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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Garidzirai, Rufaro (2020). Time series analysis of carbon dioxide emission, population, carbon tax and energy use in South Africa. In: International Journal of Energy Economics and Policy 10 (5), S. 353 - 360.
https://www.econjournals.com/index.php/ijeep/article/download/9618/5294.
doi:10.32479/ijeep.9618.

IJEEP

INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY

EJ EconJournals ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2020, 10(5), 353-360.

EJ EconJournals

Time Series Analysis of Carbon Dioxide Emission, Population, Carbon Tax and Energy use in South Africa

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Received: 22 March 2020 **Accepted:** 23 June 2020 **DOI:** https://doi.org/10.32479/ijeep.9618

ABSTRACT

The nexus among carbon emission, energy use, population and carbon tax cannot be overlooked. Such a relationship plays an important role to environmentalists, economists, policy makers and researchers. Thus, this study investigates the nexus among carbon emission, population, energy use and carbon tax from 1970 to 2018. The objective of this study sought to establish the link among carbon emission, carbon tax, energy use and population. The objective was achieved using the autoregressive distributive lag model (ARDL) since it gives accurate parameters. The results of the study show that energy use and population growth positively influence carbon dioxide emission, while carbon tax reduces carbon emission. Based on the study's results, the study recommends that South Africa`s government promote the use of clean energy and develop ways to reduce population growth in minimizing carbon emission.

Keywords: Carbon Dioxide Emission, Population, Carbon Tax, Energy use, South Africa
JEL Classifications: Q43, Q56

1. INTRODUCTION

Dialogues on carbon dioxide emission have increased in the past decades. Surrounding the conversations are the causes of carbon dioxide emission, the impact of carbon dioxide emission and the mitigation of carbon dioxide emission. There is concurrence among researchers, economists and environmentalists that carbon dioxide is not ecologically sound and is mainly caused by energy use (Department of Environment Affairs, 2020). Though energy use is the catalyst for economic development it produces a byproduct of carbon dioxide emission that causes climate change. As such the government has embarked on implementing fiscal policies to reduce this epidemic. Among all the fiscal policy instruments, carbon emission tax has proven to be the most effective and efficient way of minimizing emissions (Che et al., 2019; National Treasury, 2019). Nevertheless, several policy makers contend that carbon emission tax is regressive in nature. That is to say, carbon tax exerts pressure on poor households, especially those who spend much on energy goods and services. This widens the inequality gap, depending on the population growth rate of a country. Since the relationship among carbon emission, population, energy use and carbon tax is intertwined, such a relationship is vital and cannot be disregarded.

Though climate change is a natural process, it has been increased by human and industrial activities. This includes deforestation, the use of fossil fuels and the use of dirty energy (Nuryartono and Rifai, 2017). Such activities have contributed to negative externalities such as a surge in climate erraticism, drought, diseases and soil erosion. The economic theory upholds that carbon emission has a double-edged effect to inequality through carbon pricing. The first effect claims that carbon tax reduces carbon emission and should therefore be promoted (Haug et al., 2018). Simply put, carbon tax reduces carbon emission, improves energy production and reduces the impact of climate change. Conversely, the carbon price is retrogressive in nature. It tends to increase the inequality gap especially on poor households that spend much of their salaries in the energy services (Kaufmann and Krause, 2016).

The emission of carbon dioxide has become a key economic and environmental challenge worldwide. Unfortunately, South Africa cannot be exonerated from this challenge. It is one of the top countries that is contributing to climate change via carbon dioxide emission. South Africa ranked 14th, globally, due to heavy production in the manufacturing industries (World Bank, 2019a). Most manufacturing industries make use of primary energy that tends to increase carbon emissions. It is anticipated that carbon emission will keep on increasing. If not taken care of, carbon emission is likely to cause more problems such as diseases and climate change. The present state of carbon emission in South has attracted the researcher to investigate its causes and reduction.

