered between 1990 and 2021, Pesaran et al. [2001] developed ARDL techniques which will be used to evaluate the long − run link between South Africa's CE and ForDI. The short − run and long − run causal connections amid variables are ascertained using the Granger causality test using an error correcting model Engle et al. [1987]. centered on the earliest ground, this study will support the design of a robust background-policy and strategical benchmark for energy efficient criterion as South Africa transitions to a carbon-efficient economy. Designing effective overall strategy, it is essential to evaluate the connection amid national emancipation and CE. Dividing the paper into five parts is essential. The first part covers the introduction, and the second part evaluates the literature on the relationship between GrDP per capita and CE while accounting for germane variables such as RENE, URBP, and ForDI. The third portion provides an explanation of the research technique used for the empirical work, the fourth part presents the findings and a discussion of the study. A conclusion is provided in the fifth and final section.

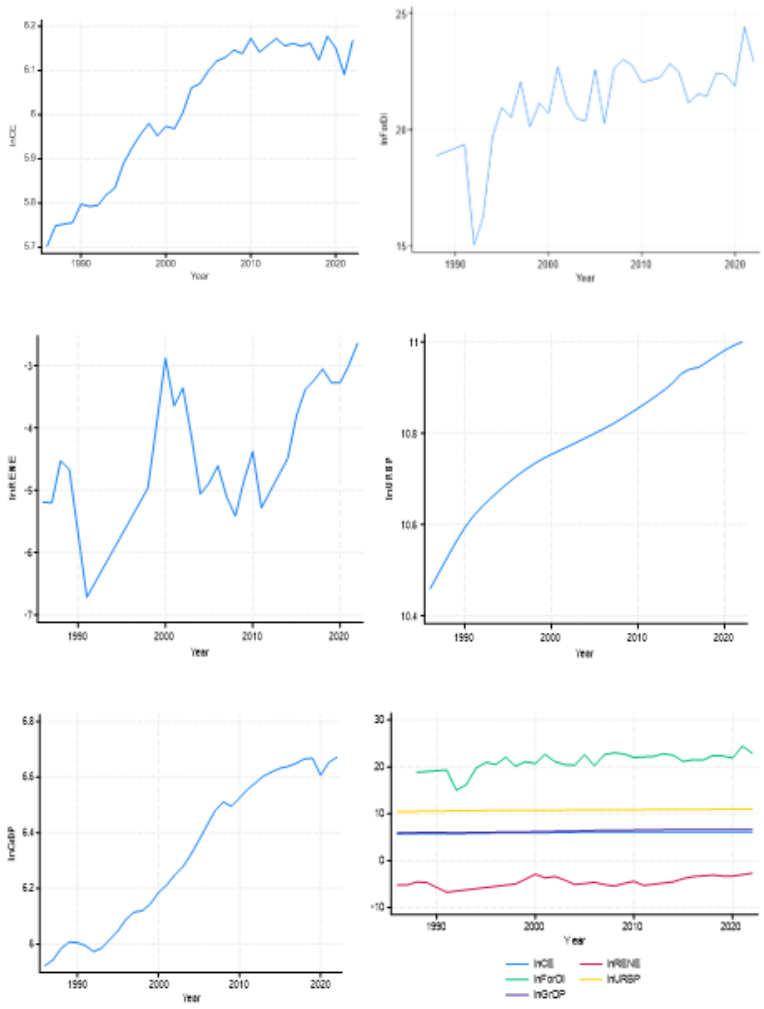

Fig 1. Schematic Behavior of Employed Variables

LITERATURE REVIEW

According to the EKC hypothesis, there will be a divergent relationship between extending finances or creating new livelihoods and the breakdown of the natural world. Although the EKC hypothesis has garnered critical attention in literature, its validity and predictive capacity are still being debated. The results have changed dramatically due to different processes, periods of time, and the addition or subtraction of important elements that could affect connections [13, 14]. It is believed that increasing rates of URBP, ForDI, CE, and economic growth are to blame for adverse ecological repercussions [15]. As such, the evaluation of the connections amid energy consumption, CE, ForDI, the GrDP, and urban population is divided into three sections in this study.

Employing empirical data to validate the EKC conjecture with respect to the relationship amid GrDP and CE in SA. The analysis of the energy – CE and urban population connection come last.

Essentially, it is important to state that there exists research in the global literature that establish a connection between economic growth, energy consumption, and pollutant emissions under the paradigm established by Ang (2007) and Soytas et al. (2007), these studies are not specific to South Africa. The studies that do address South Africa look at the relationship between energy consumption and economic growth (Ziramba, 2009; Odhiambo, 2009; Wolde-Rufael, 2006, 2009) or the relationship between economic growth and emissions (Nahman and Antrobus, 2005).

