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Integrating Industrialization, Macroeconomic Dynamics, and Environmental Degradation through CO_2 Emissions in South Africa

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Abstract

Sustainable environment play a significant role in development of every country on the globe. However, the former has been undergoing various changes due various factors adopted to assist in enhancing countries developments. The current study aims to evaluate the impact of foreign and domestic investments, industrialization, population growth and GDP per capita on environmental degradation in South Africa. Auto-regressive Distributed Lag (ARDL) and error correction are the approaches employed to determine the relationship among variables. The study outcome endorsed the existence of a long-run impact of all explanatory variables on environment degradation. Additionally, the results revealed that industrialization, economic growth and foreign direct investment heighten CO2 emissions and environmental degradation, while employment and population growth reduce the level of CO2 emissions in long-run. The study recommends collaborations amid foreign investors, domestic industries, and research institutions to advance the establishment of cleaner technologies and sustainable environmental practices in South Africa. Similarly, government should encourage and invest in green energy production to improve economy without impeding the environment.
Keywords: Carbon emissions, CO2, FDI, industrialization, environment degradation, economic growth, Population size

1 Introduction

Environmental degradation is defined as the deterioration of the atmosphere resulting from both natural disasters and anthropogenic factors (Federico, 2010). In contemporary discourse, global warming and the pursuit of a sustainable environment have emerged as significant economic concerns for researchers, scholars, and policymakers alike (Audi & Ali, 2018). According to the World Meteorological Organization (2020), these challenges have intensified and accelerated the process of environmental degradation. The Industrial Revolution, which began around 1750, is widely regarded as a pivotal moment in the history of climate change, as it marked a substantial increase in carbon dioxide (CO_2) emissions that were previously negligible (Ahmed et al., 2022). Prior to industrialization, atmospheric CO_2 concentrations were approximately 280 parts per million (ppm); however, due to the rapid pace of industrial activity, this figure surged to 419.3 ppm, representing the highest levels recorded in the past 800,000 years (Lindsey, 2020). Recent literature (Abdollahi, 2020; Hu et al., 2020; Nasir et al., 2021; Nathaniel, 2020) underscores the significant contributions of industrialization and energy consumption to the escalating rates of CO_2 emissions, thereby exacerbating environmental degradation.

Industrialization, as one of core determinants of production growth, is intrinsically linked to economic growth. In their pursuit of enhanced production capabilities and improved economic performance, countries confront the pressing challenge of achieving sustainable economic growth (Hanif et al., 2019). This challenge serves as a significant bottleneck for many developing nations striving to meet the Sustainable Development Goals (SDGs) established by the United Nations in 2015. These nations must navigate the complexities of balanced development, which necessitates the integration of economic, social, and ecological sustainability (UN, 2017). Historically, developed countries have recorded the highest levels of carbon dioxide (CO_2) emissions and continue to exhibit the highest per capita emissions. Consequently, as developing countries endeavour to achieve substantial economic advancement, they are anticipated to generate higher CO_2 emissions compared to their developed counterparts (Li & Lin, 2015; Jung et al., 2000; Raihan, 2023; Smit et al., 2010).

Carbon dioxide (CO_2) emissions are closely correlated with various macroeconomic factors, including foreign direct investment, gross domestic product (GDP), employment, and population growth. Developing countries seeking to enhance their economic performance often attract foreign investors. Such investments typically lead to the establishment of new industries or the improvement of existing ones, which are frequently associated with environmental pollution, particularly through increased CO_2 emissions. This trend is exacerbated by the relocation of polluting industries from developed to developing nations (OECD, 1999; Shahbaz et al., 2018). Consequently, this situation presents a dilemma for less-developed countries: while they strive to advance economically, they also value the importance of maintaining a clean environment for the well-being of their citizens.

Another significant economic factor influencing environmental change is GDP. In their pursuit of economic growth, countries are compelled to exploit natural

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resources and energy, leading to excessive consumption that contributes to environmental degradation (Huang & Ren, 2024; Mikayilov et al., 2018). Moreover, population growth is theoretically expected to have a positive impact on environmental degradation. An increasing population is associated with heightened demand for natural resources, such as land, water, and forests. Additionally, as urban populations expand, energy consumption tends to rise substantially (Korsa et al., 2024; Rehman et al., 2022).

South Africa, as one of the rapidly industrializing nations on the African continent, faces significant challenges related to pollution, despite various measures and policies aimed at environmental protection. South Africans perceive pollution as a serious issue that requires effective intervention (Ndoma, 2024). To address this concern, it is crucial to identify the underlying determinants of environmental degradation. Therefore, the current study aims to investigate the impact of industrialization and macroeconomic factors on CO2 emissions and environmental degradation in South Africa. Throughout this study, the terms "CO2 emissions" and "environmental degradation" are used interchangeably.