The second research problem emanates from the literature on energy use, population, carbon tax and carbon emission. Most of the literature is found in Asia and Europe (Abolhosseini et al. 2014; Ahamada et al., 2017; Fremstad and Paul, 2017; Markkanen and Anger-Kraavi, 2019). There are a few studies conducted in Africa such as (Winkler, 2017; Awojobi and Tetteh, 2017). According to the researcher's knowledge, there is no study that has combined energy use, carbon tax, population and carbon emission altogether. Rather, the literature reviewed combined two or three of the abovementioned variables. It seems the literature on carbon emission, energy use and carbon pricing combined has received diminutive attention. Thus, this gives the researcher a research cavity to examine the causes of climate change and the impact of carbon tax on carbon emission. The study is envisaged to contribute to environment and economic policies in line with the National Development Plan of 2030 to reduce carbon emission and inequality.

This study is systematized as follows. Section two discusses the South African environment and economic stylized facts. Section three presents the theoretical and empirical literature, while the research methodology and results of the study are discussed in section four and five respectively. The conclusion, limitation of the study and recommendations are discussed in section six. The subsequent section discusses the stylized facts on South Africa's energy use, carbon emission and population.

2. STYLIZED FACTS ON SOUTH AFRICA`S ECONOMIC AND ENVIRONMENTAL ISSUES

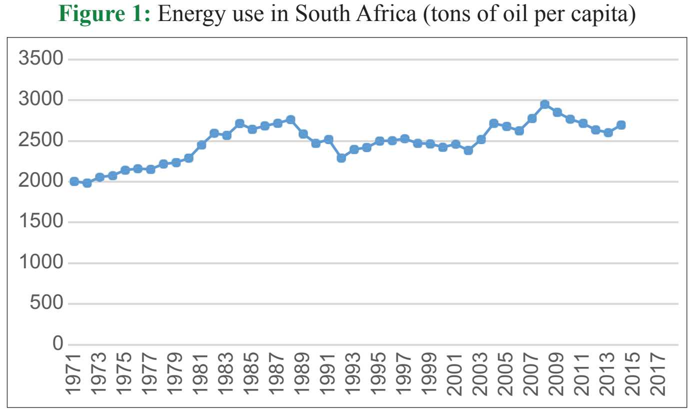
South Africa`s energy sector has been well developed since 1994. This is due to an abundance of natural resources such as coal. Since then, coal has become the primary source of energy in South Africa (Department of Energy, 2020). Due to the comparative and absolute advantage, South Africa has become the fourth largest coal exporter worldwide (Statistics South Africa, 2019). Currently, it provides 80% of primary energy used for electricity generation and petrochemical industries (Department of Energy, 2020). Though South Africa is endowed with a myriad of natural resources, it imports oil and gas for production purposes (Statistics South Africa, 2019). There are other sources of energy used such as wind, hydroelectric and biomass for production purposes. All these sources are discussed below.

Figure 1 below shows the energy use in South Africa expressed in kg of oil per capita. The energy use trend is an upward trend from 1971 to 2017. It shows that energy use has increased significantly except in the period of 1989-1992 and 2009-2013. Notable is that South Africa uses more than 2000 kg per capita. For instance, the energy consumption in 1971 was at 2000 kg per capita. Interestingly, energy rose sharply from 1971 to 1989. The consumption rose from 2000 to 2700 per capita. However, from 1990 to 1993 there was a decline in energy use in South Africa. This has been triggered by a rise in the cost of energy that led to a diminution in energy use. Energy consumption gained an upward trend again from 1994 to 2009. The upward trend reflects South Africa's independence that gave previously disadvantaged groups the economic freedom to use energy that they were not using before. Furthermore, energy consumption grew due to an increase in the number of colliery operators. Energy consumption reached its peak in 2009/2010 due to the 2010 Soccer World Cup.

Using energy has resulted in an increase in carbon dioxide emissions which contributes more than 90% to greenhouse emissions in South Africa (Nuryartono and Rifai, 2017). Currently, South Africa is one of the top carbon dioxide emitters worldwide. The major source of the carbon dioxide is dirty energy from the burning of fuels and making of cement (Index Mundi, 2019). The burning of fuel produces carbon dioxide that mixes with oxygen to form carbon dioxide emissions (Global Climate Change, 2020). This has led to an increase in the earth's temperatures, the increase in the level of sea water, and decreased crop production leading to drought. It is pertinent to note that carbon emission increased six-fold since 1960 (World Bank, 2019a). Seeing the damage caused by climate change, South Africa`s government devised measures to combat climate change. These include regulations, carbon tax, and shifting to cleaner energy (National Treasury, 2019). Of importance is that carbon tax is currently called carbon pricing and the terms can be used interchangeably.