The goal of Shikwambana et al. (2021) was to ascertain how South Africa's emissions and economic growth are related. To analyze the study trends, the sequential Mann-Kendall (SQMK) test, the environmental Kuznets curve hypothesis test, and the linear correlation coefficient were used. It was shown that the expansion of the economy and carbon dioxide emissions have a strong positive linear relationship.

[39, 40] study are the only one conducted in South Africa that uses contemporary developments in time series econometrics of cointegration and causality to examine the connection between energy consumption, pollutant emissions, and economic growth in a logical multivariate framework, as a result of acute literature on SA economy make it difficult to evaluate much literature on South Africa economy.

According to the main strategy, several analyses have looked into the occurrence of EKC-anticipated ways of behaving in various nations and have produced inconsistent findings because of different methodologies employed, research fields, time spans, and factual approaches [16]. Recent EKC legitimacy findings seem to be problematic. [15], for instance used a VECM assessment of the EKC to evaluate the connection amid CE and economic growth in five region that are part of the Association of Southeast Asian Nations (ASEAN). According to the empirical findings subject to secondary data range from 1980-2006, the EKC hypothesis seems to have some backing in the five ASEAN states. Al-Mulali et al. [17] evaluated the EKC hypothesis in Vietnam between 1981 and 2011, concluding that it was invalid because of the long-lived positive correlation between the country's gross domestic output and pollution. Moreover, it was discovered that while the use of petroleum derivatives causes increased pollution, RENE consumption had no effect on the reduction in environmental pollution.

Between 1961 and 2010, [18] looked into the connections between Turkey's GrDP, CE, and power produced sustainably. The results demonstrated that a one-year lag in climate change is provided by improvements in infinite power. Furthermore, a U – inverted EKC link amid per capita GHG emissions and income was discovered. Referring to the next technique, numerous empirical works have proved that facilitating energy use, stimulating new investments, and economic growth may have detrimental impacts on climate change. Policymakers believe ForDI has a substantial effect on increasing the host nation's efficiency [19]. This focus also emphasizes how industrial reconstruction and information flow are two ways that foreign direct investment (ForDI) enhances the effectiveness of electricity consumption. Shahbaz et al. [20] showed that outflows increase due to the attraction of ForDI, the sense of financial action, and the efficacy of the securities exchange. Using annual data from 1980 to 2014, Bakhsh et al. [21] discovered that ForDI affects climate change in Pakistan via volume, method, and framework channel impacts. Higher contamination outflows are caused by expanded financial development, as evidenced by the procedure's and arrangement's effects. The scale impact demonstrated that although pollution hinders Pakistan's economic growth, work and capital availability have a positive impact. Additionally, it was discovered that ForDI had a negative effect on CE and exhaustible waste. [22], there is a bidirectional causal relationship between ForDI streams and economic growth, vis-a vis

between ForDI and CE. This suggests that ForDI may be harmful to countries. Research on the Bay Participation Board and ASEAN-5 has shown that energy consumption and the financial turn of events are the main sources of pollution emissions, although ForDI inflows have minimal effect [23]. Based on this, the economy system of Pakistan fails to achieve genuine concentration, and the impact of ForDI on national contamination continues to be a contentious issue. Granger causality was applied by Tang et al. [11] to evaluate the connections amid energy consumption, CE, ForDI, and economic growth in Vietnam between 1976 and 2009. The connections are considered valuable with EKC, which suggests a redesigned U − shaped connection between CE and financial turn of events. The findings also indicated a multiple causal connection amid CE and compensation, as well as amid ForDI and CE. The main drivers of CE in SA are ForDI, energy use, and compensation. The relationship between ForDI and pollution in the five ASEAN nations is also examined by Merican et al. [24] the findings, which made use of the autoregressive distributive lag assessment, indicated that foreign direct investment (ForDI) leads to an increase in outflows in the Thailand-Malaysia-Philippines though, opposite connection is feasible amid ForDI and contamination in Indonesia. Liu et al. [25] led a special analysis into the effects of ForDI, global business, environmentally friendly power, and mechanical progress on China's CE outflows from 1995 to 2017. The findings indicates that every model included in the review had a cointegration connection, signifying that ForDI and GrDP had a significant effect on CE. Pao et al. [26] using ARDL approach to test for cointegration from 1980-2007 examining the EKC conjecture. They discovered strong evidence for a causal connection amid ForDI and emanations given strong evidence for a connection amid ForDI and yield and between energy use and CE.

According to the empirical findings, URBP is view as a measure of the quantity and quality of various settings decreasing, much as monetary extension. Due to steady economic growth, globalization, and jobs creation that open up in downtown regions, significant metropolitan towns have developed into hubs for finance, politics, education, and culture in many rural countries [27].

