(RESEARCH ARTICLE)

# A Study on the Impact of Foreign Direct Investment on Climate Change: Empirical Evidence from the Manufacturing Sector of South Africa

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## Abstract

With the rapid economic development and environmental issues. As one of the important key driving factors, foreign direct investment has been argued to be good and a curse to most countries in the world, in particular the developing economies. Despite the contribution to promoting growth, FDI is also an avenue for dumping its consequences on the quality of the environment. Thus, the fundamental approaches to industrial growth, government interventions, and market structure have ignored the main consequences of the common idea of "growth first, clean later" (Quan-Hoang Vuong and Minh-Hoang Nguyen, 2019). This study investigates the relationship between carbon emissions ($CO_2$) and foreign direct investment (FDI), renewable energy consumption (REC), Trade openness (TO), gross domestic products (GDP), non-renewable energy (NRE), manufacturing sector (MS), for a time series of the South Africa country throughout 1990-2020. The debate surrounding environmental concerns remains a national issue to date. To the best of our knowledge, the impact of Foreign direct investment in the manufacturing sector on $CO_2$ emissions has not been completely explored in the previous energy economics literature. In order to further investigate the impact of MSFDI on $CO_2$ emissions, we adopted a series of econometric techniques for the visualization of the available data. We used econometric estimations to verify cross-sectional dependence, co-integration, and stationary between the variables.

**Keywords:** South Africa; Manufacturing sector; $CO_2$; Climate change

## 1. Introduction

The unrestrained use of energy sources in South Africa has been a consequence of increased climate change, which is mostly associated with the increasing carbon emission of harmful greenhouse gases into the atmosphere, typically caused by the combustion of fossil fuels through industrial activities such as transportation and energy-intensive industries. Numerous research studies declared that climate change mitigation has become the center of debates and concerns around the globe. Therefore, it's unsurprising that there is an intense debate about how to mitigate the harmful consequences of climate change, which is largely driven by traditional energy sources (RENA, 2018). Respectively, in recent years, developing countries have received much attention from researchers and policymakers due to industrialization and rapid economic development, and debate on potential solutions. Thus, the relationship between $CO_2$ emissions and economic growth is highly debated, where the discussion differs on whether it is a positive or negative relationship. It was acknowledged by the Environmental Kuznets Curve hypothesis in showing the U-shaped relationship between pollution level and income, which came out with suggesting that with each additional usage of fossil fuels, the level of pollution increases (Ilhan Ozturk and Usama Al-Mulali, 2015). Moreover, the existing factors that affect climate change are the core interests of researchers who endorse climate change mitigation. The driving forces are addressed separately in terms of their negative and positive effects. Nevertheless, the pivotal connection between the factors themselves forms a sequence of uninitialized functions. Our research covers the dominant features such as

fossil fuel, renewable energy consumption, Industrial activities, exports, imports, foreign direct investment, and technology and innovation.

Moreover, industrialized countries began to put together key environmental accords and agendas to reduce and control GHG emissions in the atmosphere. For instance, the United Nations Framework Convention on Climate Change was adopted in 1992 and signed during the United Nations Conference on Environment and Development in Rio de Janeiro. Another international agreement, the Kyoto Protocol, was signed by the UNFCC on 11 December 1997 to establish binding objectives for 37 industrialized countries and the European Union to reduce their GHG emissions. Indeed, the Rio Summit in 1992 adopted the United Nations Framework Convention on Climate Change (UNFCCC). Indeed, the negative impact of carbon emissions has turned the focus to renewable energy that ensures the accessibility of clean, affordable, and reliable energy, as well as achieving the Sustainable Development Goals. Africa's potential to pass to a new era of progress will necessitate a shift to low-carbon, high-efficiency energy that provides energy to the whole country.

South Africa has gradually removed trade restrictions and opened up its economy to the outside world, and a significant amount of FDI inflow has increased over the past few decades. The inflow of foreign direct investment is regarded as a source of advanced technological innovation, which leads to promoting technological diffusion. Foreign direct investment creates jobs, increases productivity in the host nation, and lowers unemployment. South Africa has been focused on the FDI inflow to achieve its goal of economic and social development. According to the Yearbook (2017), the secondary and manufacturing industries 52.75% is allocated of the FDI, while primary and tertiary industries account for 2.56% and 44.69%, respectively. Furthermore, the addition of capital stock in manufacturing industries is the main contributor to $CO_2$ emissions in the country. The relationship between FDI and $CO_2$ emissions is still controversial and uncertain. Some researchers, such as Zhang and Zhou (2016), Faheem et al. (2022), Gyamfifi et al. (2022), and Shabir, Ali, Hashmi, and Bakhsh (2022), reported a negative relationship between FDI and $CO_2$ emissions, while another researcher, such as Xie et al. (2020), Salahuddinet al. (2018; Salahodjaev and Isaeva (2022) and Farooq (2022) found a positive relationship between FDI and $CO_2$ emissions.

Moreover, African countries have seen a great increase and a high concentration of foreign direct investment during the last decades. Since 2008, the global economy has revealed an increase in FDI. In 2010, the annual FDI reached about $9,893 billion. South African countries have benefited extremely from FDI (UNCTAD 2019). Therefore, the world records and FDI distribution for developed economies to developing and less developed countries showed the largest service sector concentration. This was followed by the manufacturing sector is dominated by three sectors, namely food& beverages, petroleum & chemical, and metals & machinery. These sectors account for about two-thirds of manufacturing production. Thus, these sectors are the major contributors to carbon dioxide emissions, which causes climate change. Throughout FDI, host economies can gain from their access to worldwide marketing networks. In general, the magnitude of the positive effects of FDI inflows on host economies is influenced by the business environment and investment climate of the host nations, as well as the characteristics of the FDI-associated multinational corporations. (Abdouli & Hammami, 2017). Foreign direct investment, which is an indication of a large company operating internationally and ownership of manufacturing and assets, is leading to economic globalization that may provide direct control over livelihoods and manufacturing.