Carbon tax has a negative influence on households. Households may have to spend more on energy which tends to decrease the household income, increasing the inequality gap (Kaufmann and Krause 2016). For instance, in South Africa, carbon tax is charged on fuel combustion, industrial production and other emissions in line with the National Development Plan (2020). The National Development Plan stipulates that emissions should be reduced

Figure 1: Energy use in South Africa (tons of oil per capita)



Source: World Bank

by 34% by end of 2020 and by 42% in half a decade from now (World Bank, 2019b). To achieve this objective, consumers should pay nine cents per litre of petrol to cater for climate change. An increase in the fuel prices makes energy use expensive as well.

3. LITERATURE REVIEW

The association concerning carbon dioxide, energy use and carbon tax can be elucidated by the environment Kuznets theory. The theory suggests that a country that does not specialize in energy use is environmentally clean (Kuznets, 1950). However, countries such as South Africa that use energy tend to degrade the environment causing carbon dioxide emissions. Kuznets (1950) posits that energy use increases the inequality gap through carbon taxation up to a certain level of income. This depicts an increasing link between environmental degradation and income inequality. Thus, people are now spending more on energy goods and services, thereby making the poor poorer. This argument was supported by environmentalists and economists. They contend that this period allows producers to switch to cleaner energy which reduces climate change and eventually decreases income inequality (Boyce, 1994; Nnyeneime, 2018).

There are relatively no/few studies that probed into energy use, carbon emission, population growth and the carbon tax relationship. On the other hand, there are several studies that investigated two or three of the above-mentioned variables. For instance, Ahamada et al. (2017) examined the link among carbon emission, economic growth and energy prices in 22 France local regions. The study employed the panel data research methodology from 1995 to 2009 and found that economic growth causes carbon emission, while carbon tax reduces carbon emission. A similar finding was found by Fremstad and Paul (2017) who studied the distributional analysis of carbon tax in the United Kingdom. The authors used the input-output methodology and found that carbon tax affects 60% of poor households with low-income. A study done in South Africa by Winkler (2017) studied the link between minimizing energy poverty through carbon tax by using the simple spreadsheet model. The author found that income from taxation can be used to reduce poverty through the multiplier process. The authors posit that income from taxation can be reinvested back in the economy in the form of social grants to reduce poverty and the inequality gap.

Feng et al. (2010) studied the effects of carbon emission taxation in the United Kingdom. The study compared the effectiveness of both greenhouse tax and carbon emission tax in relation to climate change. The results of the study reveal that greenhouse tax is more effective compared to carbon emission tax. The scholars argued that all the taxes are regressive, and that the greenhouse tax is better compared to carbon emission tax. These findings were conflicting with the study done by Niall (2015) who examined the factors that drive inequality in Ireland. The author employed the concentration index methodology and found that energy use taxation is the main factor that contributes to inequality.

Lutz (2017) examined the link between climate change and population in Austria and found that population growth increases the chances of carbon emission. The author posits that climate change is caused by human activities such as energy use and deforestation. This finding is also in line with the study done by Mondal (2019) who investigated the effect of population on climate change in Bangladesh. The author employed the chronological data methodology and found that population causes climate change. Since a high population growth is positively related to energy use, Abolhosseini et al. (2014) analysed the effect of energy consumption on carbon emission in 15 European countries. The study employed panel data techniques from 1995 to 2010 and found that energy consumption is positively related to climate change. In other words, an increase in energy consumption caused the emission of carbon dioxide. Liu et al. (2019) found similar findings though their study was done on G7 countries using a different methodology, namely the multispatial convergent cross mapping (CCM). The authors concluded that energy use causes carbon emission.

Nuryartono and Rifai (2017) studied the link among carbon emission, economic growth and energy use in four Asian countries from 1975 to 2013. The study employed the vector error correction model. No association between economic growth and energy use was found in Singapore and Indonesia, while a positive relationship was observed in Malaysia and Thailand. Another interesting result is that the relationship between energy consumption and carbon emission was found to be insignificant in Malaysia. However, it is a different case in Tanzania where Albiman et al. (2015) found that energy use is the main cause of carbon dioxide emissions. The authors reached this conclusion after employing the Toda and Yamamoto causality test from 1975 to 2013. The study further concluded that energy use increases economic growth in Tanzania.