In particular, the rate of urbanization has recently had an impact on the generally limited supply of assets, which has negative effects on the natural conditions of countries Li et al. [25]. According to the EKC hypothesis, urbanization plays a major role in the emanation's monetary development nexus. Glaeser et al. [28] is seen as leading the discussion on urbanization and natural causes. They and others have argued that the natural conditions of many urban areas deteriorate as metropolitan populations grow [29]. Little previous empirical studies have shown the usefulness of considering URBP when examining the connection between CE, GrDP and 137 economies were evaluated on climate change. Bekun et al. [2] concludes that URBP causes CE. From 1990 to 2023, Furthermore, Halliru et al. [30] investigated the relationships between energy consumption, URBP, and CE in ASEAN economies using a modified board-based normal least squares approach. The long-term data showed a genuinely critical positive correlation amid energy use and CE outflows., Waka. [31] found, supported by precise evidence, that urbanization had a significant impact on CO2 emissions in an example of Asian economies. From 1991 to 2019, Ofari et al. [32] examined the relationships between RENE, income, URBP, and CE fluxes in *SSA*. Long-run outcomes that make use of continuously updated longitudinal data with uninterruptedly flow inclination-adjusted processes increasingly to demonstrate the cogency of the EKC hypothesis. Rapid URBP and GrDP are also connected with increased CE, whereas RENE is the most active strategy for addressing declining CE. Sunde [33] examined how ForDI, export affect economic growth in emerging nations between, demonstrating the existence of a modified U − shaped pattern in the connection amid economic growth and other employed variables.

Previous study has yielded mixed results regarding the effects of energy use, ForDI, urbanization, and economic growth on climatic change, which makes it difficult to extrapolate these findings to Vietnam. Research findings vary because various periods and/or altered procedures were used, or because elements were overlooked. The study employed URBP and ForDI because, starting from 1986, many industries progressed more quickly; increased from 12% in 1986 to 68% in 2022 (World Bank, 2022), while ForDI inflows increased from 2, 103.2 USD to 6.776.5 billion USD in 2022 (WDI, 2022). As a result, this study integrates the variables RENE, URBP, and foreign direct investment inflows into the model, which is intended to play a crucial role in the EKC method. A few gaps in the writing were discovered by these analyses. First off, even though South Africa (SA) has successfully reenergized financial development in recent years, the majority of previous empirical papers

focused on the effects of energy usage on CE; scarce empirical work examines the connection amid GrDP, CE outflows, and environmentally friendly energy usage using the EKC hypothesis to account for variables like URBP and ForDI. Many analyses have only focused on how energy use affects SA CE outflows. Furthermore, there are a few benefits that this study possesses over the earliest study. It attempts to prevent the inclination created by absent elements by keeping in mind ForDI and the total population of country for the model. After resolving the systemic problems, the autoregressive dispersed slack limits testing method is used to investigate the long-run connection. Adeel-Farooq [35], the VECM techniques is arguably one of the most adaptable methods for conducting an econometric analysis of the energy-development nexus. The direction of the causal relationship between the elements is then determined by running the Granger causality tests. Despite these benefits, this sophisticated approach facilitates the short and long run identification of causal relationships.

After reviewing a great deal of literature, we found that there is not a lot written on the South African economy, particularly in the areas of economic growth, foreign direct investment, and environmental sustainability. Using an advanced techniques to investigate the true link between the variables is extremely desirable. Therefore, our work fills a vacuum in the literature by establishing the long-run link between the variables, which future researchers might refer to for more empirical investigations.

METHODOLOGY

Since carbon emissions (CE) are the most widely used proxy to forecast emissions [16], the current study gives a wider perspective to assess environmental sustainability by utilizing CE and varieties of economic variables such as renewable energy (RENE) and urban population (URBP). RENE and URBP are further used as control variables in the model.

The data for this study were obtained from the World Bank's data sources, with world development indicators (WDI) and U.S Energy Information Administration (EIA) using the annual frequency of 1986–2021.

The complete specification of the database is www.databank.worldbank.org/source/world-developement-indicators *(accessed on 1 September, 2023) and* https://www.eia.gov/international/data/world/other-statistics/more-other-statistics-data?pd=40&p. However, the world development indicators website has available data almost all countries South Africa included. Therefore, the final sample includes the data as per available number of years under observation from WDI for achieving the research objective. The complete description of countries included in the sample is available in Table 1. The dependent variable of the study is "carbon emission", while the main independent variable of the study are carbon emission milestone (MMtonnes CO_2) and foreign direct investment and economic growth, which is measured as per capita GDP by considering 2015 as a constant. The per capita GDP is related to an economy's positive outlook in terms of better life satisfaction, better health condition, more safety, more education, and better sustainability of environment for future generations, therefore, it is a good measure of sustainable economic growth [6, 25, 43]. Additionally, the study also considered renewable energy and urban population as the control variables. As the real growth adjusts the urban population for the calculation of an economy's growth in real terms, therefore, it is a good measure of the growth rate. The detailed measurements of all the variables, including their data sources, and the literature references are summarized in Table 1 below.