This study makes a significant contribution to the existing literature, particularly within the South African context. Firstly, because much of the existing empirical literature had focused on the relationships among renewable energy, gross domestic product (GDP), carbon dioxide (CO2) emissions, and sustainable environmental practices (Ekwueme et al., 2021; Lin, 2015; Lyeonov et al., 2019; Mai, 2023; Tagwi, 2022). Secondly, this study examines the impact of foreign direct investment (FDI), which is often regarded as a critical driver of national development yet contributing on CO2 emissions and environmental degradation. Thirdly, this research investigates the specific effects of industrialization and population growth within South Africa. Finally, based on the findings, the study proposes potential strategies and policies aimed at enhancing industrialization and promoting economic growth while ensuring environmental sustainability.

The structure of the remaining sections of the study is as follows: Section 2 provides a comprehensive review and discussion of the relevant literature. Section 3 outlines the data, methods, and approaches employed in this analysis. Section 4 presents and discusses the empirical findings, while Section 5 concludes the study by offering policy recommendations and identifying relevant areas for future research.

2. Literature review

2.1 Industrialisation and environmental degradation through CO2 emissions

The advent of industrialisation made a shift from manual production to mechanised production process. In this regard, industrialisation arises when there is a considerable shift from an agrarian economy to an economy that is more based on the translation of raw materials into manufactured output ready for consumption either by individuals or firms (Szirmai, 2012). Therefore, industrialisation is conceived by the African Development Bank as one of solution to the underdevelopment issues experienced by most of African countries, yet the desired development trough industrialisation, is associated with environmental deterioration or degradation (Opoku & Aluko, 2021; Wang et al., 2022); resulting from machineries adoption as complement and substitution to labour intensive in the conduction process (Moore 2014). It is significant to note that, irrespective to its role in various sphere economic activities, industrialisation impacts more on manufacturing activities.

Key driver of CO2 emission in developed economies such as China, European Union Germany, India, Japan and Russia is industrialisation and these countries are the major contributors go global CO2 emission (UN, 2017). Nonetheless, ddeveloping countries are following the steep of developed countries in shifting from agricultural economic-based to industrial economic-based. Industrialization is perceived as the engine for economic growth and 'catch up', yet in most cases is associated with the carbon dioxide (CO2) emissions which is harmful to environment (Avenyo & Tregenna, 2022; Patnaik, 2018). Additionally, the study of Adebayo and Kirikkaleli (2021) suggested that the speed and significant rate of economy experienced by East Asian economies is subjected to industrialisation. Nonetheless, the authors emphasise on the environmental issues generated by industrial growth within this region. Owing to industrialisation air and water are polluted followed by deforestation. Besides the direct impact on industrialisation on environment, the product from industries such cars, machines and some other manufacturing products contributes to environmental degradation through CO2 emissions (Shahabad et al., 2017).

Various studies, from different regions, were conducted to investigate the impact of industrialization on CO2 emissions and environmental degradation. However, findings are dichotomous as some displays a positive relationship while others suggest an inverse relationships. For instance the study by Awodumi and Adewuyi (2020); Carvalhoet al. (2018); Phong et al. (2018); Raheem and Ogebe (2017); Ullah, Ozturk, Usman, Majeed & Akhtar (2020); Zafar et al. (2020) revealed a positive association between industrialisation, carbon emissions, and environmental degradation. In other words, industrial activities enquire the use of more energy which whose combustion results in CO2 emissions and led to environment degradation. Additionally, industrial wastes contaminate or pollute air, soil and water; and consequently, posing a severe environmental risk and its deterioration. Contrary to the studies positing positive impact of industrialisation on environmental degradation, other researchers' findings such as Ahmed et al. (2021); Azam and Khan (2016); Li and Lin (2015); Sarkodie and Owusu (2017) suggested a negative relationship between industrialisation and environmental degradation through CO2 emissions. The negative association between industrialisation and environment degradation may be result from adoption of clean energy, reliance on carbon-intensive industries and stricter environmental regulations within these countries.

Contrary to the study conducted on the relationship between industrialisation and environment degradation or CO2 emissions; studies conducted on the linkage between industrial structure and CO2 emissions, indicated that since industrial structure shift industries from energy-intensive to non-energy intensive industrial structure assists in reducing the CO2 emissions (Zou et al., 2014).

Furthermore, other studies such as Appiah and Korankye (2021) suggested the absence of significant impact of industrialisation on CO2 emission in sub-Saharan

African countries. This insignificant relationship between industrialisation and CO_2 emission and environmental degradation was corroborated by finding from the study conducted by Ahmed et al. (2022) in Pakistan. From the discussed finding, it can be concluded that the relationship between industrialisation and CO_2 emissions or environmental degradation cannot be generalised as it depend on regions and countries economic state or industrialisation level. Consequently, it is important to conduct this study to explore the South African situation.