Regardless of the positive effects of FDI on growth through the transfer of skills and technology, there are some disadvantages to poor countries that are worth emphasizing. In some cases, FDI has resulted in the dumping of foreign goods into the local economy. It places workers under foreign control and encourages profit appropriation by foreigners, among others. Furthermore, the full benefit of enhanced FDI activities in the host countries is usually impacted by a variety of leakages, most notably global warming and climate change. Apart from the benefits of FDI, climate change has several environmental and health-related consequences. Especially for FDI activities of the manufacturing sector in less developed countries.
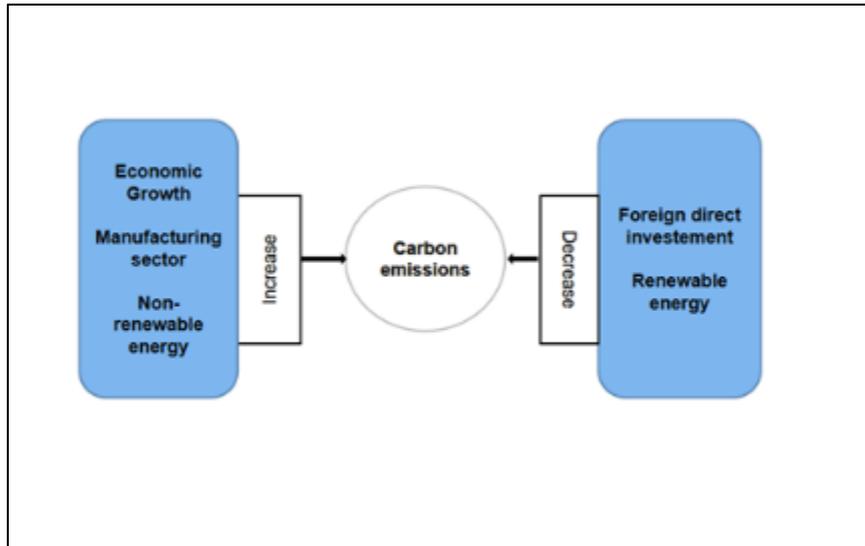
**Figure 1** Theoretical framework of the study

## 2. Overview of Stylized Facts of the South African Economy

### 2.1. Trends of foreign direct investment

Over the last decades, FDI has played an important role in the development of South Africa's economy. In comparison to other emerging market countries, foreign direct investment has remained relatively low. Regardless of the numerous advantages in South Africa in terms of natural resources and market size. Indeed, international investors have shown less interest in acquiring and expanding domestic firms. According to UNCTAD's 2021 World Investment Report (Table 1), FDI inflows declined by 39.4% in 2020 to USD 3.1 billion, compared to 2019 was a high inflow of USD 5.1 billion recorded in 2019. In 2020, FDI stocks decreased to USD 136 billion compared to 2019. The country has long been a major investor; Moreover, the pandemic has reversed this trend: inflow investment was negative in 2020 by USD 2.0. South Africa's government encourages and attracts more foreign investors, considered the main way for job creation and wealth-creating economic growth. Furthermore, European countries, as well as the United States, Japan, China, and Australia, have been active investors in South Africa.

**Table 1** Foreign Direct Investment in South Africa

| Foreign Direct Investment | 2018 | 2019 | 2020 |
|---|---|---|---|
| FDI inward flow (million USD) | 5.450 | 5.125 | 3.106 |
| FDI Stock | 138.562 | 145.247 | 136.735 |
| Number of greenfield investments | 109 | 130 | 103 |
| Value of Greenfield investments | 4.812 | 4.115 | 3.852 |

Source: UNCTAD
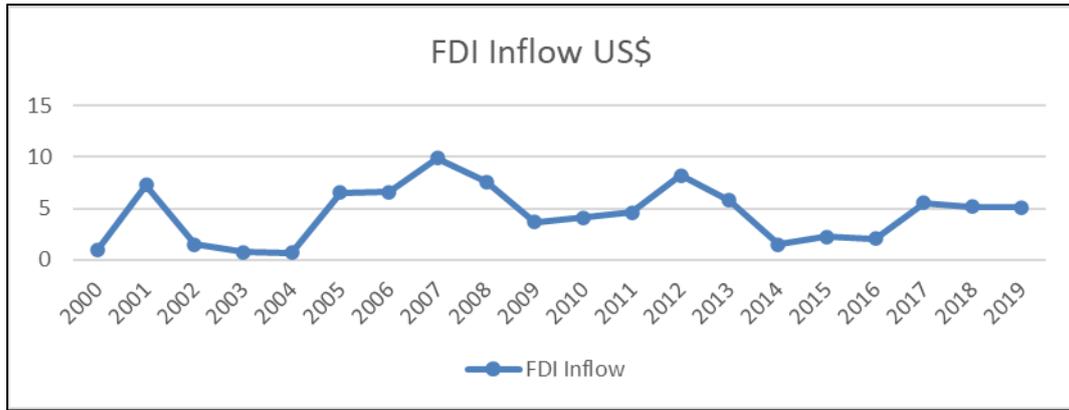
**Source:** World Bank Indicators

**Figure 2** FDI Inflows

## 2.2. FDI Inflows by Sector

For the period 2006-2020, Figure 2 below gives an overview of the contribution of the different sectors to the number of FDI projects in South Africa. From the figure, the liaison office has the most registered projects, Mining, followed by the service sector, and then the manufacturing industry, trade, and transport and communications. Apart from the year 2014 when the manufacturing sector dominated in the share of registered projects, with the Mining sector accounting for the largest, the service sector dominated from 2011 through to 2016. The manufacturing sector has been the third-largest contributor to the number of registered projects by FDI inflows in 2018 and 2019 and took the second position in 2013, 2015, and 2016. Non-mining sectors have attracted more than two-thirds of the foreign direct investment inflow, suggesting that the main goal of South Africa's foreign investment has been to capture domestic and regional markets.
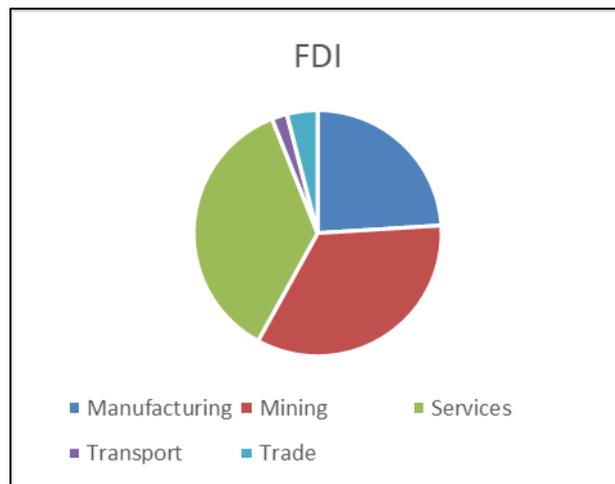


Source: South African reserved Bank.