Table 1. Measurement of Variables and Data Sources

Variables	Measurements	Data Sources	References
FDI inflow	net inflow of FDI (% of GDP)	WDI	(6, 27,)
Carbon emissions	(per capita metric ton)	IEA	(2)
Renewable energy	RENE consumption (% of total energy usage)	WDI	(2, 6)
Urban population	urban population (human size)	IEA	(1, 2,4)
Economic growth	GDP per capita (constant USD)	WDI	(2, 6)

The time-series data estimations require several data analysis procedures: aggregate descriptive statistics, aggregate unit root testing, and ARDL regression estimations.

Time-series data from the WDI and EIA covering the years 1991–2021 were used in the study. These data included GrDP per capita (USD constant), CE (per capita metric ton) (EIA, 2022), urban population (human size) [EIA, 2022], ForDI inflows (USD current) [WDI, 2022] and RENE is obtained from EIA, 2022.

There are two methods to establish a causal and sustainable relationship between CE, GrDP per capita, RENE, URBP, and ForDI. First, using the ARDL method of cointegration to assess the long-term connections between the variables. Second, the study used error correction-based causality models to test for causal relationships. According to studies by Sharma [35], Hossain [36], and others, URBP has a significant impact on environmental quality. The study suggested equation (1), which offers a model of how CE are determined by GrDP, RENE, URBP and ForDI.

Following the studies of Sharma [35], Adekunle et al [1, 9] show essentiality of URBP regarding environment sustainability, equation (1) is derived base on theoretical guidelines established by the previous studies, CE being gauge by GrDP, RENE, URBP, and FoDI as follows:

$$CE = KGrDP^{\delta_1}\ RENE^{\delta_2}\ URBP^{\delta_3} FoDIn^{\delta_4} \quad \text{(i)}$$

Analyzing eq(i) through the natural log leads to eq(ii) below

$$\ln CE = \beta_0 + \beta_1 \ln GrDP + \beta_2 \ln RENE + \beta_3 \ln URBP + \beta_4 \ln ForDI \quad \text{. (ii)}$$

Since the EKC is U inverted shape, it is essential to square the GrDP in order to evaluate if EKC assertion holds in SA.

$$\ln CE = \beta_0 + \beta_1 \ln GrDP_t + \beta_2 \ln GrDP_t^{\,2} + \beta_3 \ln RENE_t + \beta_4 \ln URBP_t + \beta_5 \ln ForDI_t + € \quad \text{(iii)}$$

t and ε show the time and error term, accordingly. CE represents CO_2 emissions per capita, URBP is the urban population, and β_i, where i = 1, …, 5, is the long-term slope of GrDP, $GrDP^2$, RENE, URBP, and ForDI, respectively. In eq. (iii), if $\beta 1 > 0$ and $\beta 2 < 0$, EKC holds.

Consequently, this affirms the presence of an inverted U-molded frame, and that implies that when GrDP rises, CE discharges likewise ascend until GrDP per capita arrives at a limit level. Then, CE emanations jerk to debilitating as the GrDP rises.

This study employed dynamic (ARDL) approach to cointegration, which was propounded by Pesaran, Shin; Smith [1992]. Testing for existence of unit root is essential to satisfy application of ARDL techniques which means all employed variables must be at level or first difference. Augmented Dickey-Fuller (ADF) and Phillips-Perron (P-P) are used to establish the suitability of ARDL techniques. The adopted technique (ARDL) is of two importance. Firstly, ARDL is used to evaluate the log-run links amid the ARDL model is designed as follows:

$$\begin{aligned} CE_t = {} & \beta_1 + \beta_i CE_{t-i} + \beta_2 GrDP_t + \beta_2 GrDP^2{}_t + \beta_3 RENE_t + \beta_4 ForDI_t + \sum_j^m \tilde{\beta}_{j,i}\, URBP_{\cdot} \\ & + \sum_j^m \tilde{\beta}_{j,i}\, GDP_{t-i} + \sum_j^m \tilde{\beta}_{j,i}\, GrDP^2{}_{t-i} + \sum_j^m \tilde{\beta}_{j,i}\, RENE_{t-i} + \beta_4 ForDI_t \\ & + \sum_j^m \tilde{\beta}_{j,i}\, URBP_{t-i} + \varepsilon_t \end{aligned}$$