Lin and Li (2015) used the panel data technique to investigate the connection concerning carbon tax and climate change in developed countries. The study found a negative relationship between carbon tax and carbon emission in the long-run. On the other hand, in the short-run carbon tax tends to increase the inequality gap. Di Cosmo and Hyland (2013) also found the same results in some developed countries. The scholars utilized the time series analysis and found that carbon tax is the most effective instrument compared to other instruments such as regulations. A study that used the Regional integrated model of climate concluded that carbon tax is an effective instrument in reducing carbon emission, though it is regressive in nature (Dennig et al., 2015).

A study done in South Africa by Bekun et al. (2019) examined the relationship between economic growth and energy consumption from 1960 to 2016. The study employed the Bayer and Hanch cointegration approach and found a long-run relationship between economic growth and energy use. Thus, an increase in energy consumption promotes economic growth and inequality as poor households spend more on energy goods and services. Mohiuddin et al. (2016) support the findings by Bekun et al. (2019). The authors examined the relationship among carbon dioxide emissions, energy consumption, economic growth and electricity production in Pakistan using VECM from 1971 to 2013. The results of the study show a long-run positive relationship among these variables. Furthermore, the granger causality test shows an unidirectional causality running from energy consumption to carbon dioxide emissions, electricity production and energy consumption.

The literature review illustrates a contrasting view regarding the relationship among carbon emission, population, energy use and carbon tax. Some studies show a negative relationship among these variables, while some show a positive relationship. To contribute to the above-mentioned literature, the study investigates the relationship among carbon emission, population, energy use and carbon tax in South Africa. To achieve this objective, the study employs a time series analysis discussed in the following section.

4. DATA SOURCES AND SPECIFICATION

To examine the relationship among carbon emission, carbon tax, energy use and population, the study used the time series annual secondary data from 1970 to 2018. The data was obtained from the World Bank, Global Insights and Statistics South Africa data base. The data for population growth, carbon emission and energy use was obtained from the World Bank. It is important to note that the study estimated the carbon dioxide model. Thus, carbon emission was used as dependent variable while population growth, carbon tax and energy use were used as independent variables. The carbon emission model is specified in equation 1:

$$Co2_t = \beta_0 + \beta\, lnctax_t + \beta lnenergy_t + \beta\, lnPop_t + \varepsilon_t \quad (1)$$

Where CO_2 is carbon dioxide emission, lnctax is the carbon tax, lnpop is the population growth, lnenergy is the energy use or consumption, β are parameters to be estimated, while ε is the error term. The variables were put in a log form to make the analysis easier as the researcher analyses using percentage changes.

4.1. Explanation of Variables and Priori Expectation

This section discusses the variables used in this study and their expected signs. The discussion is grouped into dependent variables and independent variables.

4.1.1. Dependent variables

The dependent variable is carbon emission measured by carbon dioxide emission per capita. Bekun et al. (2019) defined carbon dioxide emission per capita as the unwanted byproduct from burning fuels and cement production. The carbon dioxide emission variable tends to increase temperatures and changes the climate.

4.1.2. Independent variables

As mentioned above, the independent variables include carbon tax, population growth and energy use. Carbon tax is a certain amount charged by the government to all industries that produce carbon dioxide (Mohiuddin et al., 2016). The carbon emission tax is expected to influence carbon emission negatively. The rationale is that carbon tax reduces the emissions of unwanted gases. This measure has been used by Leve and Kapingura. (2019), Nuryartono and Rifai (2017). Population growth is defined as an increase in the number of people in a certain area (World Bank, 2019a). An increase in population is expected to exacerbate carbon emission (Mondal, 2019). The last independent variable is energy use which is the use of primary energy in South Africa. Energy use was measured in tons of oil per capita (World Bank, 2019a). The study expects a positive relationship between energy consumption and carbon dioxide emissions. The more industries use energy, the more they are likely to cause carbon emission.