**Figure 3** FDI by sector

The share of the diverse sectors in the amount of FDI inflows to South Africa is also shown in Figure 3 above. Evidently, from Figure 2, the service sector dominated the value of FDI inflows for three consecutive years (2011 to 2019). The manufacturing sector was second in 2012 and dominated in 2014 with about $2,000m and $1,391m respectively. The service sector dominated; it was also the second-largest contributor to FDI inflow project value from 2011 to 2019. This is clearly shown in Figure 2 on the sectoral share of the value of FDI in South Africa.

## 2.3. Manufacturing FDI Inflows

Figure 4 shows the manufacturing FDI inflows value, where FDI inflows to the manufacturing sector totaled US$319.82 million over the first 20 years (2000 to 2020). The value showed an increasing trend from 2000 to 2012, after which it

experienced a sharp decrease in 2013. The increases over the 2005-2012 period were slow for the first three years and jumped to US$2172.78 million in 2016.
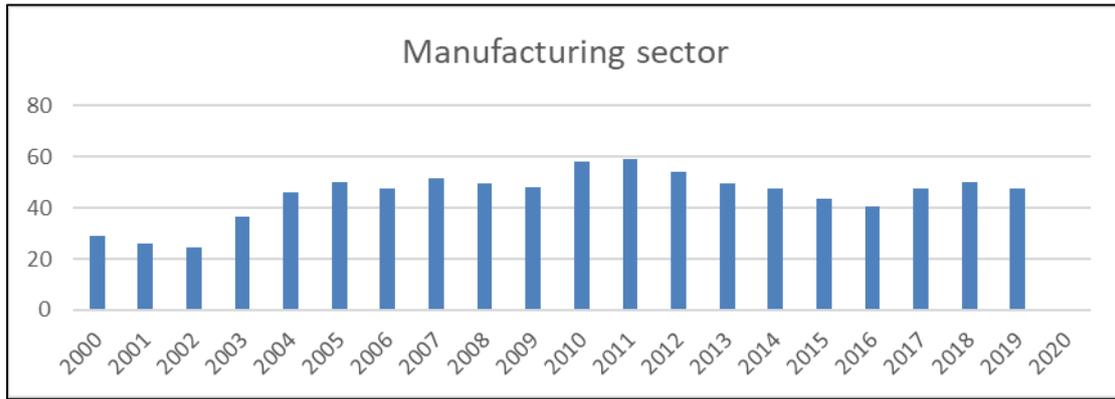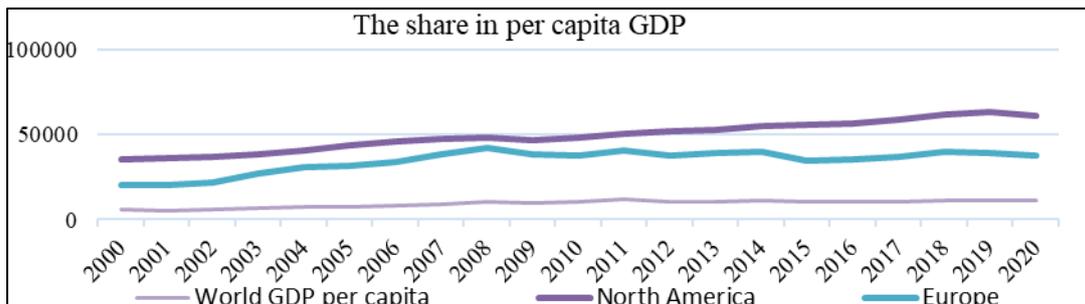


Source: World Bank.

**Figure 4** Manufacturing added value

## 2.4. The share in gross domestic product per capita (1990-2020)

While GDP has increased for three decades since 1990 among BRICS countries, economic growth marked a significant amplification, as illustrated by the level of productivity or efficiency rankings. Thus, a higher efficiency level represents the countries' GDP level (Hanns De La Fuente-Mella et al., 2020). The most declared efficient BRICS economies are the North American countries, central-western Europe, South Africa, and India. On the other hand, countries like China, Russia, and British marked a modest increase in GDP compared to other countries in the organization of Britain, Russia, India, China, and South Africa.



Source: World Bank database.

**Figure 5** The share in per capita GDP (1990-2020)

## 2.5. Climate Change and Greenhouse Gases

From Figure 3.5, which shows the Manufacturing $CO_2$ emission percent of total fuel combustion, Carbon dioxide emissions accounted for by the manufacturing sector for the years 1997 through 2000 increased over the years. This is because in 1975 the value was 15.9% but it fluctuated over the first three years, where it experienced a decrease from its amount of 11.5% in 2001. In Figures 6 the total carbon emissions depict a positive trend throughout the period under consideration, with some fluctuations between years. This shows that there has been a general increase in emissions from 1997 to 2000. Carbon dioxide emissions by the manufacturing sector show a similar trend over the years.
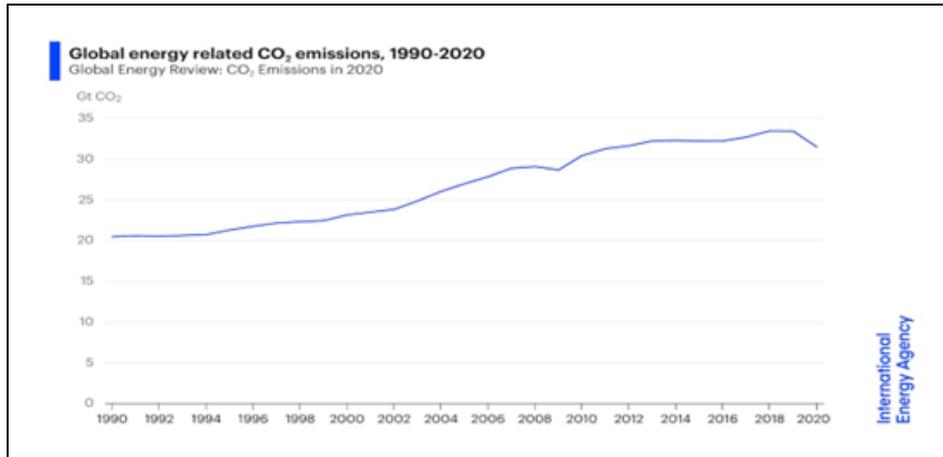
**Source**: Author's Construction from WDI Data set