2.2 The linkage between economic growth and CO_2 emissions

The relationship between economic growth and environmental degradation is theoretically explained in the Environmental Kuznets Curve (EKC) theory or hypothesis. This theory posits that a U-shaped association exists between environmental degradation and economic growth; suggesting in the early stage of development, a simultaneous growth is experienced between economic growth, per capita income and environmental degradation. However, at the latter stage income and economic growth increase while the rate of environmental degradation declines (Stern, 2004; Usenata, 2018).

Overtime, studies were conducted to assess empirical relationship exiting between economic growth, CO_2 emissions and environmental degradation. Surprising, those studies reached controversial findings. For instance, Alvarado et al. (2018) investigated the relationship between capita output and CO_2 emissions in focussing on the Association of Southeast Asian Nations (ASEAN) countries for the period from 1980 to 2016. The results indicated that a significant and positive relationship exists between GDP per capita and the CO_2 emissions. These results were supported by findings from Solarin (2020) who investigated the determinants of environmental degradation within 35 developing and emerging countries. This study findings indicated that per capita GDP or output increases environmental degradation within the investigated countries. Additionally the study by Khan et al. (2022) assessed the relationship between economic growth and carbon dioxide emissions within Asian countries. The finding of the study indicated a positive association between economic growth and CO_2 emission. In other words, each additional percentage in economic growth results in extension of carbon emission within the assed countries.

Nonetheless, the study by Choi et al. (2010) on the linkage between the two variable in China, Korea and Japan, suggested that the relationship is not a uniform, as the effect of economic growth on environmental degradation differs from one country to the other and it depends on each country's characteristics. This justifies why it is not adequate to generalise the relationship between CO_2 emission economic growths yet perform a specific study.

2.3 The linkage between employment and CO_2 emissions

Various studies analyzed the association that may exists between employment, unemployment and CO_2 emissions or environmental degradation. For instance, using the panel data sample from 1991 to 2020, Liu & Feng (2022) studied the effect of unemployment on CO_2 emissions within 77 countries and regions. The study findings revealed an inverse relationship between unemployment and CO_2

emissions. This implies that employment within the assessed countries may have a positive effect on CO2 emissions. Authors highlighted that the negative effect of unemployment on CO2 emissions is generic, as when considered the relationship between these two variables on regional level (Africa, Americas, Europe, and the Asia-Pacific regions) unemployment positively influence the CO2 emissions. Nonetheless, the study found no significant evidence of the impact of unemployment on emissions in the emissions in the Asia-Pacific regions and the Middle East regions.

Another study was conducted by Xin et al. (2023) to determine the relationship between CO2 emissions and unemployment with the Chinese economy. The study outcome suggest a positive long-run relationship between unemployment and CO2 emissions. Similar results in China were also found by Cui et al. (2022) where a linear positive relationship was found between CO2 emissions and unemployment growth with the analysed 30 provincial for the period from 2004 and 2019.

2.4 FDI inflows and environmental degradation through CO2 emissions

The current study is interested in investigating the impact of foreign direct investment on carbon a mission as main cause of environmental degradation. Theories and empirical findings on linkages between FDI and environment are inconsistent as this relationship is either positive, neutral or negative. Pao and Tsai (2010) explain the conflicting views on the linkage between FDI inflow and environment through the pollution halo hypothesis, the pollution haven hypothesis and the scale effects hypothesis. The evidence on the existence of various effects of FDI on environment is underlined by findings from various authors in various countries and regions over different period. For instance, the research carried out on BRICS countries (Pao & Tsai, 2010), Pazienza (2015) on OECD countries, Lin et al. (2022) on Chinese economy, and Boateng et al. (2024) on institutional quality found that high inflow of FDI improve the environmental quality. This implies inverse relationship between FDI and CO2 emissions.

In contract research conducted by Ren et al. (2014) in China, Solarin et al. (2017) in Ghana, and Shahbaz et al. (2018) in France revealed the contribution of FDI inflows on environmental degradation with the studied countries. Besides positive and positive effect of FDI on CO2 emissions and environmental degradation, some other studies' findings indicated the absence or insignificant impact of FDI on environmental behaviours. Those studies include Kivyiro and Arminen (2014) on selected countries in sub-Saharan region; Zeng et al. (2017) and, Danish and Wang (2019) in BRICS countries. It is important to also note that the study conducted by Khan et al. (2023) in developing countries revealed that the effect of FDI on environment depend on the educational revel of the FDI hosting country. If population is more educated, FDI inflows assists in reducing environmental pollution while FDI in country with less educated population leads to environmental degradation.