4.2. Econometrics Procedure

This section discusses the prior estimations, methodology and post estimation techniques used in this study. The following section discusses the unit root tests.

4.2.1. Unit root tests

The time series analysis requires one to test for stationarity. The purpose of the unit root test is to check whether the variables are stationary. Secondly, the unit root test is used to ascertain the order of integration (Schwert, 1989). To achieve these two objectives, the literature prescribes the Augmented Dickey Fuller (ADF) and Philips Perron tests. These tests set the null hypothesis as non-stationary. Thus, a probability of more than 10% confirms the non-stationarity. While a probability of <10% rejects the null hypothesis. Furthermore, the unit root tests prescribe the research methodology to be used. Gujarati (2009) prescribes that if the variables are integrated at a combination of zero and one, then an autoregressive distributive lag (ARDL) model may be utilized. On the other hand, if the variables are integrated at order one, then a Vector autoregression (VAR) or vector error correction model (VECM) can be utilized.

4.2.2. ARDL bound cointegration analysis

The study used the ARDL bounds approach to examine if a short-run and long-run relationship exists among energy use, climate change, carbon pricing and population growth in South Africa. The ARDL framework was employed due to the advantages it gives. For instance, the ARDL is the only method you can employ if the variables are integrated at different levels, that is zero and one (Tursoy, 2019). Other cointegration methods such as the Johansen cointegration and the Engle and Granger methods are employed when variables are integrated at the same order (Johansen and Juselius, 1990). In addition, the ARDL model offers reliable parameters and robust results (Harris and Sollis, 2003; Pesaran et al., 2001).

$$\Delta lnCo2_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnCo2_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnctax_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnenergy_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnpop_{t-1} + \varepsilon_t \quad (2)$$

$$\Delta lnctax_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnctax_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnCo2_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnenergy_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnpop_{t-1} + \varepsilon_t \quad (3)$$

$$\Delta lnenergy_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnenergy_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnctax_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnCo2_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnpop_{t-1} + \varepsilon_t \quad (4)$$

$$\Delta lnpop_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnpop_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnctax_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnenergy_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnCo2_{t-1} + \varepsilon_t \quad (5)$$

Where ε_t is the error term, Δ is the first difference, t-1 represents time lag. Other variables were defined in equation (1). To check whether a long-run relationship exists, the study employed the F-statistics test where the null hypothesis of no cointegration was set. The rule of thumb is to reject the null hypothesis when the F-statistic value is more than the upper and lower critical values (Pesaran et al., 2001). Therefore, we confirm the existence of a long-run relationship among the variables under study. Conversely, if the calculated F value is lower than the critical values then we accept the null hypothesis and accept that there is no long-run relationship. In the event that there is a long-run relationship the research will analyse the results and further estimate the short-run analysis. Equation 6-9 depicts the short-run equations.

$$\Delta lnCo2_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnCo2_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnctax_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnenergy_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnpop_{t-1} + \theta_t ECT_{t-1} \varepsilon_t \quad (6)$$

$$\Delta lnctax_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnctax_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnCo2_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnenergy_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnpop_{t-1} + \theta_t \ ECT_{t-1} + \varepsilon_t \quad (7)$$

$$\Delta lnenergy_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnenergy_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnctax_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnCo2_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnpop_{t-1} + \theta_t \ ECT_{t-1} + \varepsilon_t \quad (8)$$

$$\Delta lnpop_t = \beta_0 + \beta_1 \sum_{i=1}^{p} \Delta lnpop_{t-1} + \beta_2 \sum_{i=1}^{q} \Delta lnctax_{t-1} + \beta_3 \sum_{i=1}^{r} \Delta lnenergy_{t-1} + \beta_4 \sum_{i=1}^{s} \Delta lnCo2_{t-1} + \theta_t \ ECT_{t-1} \varepsilon_t \quad (9)$$

Equation 6-9 represents the Error correction term (ECT). The ECT should be negative and statistically significant. After analyzing the long-run and short-run, the study employed the post estimation techniques.

4.2.3. Post estimation techniques

For the post estimation techniques, the study employed the serial correlation, the heteroscedasticity, the cumulative sum and the cumulative sum of squares tests. The first two were employed to check if the model is a good fit. Thus, it set the null hypothesis on no serial correlation and heteroscedasticity. The rule of thumb is to accept the null hypothesis if the probability values are above 0.10 and conclude that the study is free from serial correlation and heteroscedasticity. For the cumulative sum and cumulative sum of squares, the blue line should be within the range of red lines. This shows that the study model is stable and good.