**Figure 6** Carbon-Dioxide (CO2) Emissions for South Africa for the years 1990 to 2020 (in per capita)
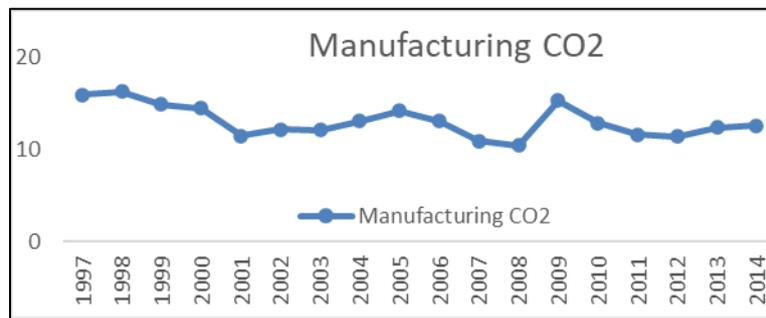


**Source:** Author's Construction from WDI Data set

**Figure 7** Manufacturing CO2 Emissions (Kt), 1997 to 2014.

## 2.6. Renewable energy technology in South Africa

The potential of renewable energy comes with the geographic location of South Africa, which receives a large amount of solar energy as well as wind. Biomass is currently witnessed as a large contributor, with 9% to 14% of the total energy mix.
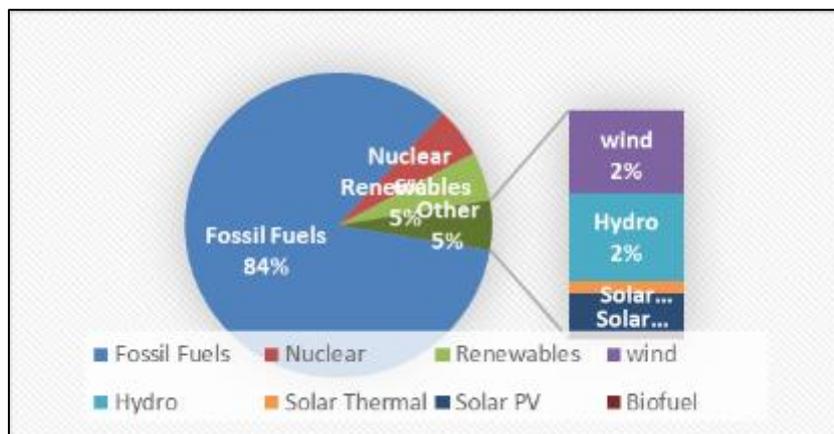


Source: International Energy Agency Database.

**Figure 8** The energy mix in South Africa

## 3. Methodology

### 3.1. Model Specification

A series of econometric tests and analyses were performed to investigate the impact of Foreign Direct Investment on Climate Change emissions and green Manufacturing in South Africa using time-series data from 1990 to 2020. To determine the impact of this study, following Laborie (2012), employ the mathematical model below:

$$CO2 = f(FDI, RE, MVA, TOP, GDP, NRE) \ldots\ldots\ldots \text{ Eq. (1)}$$

The suggested model is presented in Eq. (1). $CO_2$ emissions are the dependent variable indicated as $CO_2$ emissions per capita. Foreign direct investment (FDI) is denoted as the total output of climate change mitigation technologies. The manufacturing sector in climate change mitigation is described as the percentage of domestic innovation in patents, R&D, and investments. Renewable energy consumption (REC) is described as the total output of renewable sources such as solar, wind, and hydroelectric. Gross domestic product (GDP) is in $ US$. Non-renewable energy is denoted as coal, gas, and oil. Trade openness is export and import trade in $ US$.

### 3.2. Definition and Measurement of Variables

The dependent variables of the model are carbon emissions as a proxy for climate change. The independent variables are Foreign Direct Investment (FDI), Renewable energy (RE), Manufacturing Value added (MVA), Trade openness (TO), Gross Domestic Product per capita (GDP), and Non-renewable energy (NRE). Table 2 below shows the summary of the variables of the model, their expected signs, the unit of measurement, and their denotation.

**Table 2** Variables, their Denotations, and Expected Sign

| | Denotations | Unit | Expected sign |
|---|---|---|---|
| Carbon Dioxide Emissions | $CO_2$ | Quantity of $CO_2$ tons from sectoral fuel combustion % | |
| Foreign Direct Investment | FDI | Sectoral inflow in US$ | - |
| Renewable energy | RE | (% of total solar, wind, and hydroelectric consumption) | - |
| Manufacturing added value | MVA | Million USD | + |
| Trade openness | TO | Index/Ratio | - |
| Gross Domestic Product | GDP | Million USD | + |
| Non-renewable energy | NRE | Kiloton | + |

Source: Author's Constructions.

### 3.3. Empirical Model

The research develops an empirical model for analysis based on the literature by Fakhri (2015) for this current study, and a clear understanding of the variables of the model and how they are assessed. The explicit empirical model for the analysis is written as follows in logarithmic form:

$$nCO2_{it} = \alpha_0 + \alpha_{1i}\ln(FDI_{it}) + \alpha_{2i}\ln(RE_{it}) + \alpha_{3i}\ln(MVA_{it}) + \alpha_{4i}\ln(TO_{it}) + \alpha_{5i}\ln(GDP_{it}) + \alpha_{6i}\ln(NRE_{it}) + \varepsilon_{it}$$
$$\text{Eq. (2)}$$

Notes: $\alpha_0 = A_0$, The indices (i) and (t) represent, respectively, the country and the period: $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6$ present the long-term elasticities.

We will use several econometric tools and approaches, for instance unit root test, the ARDL bounds test, the dynamic ARDL simulations model, and the causality test.

## 3.4. Correlation statistics

A research methodology is based on the scientific method of cognition, system approach, formal-logical method of analysis and synthesis, and representative statistical samples (Wayne Goddard and Stuart Melville, 2004). The study's theoretical results are based on an analysis of a variety of South African statistical data obtained from the World Bank platform. One of the most popular quantitative methods in applied social science nowadays is the linear regression model. (David A Belsley, Edwin Kuh, and Roy E Welsch, 2005).

Hence, Regression analysis, also known as data reliability and specification analysis, is the first phase in our process. We perform this by using the multicollinearity test, serial correlation test, variance inflation factor test, and heteroscedasticity test. Therefore, before introducing the subsequent phases, we shall briefly define each test and its primary application.