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2.5 Population growth and environmental degradation through CO2 emissions

Population growth is another factor that may lead to environmental degradation through the high consumption of natural resources. While the global population, albeit at an apathetic pace, natural resources do not increase. Consequently, the linkage between population growth, resources scarcity and environment degradation through consumption of natural resources, creation of wastes and contribution to the CO2 emission via production (Malthus, 2005; Ray and Ray, 2011). Various empirical studies were conducted to investigate impact of population growth on CO2 emissions and environmental degradation but, surprisingly, their conclusions are controversies. For instance the study by Hong et al. (2022); Islami et al. (2022); Liu et al. (2021) and, Rehman, and Rehman (2022) ascertained a positive impact of population growth on CO2 emission and environmental degradation; while the study by Rehman et al (2021) established an inverse relationship between environmental degradation, CO2 emissions and environmental degradation. Additionally, Fan et al. (2006)'s study indicated that the effect of population on CO2 emission and environment degradation varies from one country to the other. Thus, it is irrational to rely on theoretical or arbitral conclusion. Furthermore, the study by Shaari et al. (2021) discovered the absence of relationship among these variable. From these empirical results, since there is no common conclusion, it is crucial to investigate how population growth influence environmental degradation in South Africa.

3 Data and Methodology

3.1 Data and variables

The current study engages the times series from 1980 to 2023 employed to achieve the formulated empirical objective. Used data was retrieved from the World Bank Development Indicators (WDI). The study sample selection was restricted to availability of the data. Before 1980 most variables have missing data, at the time this study was conducted, data beyond 2023 was not yet published. The core variables of the study are CO2 emissions used as a proxy of environmental degradation and industrialization. The study also employed foreign direct investment (FDI), employment, GDP per capita used as a proxy of economic development, employment and population size as control variables. Therefore, the CO2 serves as the dependent variable whilst the rest of variables are explanatory or independent variables expected to have a significant impact on environmental degradation. Table 1 displays used variables, their measurement, description and source.

Table 1: Variables ddescriptions and data sources

Variable	Symbol	Description and measurement	Source
Carbon dioxide emissions	CO2	Metric tons per capita	World Bank
Industrialization	InIND	Manufacturing Value Added (US$)	World Bank
Employment	EMP	% of total labor force	World Bank
Economic growth	lnGDP	Gross domestic Product (GDP per Capita)	World Bank
Foreign direct investment	FDI	% of GDP	World Bank
population size	lnPOP	Population in million	World Bank

To have a better understanding of variable description, the author performed a descriptive statistics of the underpinned variables. The summary statistics of the latter is presented in Table 2. As indicated in Table below, the value of the median values of all selected variables are close to their mean implying that these series are symmetric. Additionally, the range between minimum and maximum coupled with standard deviation suggest a moderate fluctuations amongst the selected series. Nonetheless, a high standard deviation and low standard deviation in IND and POP respectively, suggest that over the assessed period South African experienced significant changes into its industrialization compared to the population size. Additionally, all series are skewed to the right except employment and GDP. This negative skewedness, justifies the positive relationship between economic growth and employment growth or job creation. The experienced economic sluggish led to a decline in job growth.

Table 2: Summary statistics of variables

	CO2	EMP	FDI	GDP	IND	POP
Mean	7.877977	18.86081	1.396050	10.58333	27.04262	1.373382
Median	7.866865	18.84751	0.903797	10.71510	25.87908	1.225100
Maximum	9.495784	22.19196	9.660265	11.64878	35.60760	2.781380
Minimum	6.492222	13.96787	-0.060074	9.126524	23.33944	0.653837
Std. Dev.	0.768246	2.448189	1.823669	0.779643	3.339035	0.446285
Skewness	0.103273	-0.111695	3.116898	-0.328621	0.973108	1.106769
Kurtosis	2.037309	1.746861	13.97203	1.796177	3.018067	4.362340
Jarque-Bera	1.373366	2.295369	225.5980	2.664972	5.366449	9.570605
Probability	0.503242	0.317371	0.000000	0.263821	0.068342	0.008352

3.2 Estimation procedure

Based on its advantages and versatile in assessing long-run equilibrium relationships amongst time series data, the Autoregressive Distributed Lag (ARDL) model and Bounds Testing approach was chosen as the adequate model of the study

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analysis. This approach was initiated by Pesaran et al. (2001) and it applicable to multivariate time series irrespective of the integration order, if they are not integrated at the second order [I(2)] or above. Thus, owing to its flexibility, the ARDL approach is preferable over the traditional analytical model such as Engle-Granger (1987) and Johansen (1988), Johansen and Juselius (1990) techniques. Additionally, the ARDL approach is known to generate reliable results even when applied to finite or small sample. To avoid the model misspecification and ensure sound results, prior to the application of the ARDL approach, it is important to perform unit root or stationarity tests to ascertain data none of used series is I(2).