5. EMPIRICAL RESULTS

This section discusses the results of the study: descriptive statistics, unit root tests, ARDL and post estimation results. The following section briefly discusses the descriptive statistics.

5.1. Descriptive Statistics

Table 2 shows the results of the descriptive statistics. Results reveal positive mean coefficients, implying that all the variables have an upward direction throughout the series. The results further review that all the study's variables are negatively skewed and fall between −1 and −0.5. Therefore, we conclude that the data is moderately skewed and normally distributed. In addition, the results show a minimum kurtosis of 0.27 and maximum of 1.46. Thus, the data kurtosis is moderate and the data used in this study is free from outliers.

5.2. Unit Root Test

This section discusses the unit root test using the ADF and PP, and the results are shown in Table 3. The results reveal that carbon tax is stationary at levels since the probability value is less than 0.10. This implies that carbon tax is integrated at order one. Notable is that, other variables were not stationary at levels since their probability values were more than 0.10. Thus, the variables were tested at first difference and were found to be stationary. As a result, population growth, carbon tax and carbon emission are integrated at level one. One can conclude that variables are integrated at a combination of zero and one. Thus, the use of the ARDL bound test is recommended by the economic literature. Therefore, the next section discusses the results of the lag structure and the ARDL bound test.

Table 1: Description of variables used

Variable	Identifier	Description	Expectation
Carbon dioxide emission	CO_2	Unwanted byproduct from burning fuels and cement production	
Energy use	Energy	The use of primary energy in South Africa measured in tonnes of oil per capita	(+)
Population	Pop	An increase in the number of people in a certain area	(+)
Carbon tax	Ctax	Certain amount charged by the government to all industries that produce carbon dioxide	(−)

Source: Own Compilation

Table 2: Descriptive statistics

Description	Lncem	lnctax	lnenergy	lnpop
Mean	12.6804	0.9293	7.8141	0.6799
Median	12.7371	0.9949	7.8286	0.8448
Maximum	13.1286	1.6118	7.9896	1.0147
Minimum	12.0351	0.1538	7.5930	0.1970
Std. Dev.	0.3308	0.4005	0.0988	0.2973
Skewness	−0.6035	−0.3235	−0.6120	−0.4156
Kurtosis	2.2649	2.0007	2.5722	1.4814
Jarque-Bera	3.6618	2.5983	3.0823	5.4943
Observations	44	44	44	44

Table 3: Unit root test

Variables	ADF	PP	Decision
lncem	0.7694	0.7367	
D(lncem)	0.000***	0.000***	1(1)
lnctax	0.0659*	0.0509*	1(0)
lnenergy	0.5765	0.5484	
D(lnenergy)	0.000***	0.000***	1(1)
lnpop	0.1636	0.4551	
D(lnpop)	0.6811	0.0503*	1(1)

*, **, *** represents 1%, 5% and 10% respectively

5.2.1. Lag selection criteria

Before employing the bounds test, it is crucial to determine the lag length used in the study. The results of the lag selection criteria are illustrated on Table 4. The results reveal that the likely ratio (LR), final prediction error (FPE), akaike information criterion (AIC), Schwarz Criterion (SC) and Hanna-Quinn (HQ) were recommended. However, the study used the common AIC and lag two was selected. Therefore, the ARDL long-run and short-run were carried using the AIC.

5.3. ARDL Bounds Test

The long-run relationship was tested by the Bounds test and the results are illustrated in Table 5. According to the Bounds test results, the calculated F-statistic (18.96) is greater than the upper bound critical values of 1%, 2.5%, 5% and 10%. As a result, the null hypothesis of no cointegration is rejected and it is concluded that there is a long-run relationship among the variables under study.

5.3.1. Long-run analysis

Table 6 provides long-run results of the two models used in this study: climate change and inequality model.