## 3.5. Panel unit root tests

The purpose of the unit root test is to ensure that the panel data datasets are stationary or the presence of unit roots. However, the variables in the study were checked for stationarity to avoid spurious unrelated regression estimation as a result of the use of non-stationary variables. The stationarity of the model's variables was investigated using the Augmented Dickey-Fuller (ADF) test and the Philips Peron (PP) test for unit root. For the parameter estimated to be valid, the datasets used in generating the empirical model equation should be a stable stochastic process Dickey & Fuller (1979) Fakhri (2015). A stationary stochastic process has constant mean and variance throughout time, and its covariance between two periods rather than the actual moment this covariance is computed (Gujarati, 2003).

$$CI\widehat{P}S = N^{-1} \sum\nolimits_{i=0}^{n} CDF$$

Eq.(3)

Where N represents the natural log of the series, y denotes the change operator, N represents the natural log of the series, t is time, CDF is the parameter estimates, and n is the trend variable. For various reasons,

The Phillips-Perron (PP) test is non-parametric and, unlike the ADF, it does not require the level of serial correlation to be chosen. Although it uses the same estimation process as the ADF, it includes autocorrelation and heteroscedasticity correction. However, its main disadvantage is that it is based on asymptotic theory, which means it works better in large samples. Similar to ADF, it is insensitive to structural breaks. The PP test for unit root is also often robust to deviate from basic sets of properties.

To test the unit, several root tests can be used, such as Dickey-Fuller Augmented (ADF), Phillips-Perron (PP), and Dickey-Fuller Generalized Least Squares (DF-GLS). In addition, all the variables' relationships were examined before using the dynamic ARDL simulations model (Dickey & Fuller, 1979 utilizing the following equation.

$$\sum_{i=1}^{r} \beta_1 \Delta CO2_{t-1} + \sum_{i=1}^{r} \beta_2 \Delta FDI_{t-1} + \sum_{i=1}^{r} \beta_3 \Delta RE_{t-1} + \sum_{i=1}^{r} \beta_4 \Delta MVA_{t=1} + \sum_{i=1}^{r} \beta_5 TOP_{t=1} + \sum_{i=1}^{r} \beta_6 GDP_{t=1} + \sum_{i=1}^{r} \beta_7 \ NRE_{t=1}$$
$$+ \mu_t$$

.................... Eq. (4)

Where $CO_2$ signifies carbon dioxide emissions, t represents time; RE is the total output of renewable energy sources, FDI is the foreign direct investment, MVA is the manufacturing added value, TO is the trade openness, GDP is the gross domestic product per capita, and NRE is non-renewable energy. In contrast, equation (3) signifies a constant in the model. Moreover, $\beta_1, \beta_2, \beta_3, \beta_4,$ and $\beta_5$ Represent the coefficients of the independent variables. Finally, $\mu_t$ Represents the error term.

$$CO2_t = \alpha_0 + \beta_1(FDI_t) + \beta_2(RE_t) + \beta_3(MVA_t) + \beta_4(TOP_t) + \beta_5(GDP_t) + \beta_5(NRE_t) \quad .......... \quad Eq.(5)$$

## 3.6. Co-integration test

After performing the unit root test, the variables of our sample are integrated in a different order. That is a combination of both level and first difference stationary. To ensure the existence of a long-run relationship among the selected variables. For the appropriate co-integration, we employed the ARDL bound co-integration to check whether there is a

long-run association that exists or not that as proposed by (Shin, Smith, et al., 2001). Therefore, the Co-integration test should be performed on the level form of the variables and not on their first difference. Nevertheless, all the relationships within the 1(1) data series are likely to underpin the co-integration subsistence; therefore, assessing the validity of the co-integration analysis becomes essential. Therefore, we consider the equation of the bounds estimation that is as follows:

$$\Delta CO2_t = \forall_0 + CO2_{t-i} + \forall_1 FDI_{t-i} + \forall_2 RE_{t-i} + \forall_3 MVA_{t-i} + \forall_4 TOP_{t-i} + \forall_5 GDP_{t-i} + \forall_6 NRE_{t-i} \ldots\ldots\ldots eq:(6)$$

In the equation of bound estimation, $\forall_0$ Represents the first difference, $CO_2$ signifies carbon dioxide emissions, t represents time; FDI is the foreign direct investment, and RE is the total output of renewable energy sources (solar, Wind, and hydroelectric), MVA denotes the manufacturing value-added, TO is the Trade openness, and GDP is the gross domestic product per capita. In addition, I denote the length of the optimal lag determined by the Akaike Information Criterion (AIC). $\forall_1, \forall_2, \forall_3, \forall_4, \forall_5$, Exploring the long-run relationship respectively. We can consider the long-run and short-run for the ARDL model, in the case of the long-run association's existence, as a similar study by (M. K. Khan et al., 2019) Used as well. Thus, we design our null and alternative hypotheses based on the ARDL model:

$H_0 = \forall_0 = \forall_1 = \forall_2 = \forall_3 = \forall_5 \forall_6 = 0$ while

$H_1 \neq \forall_0 \neq \forall_1 \neq \forall_2 \neq \forall_3 \neq \forall_{4\neq} \forall_5 \neq \forall_6 \neq 0$

As we know, the rejection or acceptance of the null hypothesis is purely based on the results of the F-statistic at the 10%, 5%, or 1% level. Therefore,(Boontome et al., 2017) Suggest that the long-run association exists in case the calculated F-statistic is greater than the critical value for the upper bound 1(1), then we can conclude that there is co-integration. That is, there is a long-run relationship. Reject the null hypothesis. Estimate the long-run model, which is the error correction model (ECM). On the other hand, if the calculated F-statistic is lower than the critical value for the lower bound I (0), then we conclude that there is no co-integration, hence, no long-run relationship. Do not reject the null hypothesis. Estimate the short-run model, the autoregressive distributed lag (ARDL) model. If the F-statistic falls between the lower bound I (0) and the upper bound I (1). The test is considered inconclusive.