3.3. Model specification

The study followed both theoretical or conceptual framework and empirical framework. As discussed in the literature and also]presented in Figure 1, the conceptual framework presented and discussed the theoretical relationship between variables while the empirical framework dealt with mathematical and statistical effect of independent variables on environmental degradation which is the response variable. Conceptually the study describe the relationship between selected variables as follows:

Conceptual framework

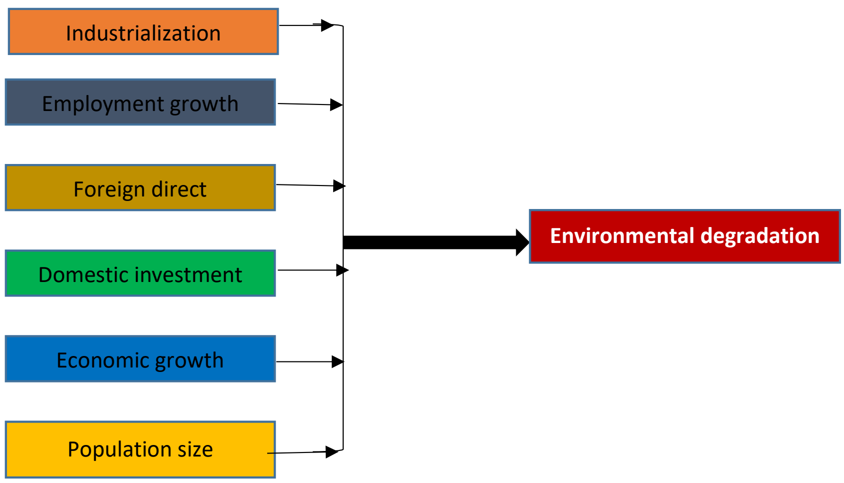

Figure 1: Conceptual framework

Based on the conceptual framework displayed in Figure 1, the mathematical representation of the relationship between environmental degradation and selected independent variables is described by equation 1 and extended in equation 2 below.

$$Y_t = \beta X_t + e_t \tag{1}$$

$$C02_t = f(IND_t + EMP_t + FDI_t + GDP_t + POP_t + e_t \quad (2)$$

Where $CO2_t$ denotes carbon dioxide emissions, IND_t denotes industrialization and EMP, FDI, GDP and POP represent employment, foreign direct investment, economic growth and population size respectively. To avoid the issue of multicollinearity and ensure that the elasticity of environmental degradation is adequately elucidated by the selected explanatory variables, the study variables (not in percentages) were transformed into natural logarithm. Thus, the subsequent Equation 3 the long-run and short-run relationship, the subsequent Equation 3 was estimated:

$$\Delta CO2_t = \beta_0 + \sum_{i=1}^{q^1} \beta_{1i}\, \Delta CO2_{t-1} + \sum_{i=0}^{q^2} \beta_{2i}\, \Delta lnIND_{t-1} + \sum_{i=0}^{q^3} \beta_{3i}\, \Delta EMP_{t-1} + \sum_{i=0}^{q^4} \beta_{4i}\, \Delta FDI_{t-1} + \sum_{i=0}^{q^4} \beta_{5i}\, \Delta lnGDP_{t-1} + \sum_{i=0}^{q^4} \beta_{6i}\, \Delta lnPOP_{t-1} + \lambda_1 CO2_{t-1} + \lambda_2 lnIND_{t-1} + \lambda_3 EMP_{t-1} + \lambda_4 FDI_{t-1} + \lambda_5 lnGDP_{t-1} + \lambda_6 lnPOP_{t-1} + e_t \quad (3)$$

Where Δ denotes changes in variables, β_0 is the intercept, $\beta_1$to β_6 are the short-run coefficients; while λ_1 toλ_7 are the long-run coefficinent and e_t is the error term representing all variables that may have impact on carbon emissions or environmental degradation, yet not accounted for in the model.

Using bounds testing, F-statistic is compared to critical values to determine the presence or absence of long-run relationship between variable. Hollowing Equation 3, the tested hypotheses were formulated as follows:

Null hypothesis (H_0): $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$

Alternative hypothesis (H_0): $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq 0$

In case the F-statistic is greater that the upper bound critical value, the null hypothesis of no cointegration is reject in favour of the alternative suggesting the presence of long-run relationship. In contrast, failing to reject the null hypothesis (when F-statistic fall below the lower bound critical values) implies the absence of long-run relationship among variables. Nonetheless, if the F-statistic lies between upper and lower bound critical values, no conclusive inference should be made unless further information is provided.