AIC use to select optimal lag in estimating (iv) is:

$$AIC = \left(\ln|J_z|^2 + \frac{2k^2 v}{N}\right) k = 1,2,\dots,p \qquad v$$

$$\begin{pmatrix} \Delta \ln CE \\ \Delta \ln GrDP \\ \Delta \ln GrDP^2 \\ \Delta \ln RENE \\ \Delta \ln URBP \\ \Delta \ln ForDI \end{pmatrix} = \begin{pmatrix} \emptyset_1 \\ \emptyset_2 \\ \emptyset_3 \\ \emptyset_4 \\ \emptyset_5 \\ \emptyset_6 \end{pmatrix} + \begin{pmatrix} \ni_{11,1} \ni_{12} \ni_{31} \ni_{41} \\ \ni_{21} \ni_{22} \ni_{23} \ni_{24} \\ \ni_{31} \ni_{32} \ni_{33} \ni_{34} \\ \ni_{41} \ni_{42} \ni_{43} \ni_{44} \\ \ni_{51} \ni_{52} \ni_{53} \ni_{54} \\ \ni_{61} \ni_{62} \ni_{63} \ni_{64} \end{pmatrix} \begin{pmatrix} \Delta \ln CE_{t-1} \\ \Delta \ln GrDP_{t-1} \\ \Delta \ln GrDP^2{}_{t-1} \\ \Delta \ln RENE_{t-1} \\ \Delta \ln URBP_{t-1} \\ \Delta \ln ForDI_{t-1} \end{pmatrix} \quad \text{vi}$$

$$\begin{pmatrix} \ni_{11,g} \ni_{12,n} \ni_{13,g} \ni_{14,g} \\ \ni_{21,g} \ni_{22,g} \ni_{23,g} \ni_{24,g} \\ \ni_{31,g} \ni_{32,g} \ni_{33,g} \ni_{34,g} \\ \ni_{41,g} \ni_{42,g} \ni_{43,g} \ni_{44,g} \\ \ni_{51,g} \ni_{52,g} \ni_{53,g} \ni_{54,g} \\ \ni_{61,g} \ni_{62,g} \ni_{63,g} \ni_{64,g} \end{pmatrix} \begin{pmatrix} \Delta \ln CE_{t-g} \\ \Delta \ln GrDP_{t-g} \\ \Delta \ln GrDP^2{}_{t-g} \\ \Delta \ln RENE_{t-g} \\ \Delta \ln URBP_{t-g} \\ \Delta \ln ForDI_{t-g} \end{pmatrix} + \begin{pmatrix} \partial_1 \\ \partial_2 \\ \partial_3 \\ \partial_4 \\ \partial_5 \\ \partial_6 \end{pmatrix} ECT_{t-1} + \begin{pmatrix} \in_4 \\ \in_5 \\ \in_6 \\ \in_7 \\ \in_8 \\ \in_9 \end{pmatrix} \quad \text{vii}$$

where ε_4 to ε_6 are distributed normally and exogenous with a constant variance, g stands for lag length which its optimality is essential, and determined using the AIC or SBC criterion. Using Equation (vii), possible two ways in which causality is examined in this paper are: First, the F-measurement or Wald test views as the important ∋ coefficient's significance on the first-differenced series to survey causality in the short run. Second, t- or Wald tests are utilized to view as the applicable ∂ coefficient's importance on the slacked ECT to recognize causality over the long run. If the ECM is robust with a minus sign, it shows long-run causality. The CUSUM-of-squares (CUSUMSQ) and cumulative sum (CUSUM) tests are used to justify the stability of the model employed.

RESULTS AND DISCUSSION

Table 2 presents an overview of the descriptive statistics for the variables we employed in our analysis. The number of observations is 36, with six variables that are being employed in this study to establish a better understanding of the connection amid these variables. Carbon emission (CE) employed as endogenous variable and exogenous variables employed are the urban population (URBP), renewable energy (RENE), foreign direct investment (ForDI) and gross domestic product (GrDP). It is essential to test for order of integration prior employing the ARDL technique, we apply ADF and PP test to satisfy that all variables were integrated at I(0) and I(1) which can be seen in Table 3 and 4 below. Essentially, ARDL method is suitable for this study since the order of integration has been established, the optimal lag structure is 2 which is confirmed by AIC criterion.