## 3.7. Auto-regressive distributed lag (ARDL)

According to the unit root test analysis, to ascertain that no variables are integrated of order 2. Based on the bound test result, if the variables are co-integrated, specify both short-run (ARDL) and long-run (VECM) models. On the other hand, if variables are not co-integrated, specify only the short-run (ARDL) model. Therefore, we apply the long-run ARDL model in this study.

$$CO2_t + \alpha_0 + \sum_{i=1}^{q} \rho_1 (FDI_{i-1}) + \sum_{i=1}^{q} \rho_2 (RE_{t-1}) + \sum_{i=1}^{q} \rho_3 (MVA_{i-1}) + \sum_{i=1}^{q} \rho_4 (TOP_{i-1}) + \sum_{i=1}^{q} \rho_5 (GDP_{i-1}) + \sum_{i=1}^{q} \rho_6 (NRE_{i-1}) + \varepsilon_t$$

Eq.(7)

In the following equation, $\rho_1$, and $\rho_5$ Denote variation in the long run in the selected variables. In addition, we have automatically selected the Akaike information criterion (AIC) lag length for each variable of our sample. In contrast, the following error correction model takes into account the short-run ARDL model.

$$CO2_t = \alpha_0 \sum_{i=1}^{q} \emptyset_1 \Delta FDI_{t-i} + \sum_{i=1}^{q} \emptyset_2 \Delta RE_{t-i} + \sum_{i=1}^{q} \emptyset_3 \Delta MVA_{t-i} \sum_{i=1}^{q} \emptyset_4 \Delta TOP_{t-i} + \sum_{i=t}^{q} \emptyset_5 \Delta GDP_{t-i}$$
$$+ \sum_{i=1}^{q} \emptyset_6 \Delta NRE_{t-i} + \beta ECT_{t-1} + \varepsilon_t$$

Eq.(8)

In equation (5), ECT represents the error correction term that evaluates the speed of adjustment from disequilibrium short-run to long-run; typically, the average length of ECT is from 1 to 0. To more clearly understand the concept of error correction term (ECT), it should have having negative coefficient as well as be statistically significant and identified as adjusted to equilibrium in the next period. Moreover, we also checked the stability of the model proposed by Brown et al., 1975).

## 3.8. Dynamic ARDL simulations

To use dynamic ARDL simulations for the estimate, all the variables must be stationary at first difference 1(1), and all the study variables must be co-integrated. Therefore, we apply the equation of the ARDL simulation model in this study.

$$\Delta CO2_y = \alpha_0 + \theta CO2_{t-1} + \beta_1 \Delta FDI_t + \theta_1 FDI_{t-1} + \beta_2 \Delta RE_{t-1} \theta_2 RE_{t-1} + \beta_3 \Delta MVA_{t-1} + \theta_3 MVA_{t-1} + \beta_4 \Delta TOP_{t-1} + \theta_4 TOP_{t-1} + \beta_5 \Delta GDP_{t-1} + \theta_5 GDP_{t-1} + \beta_6 \Delta NRE_{t-1} + \theta_6 NRE_{t-1} + \varepsilon_t$$

Eq.(9)

## 3.9. Granger causality tests

The Granger causality estimation is a critical method that was first developed by (Engle-Granger, 1998). The primary objective of the Granger causality tests is employed to examine the causal directions employing a supplemented delayed error correction term among gross domestic product per capita, foreign direct investment, manufacturing added value, trade openness, renewable energy, and non-renewable energy, in the short and long run. In this paper. The (VECM) model is given by the following equations as follows:

$$\Delta CO2_t = \phi_1 + \sum_{i=1}^{p} \phi_{11i} \Delta FDI_{t-1} + \sum_{i=1}^{p} \phi_{12i} \Delta RE_{t-i} + \sum_{i=1}^{p} \phi_{13I} \Delta MAV_{t-i} + \sum_{i=1}^{p} \phi_{14i} \Delta TO_{t-1} + \sum_{i=1}^{p} \phi_{15i} \Delta GDP_{t-1} + \sum_{i=1}^{p} \phi_{16i} \Delta NRE_{t-1}$$

Eq.(10)

## 3.10. Robustness tests

### 3.10.1. Fully modified ordinary least squares

We utilized the (FMOLS) method to capture the indifferent estimators of co-integrating estimations based on the given equation. The (FMOLS) technique deforms (OLS) to distinguish the implicit endogeneity bias error (Khan, Yasir, Taimoor Hassan, Dervis Kirikkaleli, Zhang Xiuqin, and Cai Shukai, 2021). Additionally, FMOLS is effective in the existence of a mixture of normal and asymptotic. We employed the (FMOLS) estimation approach to explore the dynamic impact of FDI on $CO_2$ emissions, together with other variables.

$$mCO_t = \beta_0 + \beta_1 mY_1 + \varepsilon_t \dots \dots \dots \dots Eq.(11)$$

According to Eq. (12), $\iota nCO_{2t}$ is the dependent variable, $\beta_0$ signifies the intercept, and $\beta_1$ represents the vector slope coefficient; $\iota nX_1$ He vector of response variables including FDI. Lastly, $\mathcal{E}_t$ Is the error term in the equation.

## 4. Empirical results and discussion

### 4.1. Descriptive Data

This part of the study presents the descriptive statistics of the study variables. The descriptive statistics present the mean, median, and standard deviation, as well as minimum and maximum values, Jarque-Bera, probability, and the total number of observations of the study variables in Table 3 below.

**Table 3** Descriptive Statistics of variables.

|  | LCO$_2$ | LFDI | LGDP | LMAV | LNRE | LRE | LTO |
|---|---|---|---|---|---|---|---|
| Mean | 14.200 | 200438.1 | 247.75 | 17.63 | 86.26 | 14.29 | 47.74 |
| Median | 14.200 | 7.620 | 197.02 | 18.50 | 86.30 | 13.90 | 46.20 |
| Maximum | 22.200 | 968831.4 | 458.200 | 21.600 | 88.100 | 18.600 | 66.000 |
| Minimum | 10.400 | -75722.41 | 115.550 | 12.400 | 84.200 | 9.780 | 35.700 |
| Std. Dev | 2.856 | 329648.8 | 114.890 | 3.130 | 1.114 | 3.306 | 8.038 |

| Skewness | 1.206 | 1.171 | 0.419 | -0.454 | -0.296 | 0.013 | 0.401 |
|---|---|---|---|---|---|---|---|
| Kurtosis | 4.238 | 2.756 | 1.665 | 1.818 | 1.962 | 1.304 | 2.332 |
| Jarque-Bera | 7.661 | 5.777 | 2.591 | 2.312 | 1.488 | 2.993 | 1.137 |
| Probability | 0.021 | 0.055 | 0.273 | 0.314 | 0.474 | 0.223 | 0.566 |
| observation | 27 | 27 | 27 | 27 | 27 | 27 | 27 |