When Bounds testing approach is used to determine the cointegration between variables, it also important to estimate the error correction model and short-run dynamics. This step assist not only in determining the short-run relationship but also in ascertaining the speed of adjustment towards the long-run equilibrium after short-run shocks in the model (Menegaki 2019).

$$\Delta CO2_t = \beta_0 + \sum_{i=1}^{q^1} \beta_{1i}\, \Delta CO2_{t-1} + \sum_{i=0}^{q^2} \beta_{2i}\, \Delta lnIND_{t-1} + \sum_{i=0}^{q^3} \beta_{3i}\, \Delta EMP_{t-1} + \sum_{i=0}^{q^4} \beta_{4i}\, \Delta FDI_{t-1} + \sum_{i=0}^{q^4} \beta_{5i}\, \Delta lnGDP_{t-1} + \sum_{i=0}^{q^4} \beta_{6i}\, \Delta lnPOP_{t-1} + \beta_7 ECT_{t-1} + e_t \quad (4)$$

In Equation 4, β_7 represents the coefficient the error correction term (ECT). This coefficient is used to determine the speed of adjustment from short-run dynamics towards long-run equilibrium.

4 Empirical findings and discussion
4.1 Unit root and bounds testing

As highlighted in section 3.2, the unit root test as pre-analysis test plays an important role in determining the integration order for selected variables and selecting adequate model for the study. The Augmented Dickey-Fuller (ADF) test was the selected test for unit root. The results presented in Table 3 indicate that CO2 emissions (CO2) and employment (EMP) are not stationary at levels yet become stationary after first difference. This implies that they are I(1). In contrast, foreign direct investment (FDI), GDP per capita (GDP), population size (POP) and industrialization are stationary at levels, meaning that they are I(0). These unit root test results support the selection of ARDL model, as the latter is an adequate when analysing a data containing a mixture of integration order.

Table 3: ADF Unit Root Tests

Variable	**levels**		**First difference**		**Decision**
	constant	**Constant & trend**	**constant**	**Constant & trend**	
CO2	0.783	0.971	0.000***	0.000***	I(1)
EMP	0.419	0.805	0.000***	0.000***	I(1)
FDI	0.000***	0.000***	0.000***	0.000***	I(0)
GDP	0.000***	0.994	0.017**	0.243	I(0)
IND	0.009***	0.520	0.000***	0.000***	I(0)
POP	0.005***	0.070*	0.000***	0.000***	I(0)

Note: (***), (**) and (*) denotes significance level at 1%, 5% and 10% respectively.

The bound testing assisted in the determining the presence or absence of cointegration amongst variables. The results in table 4 confirm the rejection of the hull hypothesis of no cointegration. This is because the computed F-statistic (6.192) is greater that all the upper bound critical values 3.35; 3.79; 4.68). Thus, a long-run relationship exists between environmental degradation, industrialization, economic growth, domestic and foreign direct investment, employment level, and population size in South Africa. In other words, all selected independent variables jointly have a long-run impact environmental degradation in South Africa.

Table 4: ARDL bounds test Results

Model	Lag length	F-statistic	Clinical values & Bounds		
			Significant level	Lower Bounds	Upper Bounds
CO2=f(EMP, FDI, GDP, IND, POP)	(1, 3, 0, 3, 3,3)	6.192	10%	2.26	3.35
			5%	2.62	3.79
			1%	3.41	4.68

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4.2 Assessment of long-run relationship

Although the results in Table 4 confirm the long-run relationship among variables, they no not specify whether a given independent variables has a positive or negative impact on environmental degradation. The results presented in Table 5 indicate the sign and the magnitude impact of explanatory variables on the response variable. While employment and population size have a negative relationship with carbon emissions or environmental degradation; foreign direct investment, economic growth and industrialisation positively influence environment degradation or CO2 emissions. Mathematically, the level of environmental degradation or CO2 emissions decrease by 0.361 percent and 1.16 percent as response to a one percent increase in employment level and population size respectively. In contrast, CO2 emissions increase by 0.038 percent, 0.72 percent and 0.20 percent as a response to a one percent increase in foreign direct investment, economic growth and industrialization respectively.

Table 5: Estimated Long-Run coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EMP	-0.361972	0.060809	-5.952582	0.0001
FDI	0.038542	0.050572	0.762127	0.4607
GDP	0.718682	0.655082	1.097086	0.2941
IND	0.197618	0.189514	1.042766	0.3176
POP	-1.163531	0.405274	-2.870975	0.0141
C	1.101315	10.925685	0.100801	0.9214

4.3 ECM and short-run dynamics

After assessing the magnitude impact of explanatory variables on CO2 emission or environmental degradation, the study investigated the short-run dynamics. Table 6 displays the ECM and short-run dynamics of the model. The value of ECM coefficient is approximately 0.57 suggesting that around 57 percent of short-run shocks is adjusted every year. The short-run assessment confirms a negative impact of employment and positive impact of population size on CO2 emissions in the short-run. Similarly to the long-run results, the short-run assessment suggested a strong significant impact of economic growth on CO2 emissions in South Africa. Considering the significant level at 10%, the lagged value of industrialisation has a negative effect on environmental degradation or CO2 emissions. The FDI is the only explanatory variable with no significant short-run impact on CO2 emissions.