Table 2. Descriptive Statistics for Variables

Variable	Observation	mean	Std.Dev	Min	max
CE	36	6.00	0.15	5.70	6.17
ForDI	36	1.22	1.83	0.20	9.68
GrDP	36	0.49	2.64	7.11	4.59
GrDP2	36	7.00	9.68	0.02	50.50
RENE	36	6.84	0.14	6.63	7.15
URB	36	2.45	0.89	1.16	4.56

Table 3. ADF

Variable	Level .			
	First Difference			
	Prob.(with trend)	Intercept	Prob.(with trend)	Intercept
CE	0.994	0.091	0.575	0.94
GrDP	0.811	0.993	0.000*	0.000*
GrDP^2	0.59	0.973	0.000*	0.000*

ForDI	0.000*	0.000*	0.000*	0.000*
RENE	0.767*	0.806	0.001*	0.000*
URBP	0.159	0.801	0.215	0.127

Note: *, and **, indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 4. PPT Test Output

Variable	**Level**			
	First Difference			
	Prob.(with trend)	**Intercept**	**Prob.(with trend)**	**Intercept**
CE	0.866	0.390	0.000	0.000
GrDP	0.731	0.931	0.000*	0.000*
GrDP^2	0.578	0.972	0.000*	0.000*
ForDI	0.000*	0.000*	0.000*	0.000*
RENE	0.753	0.861	0.001*	0.000*
URBP	0.044	0.222	0.486	0.154

Table 5. Bound test

T-Statistic				
	F-Stat		**k**	
	5.37		**4**	
			Critical Value Bounds	
Significance		**I0 Bound**		**I1 Bound**
1%		3.74		5.06
2.50%		3.25		4.49
5%		2.86		4.01
10%		2.45		3.52

The bounded F – test output in Table 4 is 5.37, which above the upper-bound-limit at a 5% significance level. This demonstrates the presence of cointegration in this model.

Table 6 shows the associations between the variables throughout time. Given the EKC conjecture, it is expected that GrDP per capita to CE per capita will be favourable and long-run versatility evaluations of $GrDP^2$ will be negative. Therefore, a 1% increase in GrDP per capita can result in a 6.6% increase in CE per capita, whereas a 1% increase in $GrDP^2$ can result in a 2.4% loss in CE per capita. These findings bolster the validity of the EKC hypothesis in the South African economy. Early industrialization will need a trade – off between GrDP and environmental pollution for emerging nations like South Africa, as public activity plans don't place much emphasis on ecological security. However, as industrialization progressed and wages increased, people began to prioritize environmental concerns, and higher-performing oversight bodies resulted in reduced levels of environmental contamination. Higher paid consumers will spend more on clean, green products and pay closer attention to environmental regulations and security

Table 6. Long Run Relationship

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Probability**
ForDI	-0.118	0.192	-6.135	0.000
GrDP	0.662	0.636	1.04	0.010*
GrDP2	-0.241	0.138	-1.746	0.023*
RENE	-3.057	1.137	-2.688	0.030*
URBP	0.027	0.014	2.432	0.040*
Constant	161.35	65.76	2.453	0.043*
Ectt-1	-1.982	0.305	-6.403	0.000*

Significant at a 5% level*

Furthermore, at a 5% significance level, the RENE and ForDI coefficients are negative. In this way, a 1% increase in RENE results in a 3% drop in CE per capita, while a 1% increase in ForDI results in a

0.11% decrease in CE per capita. However, a 1% increase in URBP causes a 0.03% (important at the 5% threshold) increase in per capita CE. At a 1% certainty level, the determined ECT coefficients were actually critical and negative (- 1.98). These characteristics demonstrate how any deviation from the long-term equilibrium of the factors is adjusted for each period and causes the long – term degree of equilibrium to recur.

Table 7. Cauality Output

Variable	**Short run causality**						**Long run causality**
	F-statistic (probability)						**Ect_{t-1} (t-statistic)**
	ΔCE	**ΔGrDP**	**ΔGrDP2**	**ForDI**	**RENE**	**URBP**	
CE		8.595	10.013	3.270	3.905	0.581	-0. 051(-.000)4
		(0.00)	(0.00)	(0.05)	(0.03)	(0.565)	
GrDP	8.921		5.948	8.948	1.703	5.206	0.004(0.00)4
	(0.00)		(0.00)	(0.00)	(0.199)	(0.00)	
GrDP^2	8.842	7.083		12.125	1.745	7.584	
	(0.00)	(0.00)		(0.00)	(0.191)	(0.00)	
ForDI	3.114	0.048	0.103		2.906	0.373	-2.125(-0.015)4
	(0.05)	(0.95)	(0.90)		(0.07)	(0.69)	
RENE	0.218	0.056	1.396	1.396		0.153	No cointegration
	(0.060)	(0.944)	(0.88)	(0.26)		(0.85)	
URBP	1.409	2.821	2.139	3.287	2.190		-0.762(0.00)4
		(0.060)	(0.07)	(0.13)	(0.05)	(0.129)	

Table 7 above accounts for and arranges the results from the two Granger causality models in the following manner. First off, this indicates that there is a two-way causal relationship, both short- and long-term, between GrDP, GrDP2, ForDI and CE. This result indicates that CE will increase in tandem with increases in ForDI and economic growth. The finding concurs with empirical results of (9; 1 33) who independently discovered that economic growth increases CE in emerging economy, Malaysia, South Africa, and Vietnam. Furthermore, the results demonstrate the importance of populations growth for CE, which is consistent with [2, 17, 37].