**Source:** Author's Computation from EViews.

Carbon dioxide emission recorded an average emission of approximately 14.200 per capita for 30 years, a standard deviation of 2.856, and a minimum and maximum emission of approximately 22.200 and 10.400 respectively. Implicitly, the average emission of CO2 emitted is 14.200 yearly. Also, Foreign Direct Investment (FDI) was measured as Million USD a mean of 200438.1, a minimum of -75722.41, and a maximum of 968831.4 approximately. The descriptive statistics for Gross Domestic Product (GDP) also showed that the country grew at an average of approximately 247.75 over the period, recording a minimum growth of 115.550 with the highest growth rate of 458.200 over the period. Manufacturing added value recorded an average of approximately 17.63 for the 30 years, a standard deviation of 3.130, and a minimum and maximum of approximately 21.600 and 12.400 respectively. Non-renewable energy showed an average of 160.0973 million USD, a standard deviation of 182.019 million USD, and a maximum and minimum value of 792.960 million USD and 12.2910 million USD. Renewable energy approximated 14.29 an average for the 30 years, recording a standard deviation, minimum and maximum value of 3.306, 9.780, and 18.600 respectively. Trade openness showed an average of 47.74, a standard deviation of 155.019 million USD, and a maximum and minimum value of 792.960 million USD and 12.2910 million USD.

## 4.2. Correlation matrix

The correlation among the variables partially indicated that there is a possible connection between the variables. Nonetheless, to further explore the relationship between all the selected variables, we conduct various statistical estimations to prove our hypothesis of the study.

**Table 4** Correlation matrix

| | LCO$_2$ | LFDI | LGDP | LMAV | LNRE | LRE | LTO |
|---|---|---|---|---|---|---|---|
| CO$_2$ | 1.000 | | | | | | |
| FDI | 0.017 (0.932) | 1.000 | | | | | |
| GDP | -0.584*** (0.0020 | -0.220 (0.288) | 1.000 | | | | |
| MAV | 0.619*** (0.001) | 0.240 (0.246) | -0.923*** (0.000) | 1.000 | | | |
| NRE | 0.368 (0.069) | -0.369 (0.074) | 0.745*** (0.000) | -0.579*** (0.002) | 1.000 | | |
| RE | -0.610*** (0.001) | 0.151 (0.470) | -0.894*** (0.000) | -0.892*** (0.000) | -0.693 | 1.000 | |
| TO | -0.695*** (0.000) | -0.212 (0.306) | 0.726*** (0.000) | -0.836*** (0.000) | 0.507*** (0.009) | -0.859*** (0.000) | 1.000 |

* Represents significant at 10%, ** represents significant at 5%, and *** represents significant at 1% respectively; **Source:** Author's Computation from EViews

## 4.3. Panel Unit Root test

The outcomes of the unit root tests are presented in Table 5. The ADF and PP are tested under the null hypothesis of the unit root. Evidence from Table 5 shows that the null hypothesis of a unit root for all variables cannot be stationary at level I (0) but is stationary at the first difference, I (1).

**Table 5** Unit root test

| | ADF | | | | PP | | | |
|---|---|---|---|---|---|---|---|---|
| | Level | | First difference | | Level | | First difference | |
| | Intercept | Both | Intercept | Both | Intercept | Both | Intercept | Both |
| $CO_2$ | -0.093 (0.470) | -0.185 (0.165) | -1.014 (0.000) | -2.449 (0.025) | -0.093 (0.470) | -0.185 (0.165) | -1.014 (0.000) | -1.107 (0.000) |
| FDI | -1.138 (0.622) | -1.229 (0.274 | -3.342 (0.001) | -3.487 (0.000) | -1.138 (0.470) | -0.185 (0.165) | -1.014 (0.000) | 2.764 (0.002 |
| GDP | -0.050 (0. 350) | -0.134 (0.665) | -0.884 (0.004) | -0.886 (0.000) | -0.047 (0.371) | -0.178 (0.148) | -0.625 (0.002) | -0.625 (0.003) |
| MAV | -0.016 (0.620) | -0.274 (0.363) | -1.002 (0.000) | -0.321 (0.000) | -0.016 (0.620) | -0.248 (0.076) | -1.002 (0.000) | -0.321 (0.000) |
| NRE | -0.205 (0.131) | -0.661 (0.570) | -1.354 (0.000) | -1.357 (0.000) | -0.205 (0.131) | -0.325 (0.086) | -1.354 (0.000) | -1.357 (0.000) |
| RE | -0.021 (0.641) | -0.209 (0.075) | -0.838 (0.002) | -0.834 (0.000) | -0.021 (0.641) | -0.209 (0.075) | -0.838 (0.000) | -0.314 (0.002) |
| TO | -0.175 (0.119) | -0.636 (0.250) | -1.168 (0.000) | -4.253 (0.001) | -0.175 (0.119) | -0.636 (0.052) | -1.168 (0.000) | -1.170 (0.000) |

**Source:** Author's Computation from EViews.

## 4.4. Co-integration Test

**Table 6** Co-integration test

| | Trace Test | | | Max-Eigen Test | | |
|---|---|---|---|---|---|---|
| Hypothesized | Test Statistic | Critical value 5% | p-value | Test Statistic | Critical value 5% | p-value |
| None* | 386.081 | 125.615 | 0.000 | 129.455 | 46.231 | 0.000 |
| At most 1* | 256.625 | 95.753 | 0.000 | 117.518 | 40.077 | 0.000 |
| At most 2* | 139.107 | 69.818 | 0.000 | 95.385 | 33.876 | 0.000 |
| At most 3* | 43.721 | 47.856 | 0.115 | 20.622 | 27.584 | 0.299 |
| At most 4* | 23.099 | 29.797 | 0.241 | 13.635 | 21.131 | 0.395 |
| At most 5* | 9.464 | 15.494 | 0.324 | 6.436 | 14.264 | 0.557 |
| At most 6* | 3.027 | 3.841 | 0.081 | 3.027 | 3.841 | 0.081 |

**Source:** Author's Computation from EViews.

## 4.5. ARDL bounds

To determine whether there is a long-run relationship between the series, the ARDL bounds technique was used. In Table 7, the findings of the F-statistics are displayed. The co-integration is evaluated using F-statistics. However, the value of the t-statistics is also found to be greater than the value of the upper bound at the 10% level of significance, which implies the existence of co-integration among the variables under examination. The estimated F-statistics value is found to be greater than the upper limit value at both the 10% and 5% levels of significance.