Table 6: ECM and short-run dynamics results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(EMP)	-0.175514	0.035105	-4.999727	0.0003***
D(EMP(-1))	0.061729	0.049792	1.239724	0.2388
D(EMP(-2))	0.064591	0.046764	1.381219	0.1924
D(FDI)	0.021894	0.028845	0.759013	0.4625
D(GDP)	0.711038	1.756873	0.404718	0.6928
D(GDP(-1))	-1.023915	2.742578	-0.373340	0.7154
D(GDP(-2))	7.545903	2.194164	3.439078	0.0049***
D(IND)	0.121987	0.077209	1.579954	0.1401
D(IND(-1))	-0.107382	0.093155	-1.152719	0.2715
D(IND(-2))	-0.134963	0.067424	-2.001712	0.0684*
D(POP)	-0.053399	0.140913	-0.378951	0.7113
D(POP(-1))	0.043349	0.140584	0.308347	0.7631
D(POP(-2))	0.400309	0.148769	2.690807	0.0196**
ECM(-1)	-0.568047	0.108795	-5.221257	0.0002***

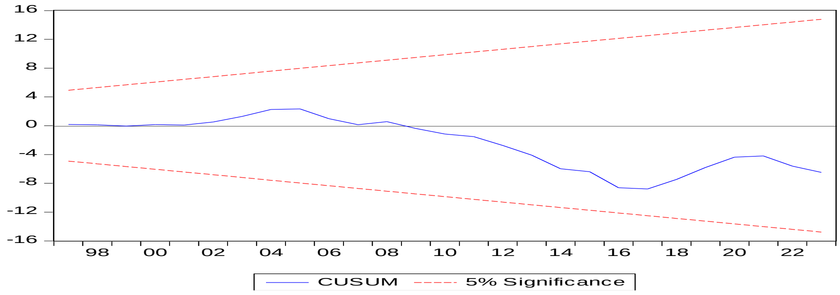
Note: (***), (**) and (*) denotes significance level at 1%, 5% and 10% respectively

4.4 Robustness check and diagnostic test

Residuals diagnostic tests were involved in the study for establish the accuracy of findings and relevance of used model. The results presented in Table 7 indicates than the null hypotheses for normality, autocorrelation, and heteroscedasticity tests were not rejected. This implies that the study residuals are normally distributed, homoscedastic and free of serial correlation. Additionally, the Ramsey test hypothesis suggesting that the model is correctly specified was not rejected, while CUSUM and CUSUMQ confirmed that the model is stable at 0.05 significant level. Thus the model employed in this study was robust and the results are reliable.

Table 7: Diagnostic tests results

Test	F-T stats &/or P-value	Interpretation
Normality-JB	(1.789)0.5392	No normality issue
LM test	(1.255) 0.326	No Autocorrelation issue
Breusch-Pagan-Godfre	(0.4794) 0.7057	No Heteroscedasticity issue
Ramsey test	(0.192) 0.851	model is correctly specified
CUSUM	The model is stable	Stable
CUSUMQ	The model is stable	Stable



4.5 Discussion of Findings

The study analysis revealed that industrialization has a long-run positive impact on dioxide carbon (CO2) emissions, and there after influence environmental degradation in South Africa. The probable explanation for this relationship is that industrialization growth involves high level of energy consumption, and the latter is generally acquired from fossil fuels (coal, oil, and natural gas) which, when burned, generate CO2. Additionally, successful industrialization refers to enhancement in industrial processes, logistics and transportation needs. Yet all of these development are associated with the CO2 emissions. Consequently, industrialization leads to environmental degradation. This study result of the existence of positive impact of industrialization on CO2 emission is in line with various studies whose results concluded that the proliferation of industrialisation is associated with carbon emission and environmental degradation (Awodumi & Adewuyi, 2020; Carvalhoet al., 2018; Phong et al., 2018; Raheem & Ogebe, 2017; Ullah et al., 2020; Zafar et al., 2020).

Based on the results in section 4.5, the positive relationship between industrialisation and CO2 emission justifies, as also it can be justified by, the positive effect of foreign direct investment inflows on the CO2 emission. Foreign investors mostly target countries in which they can raise up manufacturing plants or benefit from extraction of natural resources such as gas, oil, and minerals. These activities also involve energy consumption and consequently contribute to the CO2 emissions and environment degradation. In other words, while FDI may offer economic benefits and possibly causes technological improvement, the direct effects of improved industrial activities and resources extraction, often leads to higher CO2 emissions. However, it is important to note that the relationship between the two variable (FDI and CO2 emissions) can be complex, and the net effect of FDI on CO2 emissions may differ based on the type of investment and the economic context of the host country. This justifies why a positive relationship was found by some studies (Ren et al., 2014; Solarin et al., 2017; Shahbaz et al., 2018), while others found an inverse relationship between FDI and CO2 emissions ((Pao & Tsai, 2010; Pazienza, 2015; Lin et al., 2022; Boateng et al., 2024). Based on this dichotomy association between FDI and CO2 emission, the South Africa’s authorities and policy makers should initiate and implement FDI policies that support sustainable environment.