There is unidirectional causality from FDI to CE, consequently showing that FDI assumes a significant part in ecological quality. These outcomes are in line with [20] and [22], who found that ForDI harms the climate. Government needs to energize unfamiliar speculation while safeguarding the climate; later on, the reinforcing of guidelines and specialized controls on ForDI, the climate, and machineries will be expected to save energy and slice CE as indicated by public and global principles. In the foundation of regulative reports and strategies connecting with environmental sustainability, a spotlight needs to be put on empowering organizations to take on successful outflows decrease designs or favored approaches to utilize low-emanations innovation and cycles. Consequently, the public authority should be extremely cautious while choosing international investor, as well as completely evaluate the ecological effects of ForDI during and after the venture interaction.

Furthermore, there is no cointegration between RENE and CE and no causality was detected between RENE and GrDP in the short run. This suggests that as GrDP increments, more energy is consumed, and energy utilization is negative to discharges and will advance GrDP over the long haul and cause natural issues. Therefore, a country's economy needs not be helped exclusively by energy utilization. Thusly, the connection recommends that energy arrangements like fossil fuel by-product decrease, energy proficiency measures won't diminish the pace of economic growth.

Besides, there is no cointegration between RENE and CE and no causality was identified between RENE and GrDP in the short-run This suggests that as GrDP increments, more energy is consumed, and energy utilization is wearisome to emanations and will advance GrDP over the long-run and cause environmental issues. Therefore, a country's economy needs not be helped exclusively by energy utilization. Hence, the connection recommends that energy approaches like fossil fuel byproduct decrease, energy productivity measures won't diminish the pace of change in economic activities.