**Table 7** ARDL bounds test analysis.

| Test statistic | Value | | k | | H₀ | H₁ |
|---|---|---|---|---|---|---|
| F-statistics | 5.65 | | 4 | | No level relationship | Relationship exists |
| t-statistic | -3.68 | | | | | |
| significance | F-statistics | | t-statistics | | p-value F | |
| | I (0) | I (1) | I (0) | I (1) | I (0) | I (1) |
| 10% | 2.56 | 3.82 | -2.67 | -3.56 | 0.00*** | 0.03** |
| 5% | 3.19 | 4.76 | -2.82 | -4.02 | p-value t | |
| 4% | 4.88 | 6.52 | -3.45 | -4.86 | 0.00*** | 0.07* |

**Source:** Author's Computation from EViews.

## 4.6. Long-run and short-run relationship

We discovered that GDP per capita has a positive and statistically significant impact on carbon emissions. A 1% increase in GDP decreases carbon emissions significantly by 0.47% and -0.33% in the short-run but is shown a negative coefficient sign in the long run, respectively. However, the long run is found to be statistically insignificant. This is expected that the industrial sector is the main source of carbon which logically lead to environmental degradation. The plausible intuition is that most FDI into the manufacturing sector is into pollution-reducing or environment-enhancing technologies that turn to enhance productivity whilst promoting a quality environment. Moreover, non-renewable energy showed a positive sign and was statistically significant both in the short and long run. More precisely, a 1% increase in non-renewable energy, increases $CO_2$ emission significantly by 0.23% and 0.50% in the short run and long run, respectively.

**Table 8** ARDL results.

| Variable | Coefficient | Std. Error | t-statistic |
|---|---|---|---|
| Constant | -1.361** | 0.565 | -2.004 |
| $CO_2$ | 0.347*** | 0.241 | 2.875 |
| $\Delta CO_2$ | 0.119 | 0.176 | 1.630 |
| FDI | -0.216* | 0.053 | 3.721 |
| $\Delta$ FDI | 0.691** | 0.072 | -2.275 |
| GDP | -0.471** | 0.121 | 2.897 |
| $\Delta$GDP | 0.331 | 0.426 | -0.374 |
| MAV | 0.169** | 0.294 | 5.011 |
| $\Delta$MAV | 0.962 | 0.317 | 0.928 |
| NRE | 0.232 | 1.122 | 0.372 |
| $\Delta$ NRE | 0.503 | 1.266 | 0.297 |
| RE | -0.332*** | 0.885 | -2.898 |
| $\Delta$ RE | -0.937 | 0.801 | 0.027 |
| TO | -0.183 | 0.119 | -1.422 |
| $\Delta$ TO | 0.1776 | 0.130 | -1.480 |
| ECT (-1) | -0.643*** | 0.0186 | -5.052 |
| R-squared | 0.75 | | |

| | | | |
|---|---|---|---|
| N | 27 | | |
| AIC | -3.746 | | |
| D-W stat | 2.006 | | |
| F-stat | 0.000*** | | |
| Simulations | 5000 | | |

**Source:** Author's Computation from EViews.

## 4.7. Granger causality test

The results of the causality test are presented in Table 9. We found a one-way unidirectional causality running from $CO_2$ emissions to gross domestic product per capita indicating that GDP per capita impacts $CO_2$ emissions in South Africa. A one-way causality was found between RE and $CO_2$ emissions. On the other hand, a two-way causality association was revealed between MAV and $CO_2$ emissions. There is no causal link between FDI and $CO_2$ emissions. Similarly, a two-way causal linkage was found running from MAV to CO2 emissions and vice versa.

**Table 8** Granger causality.

| | Obs | F-statistic | p-value |
|---|---|---|---|
| FDI → $CO_2$ | 27 | 0.598 | 0.558 |
| GDP → $CO_2$ | 27 | 1.864 | 0.178 |
| MAV → $CO_2$ | 27 | 3.022 | 0.069 |
| NRE → $CO_2$ | 27 | 0.937 | 0.410 |
| RE → $CO_2$ | 27 | 1.515 | 0.241 |
| TO → $CO_2$ | 27 | 1.701 | 0.205 |
| CO2 → FDI | 27 | 1.864 | 0.178 |
| CO2 → GDP | 27 | 3.394 | 0.050 |
| CO2 → MAV | 27 | 0.410 | 0.008 |
| CO2 → NRE | 27 | 1.135 | 0.343 |
| CO2 → RE | 27 | 0.339 | 0.016 |
| CO2 → TO | 27 | 0.064 | 0.937 |

**Source:** Author's Computation from EViews

## 4.8. Robustness test

The outcomes of the robustness test are presented in Table 10. A now common exercise in empirical studies is a "robustness check," where the researcher examines how certain "core" regression coefficient estimates behave when the regression specification is modified in some way, typically by adding or removing regressors (Xun Lu and Halbert White, 2014). Such exercises are now so popular that standard econometric software has modules designed to perform robustness checks automatically; for example, one can use the STATA commands check or check rob. Therefore, we have cross-checked our results by employing the FMOLS and DOLS modes to verify the outcomes of the main models. Our results' coefficient values are robust and consolidated, as confirmed by the ARDL model. In addition, we did not find sufficient variations in the coefficients that can alter our results.

**Table 10** Robustness test.

| Variable | FMOLS | | DOLS | |
|---|---|---|---|---|
| | Coeff | t-statistics | Coeff | t-statistics |
| LMAV | 0.044** | (3.082) | 0.255*** | (3.356) |
| LFDI | -0.008** | (2.464) | 1.179*** | (3.329) |
| LGDP | 0.115*** | (-2.948) | 0.663*** | (4.246) |
| LTO | -0.093*** | (-3.370) | 0.663*** | 0.308936 |
| LNRR | 0.006*** | (1.920) | 0.005* | (0.175) |
| LREC | -0.229*** | (-9.920) | -0.306*** | (-4.802) |
| R-squared | | 0.99 | | 0.99 |
| Adjusted R2 | | 0.99 | | 0.99 |
| S.E. of regression | | 0.047 | | 0.101 |
| Long-run variance | | 0.005 | | 0.002 |

*** represent significance at 10%, 5%, and 1% level, respectively.

## 5. Conclusion

Climate change is primarily caused by the utilization of non-renewable energy consumption through the manufacturing sector to increase economic growth. South Africa faces in our day the issue of increasing environmental pollution. This study aimed to probe the effect of manufacturing foreign direct investment on $CO_2$ emissions and evaluate the role of renewable energy sources in the case of South Africa from 1990 to 2019. The study employed the dynamic ARDL simulation model to estimate the long and short-run effect of manufacturing foreign direct investment on CO2 emissions in South Africa.

## Compliance with ethical standards

*Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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