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If the country experiences a high level of industrialisation and its foreign direct investment inflows targets industrial development, the country will experience a significant level of economic growth. This is in line of the current study's findings where a positive relationship was found between GDP and CO2 emissions. High level of economic growth leads to the country's urbanization, infrastructure development, and increase in energy consumption. These socio-economic economic activities contribute to the CO2 emissions and environment degradation. Nonetheless, although the relationship between economic growth (GDP) and CO2 emission is frequently positive, it is indispensable to recognize that this correlation is not static as it can evolve. Several countries are currently pursuing sustainable economic strategies to decouple economic growth from CO2 emissions. Those strategies include sustainable practices, energy efficiency expansions and renewable energy adoption. The found positive relationship between GDP and CO2 emissions is also supported by Alvarado et al. (2018), Solarin (2020) and Khan et al. (2022).

Among the explanatory variable of the study, employment and population size. The expected relationship between population size and CO2 emission was positive as an increase in population is supposed to increase demand for energy other resources. Yet, this study results suggested otherwise. Possible explanation of inverse relationship between CO2 emission and GDP may be that population is a behavioural change as results of improved awareness and action regarding climate change and sustainability. Regulatory measures is another factor that can justify the negative effect of population size on CO2 emissions. However, while these two or more factors may contribute to a negative relationship between CO2 emissions and population size in certain contexts, it is essential to acknowledge that this relationship cannot be generalised in time and space. In most cases, large population leads to high CO2 emissions. Consequently, the relationship is multifaceted and subjected to a variety of socio-economic and technological factors. This explains why other research found a positive relationship between population growth and CO2 emissions (Ibrahim, 2020; Wang et al. (2017). The suggested positive relationship between population size and CO2 emissions in this study, may also imply that policies, awareness, and strategies to reduce environmental degradation takes time to penetrate people's behaviours and practice.

Similar to population size, the link between CO2 emissions and employment is complex as it may either be positive or negative depending on the period, country or sector. Supporting findings from Liu and Feng (2022), the regression results in the current study indicated that employment growth negatively impact on CO2 emissions. This relationship is possible for growth in economic restructuring, regulatory changes and economic downturns. For instance if a country is facing economic challenges the latter may impede on industrial activities resulting in shift of employment from manufacturing to service industries. Additionally, if a country experience high trends in remote work, workers will reduce the use of automobile which previously contributed to CO2 emission. Increase in these types of jobs will reduce CO2 emission. It is vital to highlight that the negative relationship between the two variables is not universal as it may change owing to the economic structure and context, geographical area and period. Contrary to this study's findings, Cui et

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al. (2022) and Xin et al. (2023) found a positive relationship between population size and CO2 emission. The justification is that increase in population lead to increase in energy, and industrial products demand which may be associated with CO2 emissions.

5 Concussion and recommendations

Improving industrialization while maintaining sustainable environment remain a countries core challenge in recent decades. The growing pace of industrialization in pursuing economic growth and development would have a significant impact on environmental degradation through emissions of dioxide of carbon. The current study investigated impact of industrialization on environmental degradation in South Africa. The study focused on a sample period from 1980 to 2023. The Autoregressive Distributed Lag (ARDL) model, Bounds Testing approach and error correction model (ECM) were employed to determine the relationships among variables. To avoid the model underspecification, other economic variables with a direct link with sustainable environment (foreign direct investment, employment level, economic growth, and population size) were included as control variables.

The study findings indicated that a long-run relationship exists between industrialization and environment degradation. Control variables also were found to have significant long-run impact on environmental degradation. While industrialization, economic growth and foreign direct investment, influence CO2 emissions and thereafter contribute to CO2 emissions and environmental degradation, employment growth and population reduce the level of CO2 emissions and thereafter contribute to a long-run sustainable environment. Nonetheless, the short-run dynamics revealed the only employment, industrialization and population size can influence the CO2 emissions in South Africa.

Based on the findings, we suggest various implications for policies and strategies to enhance sustainable environment without harming the country's economic development. These strategies include promoting collaborations among foreign investors, domestic industries, and research institutions to significantly advance the establishment of cleaner technologies and sustainable practices in South Africa. Additionally, government should encourage and invest in green energy production to improve economy without harming environment or increasing the CO2 emissions.

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