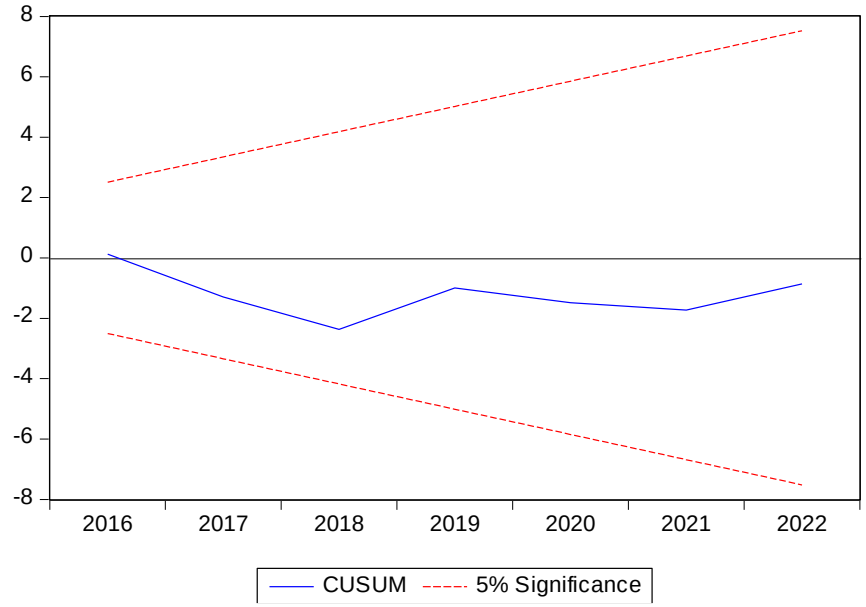

Fig 2. Cusum stability Test

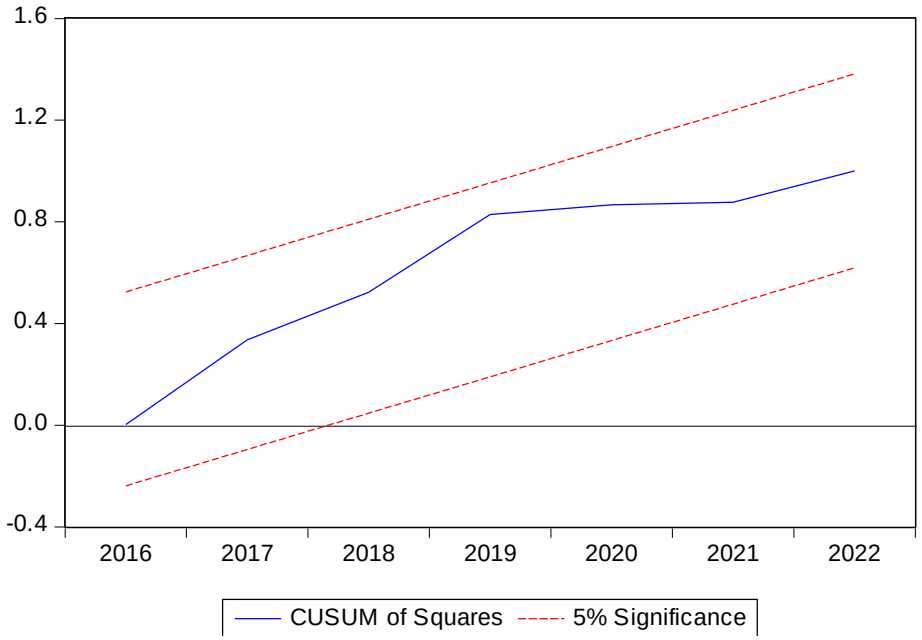

Fig. 3. Cusum of Squares Stability Test

The cumulative sum of squares (CUSUMSQ) and cumulative sum (CUSUM) are used to validate the stability of our model. Fig. 1 and Fig. 2 present the CUSUM and CUSUMSQ graphs. The lines fall within the critical bounds; thus, the results confirms that the coefficients of regression are stable.

CONCLUSION

The empirical outcome of this piece of research shows a causal connection amid foreign direct investment, economic growth, urban population and carbon emission in South Africa employing advanced ARDL techniques from 1986-2022.The study took into account the South African economy since, in order to boost environmental sustainability within the economy, these countries need to increase ForDI inflow and limit carbon emissions.

Essentially, the findings revealed that for South Africa economy, the EKC postulation relating to U-shaped curves is valid for the period of study. The study used advanced ARDL method to examine the nexus among renewable energy, gross domestic product, carbon emission, foreign direct investment, and urban population. Results also emphasize that renewable energy, urban population and foreign direct investment are essential elements in minimizing carbon emission in South Africa for the period of study. This study gives proof of the bi-directional causality between carbon

emission and gross domestic product in the short and long run. In South Africa, the long run effect of renewable energy is unfavorable. Subsequently, the SA government ought to zero in on strategies that advance the utilization of clean energy, which is less hurtful to the climate, and economic growth, since there are colossal possible wellsprings of clean energy in SA in recent time. Also, the significant expense of sustainable power in contrast with non-renewable energy source power is one of the primary impediments in present time. Consequently, environmentally friendly energy costs in SA ought to precisely address their financial benefits. Policymakers in SA ought to painstakingly deal with the foreign direct inflows for assembling tasks to precisely examine the harmony between economic growth and environmental sustainability, since our empirical results likewise show that foreign direct investment impacts economic growth in South Africa.

It is anticipated that the host economy will benefit from FDI inflows by gaining access to the current environmental degradation to ecosystem innovation. In this way, we advise the South African government to provide resources and implement policies that will attract foreign direct investment. This would enable more successful and low-carbon innovation to be executed across all endeavors, ultimately promoting economic growth in South Africa. Policymakers should enhance the nation's public transportation system and environmental sustainability because the urban population contributes significantly to carbon emissions.

In accordance with the urban population growth, government need to determine the rate of urbanization. Experience in developed countries demonstrates that urbanization is only really beneficial when it doesn't alter or intensify. people's aspirations for basic amenities like green space, transportation, air quality, or the development of medical services infrastructure, schools, notwithstanding other least favorable conditions like access to clean water, food, and security. Carbon emission discharges, a key contributor to GHG, should receive more attention.

In any case, future research ought to extend exploration to different gases, like nitrogen dioxide and methane, and other ecological elements, for example, wellbeing effects and waste, in regards to their consequences for economic growth. Besides, information on metropolitan populace and foreign direct investment inflow are by and large total information, so the review does not determine which region or city is the wellspring of expanded ecological contamination, this is likewise an idea for future research exploration and future researchers may choose to adapt the study to Sub-Saharan Africa and incorporate one or more control variables.

Authors Contribution

Conceptualization, Ahmed Oluwatobi Adekunle; Methodology, Adedeji Daniel Gbadebo; Software, Muri Wole Adedokun, Ahmed Oluwatobi Adekunle and Adedeji Daniel Gbadebo; Validation, Ahmed Oluwatobi Adekunle and Muri Wole Adedokun; Investigation, Joseph Akande; Resources, Adedeji Daniel Gbadebo; Data curation, Joseph Akande and Adedeji Daniel Gbadebo; Writing – original draft, Joseph Akande and Muri Wole Adedokun; funding acquisition, Ahmed Oluwatobi Adekunle, Muri Wole Adedokun and Joseph Akande; Project administration.

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Availability of data

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