Table 4: Lag length selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	215.2133	NA	3.09e11	−10.010	−9.8032	−9.934
1	422.8569	355.9605	5.22e15	−17.4662	−17.4663	18.252
2	487.9967	96.15867*	8.13e16	−18.3433	−18.3433	19.785

*, **, *** represents 1%, 5% and 10% respectively

Table 5: ARDL bounds test

T-statistic	Value	K
F-statistic	5.3756	4
Bounds	10	11
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.7	5.06

5.3.1.1. Results of carbon emission model

The results in Table 6 show that carbon tax has a negative and significant effect on carbon emission in South Africa. Hence, a 1% increase in carbon tax reduces carbon emission by 0.0910%. The results are in line with the studies done by (Lin and Li, 2015; Winkler, 2017). The authors share the notion that firms and consumers switch to cleaner production methods to avoid paying the tax. The results also illustrate a positive and significant relationship between energy use and carbon emission. Thus, a 1% increase in energy use increases carbon dioxide emission by 1.3028% in South Africa. These findings are consistent with the studies done by Leve and Kapingura. (2019) and Abolhosseini et al. (2014). The authors argued that using fossil fuel causes climate change since they produce an unwanted product (carbon dioxide emission).

Furthermore, the results show a significant and positive relationship between population growth and carbon emission. Accordingly, a 1% increase in population growth increases carbon emission by 0.2313%. Lutz (2017) and Mondal (2019) also found similar results. The authors concluded that an increase in population makes it difficult to control the environment since climate change is mainly caused by human behavior. The current study further found that increased population has the probability of causing carbon emission.

5.3.2. Short-run analysis

This section discusses the short-run results of climate change and the inequality model. The results are shown in Table 7. The error correction term of climate change model is negative (−0.8943) and statistically significant at 1%. The results illustrate that 89% of any disequilibrium is restored in the next 1.12 years (1/0.8943).

5.3.3. Post estimation results

Table 8 illustrates the diagnostic test namely the serial correlation, normality and heteroscedasticity. The results show that all the probability values of the aforementioned tests are more than 0.10. Thus, the null hypothesis of no serial correlation, normality and

Figure 2: Stability tests (a) CUSUM (b) CUSUMQ

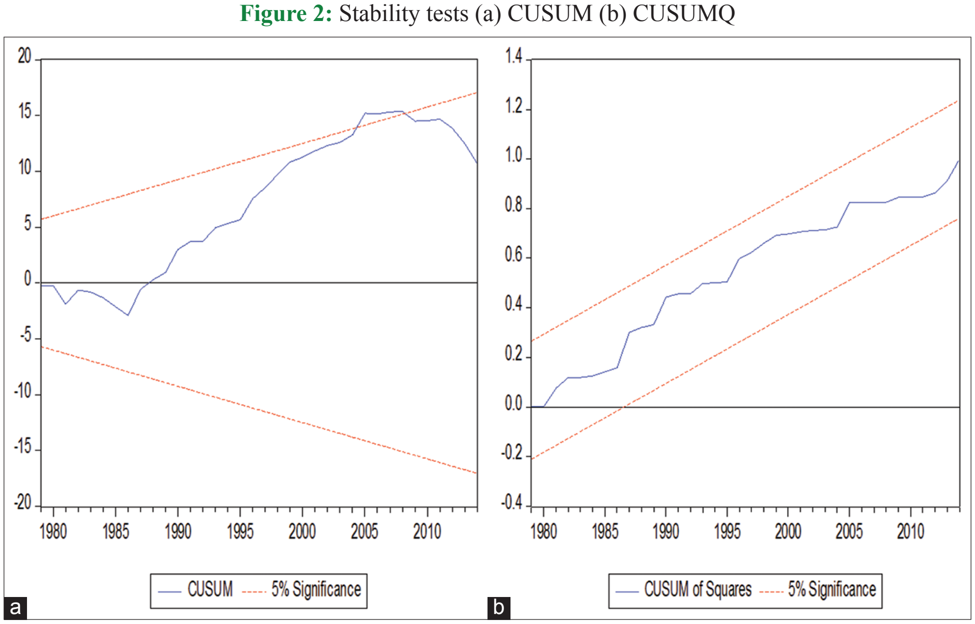


Table 6: Long-run model

Variable	Coefficient	Std. error	t-stats	Prob.
lnctax	−0.0901	0.0395	−2.3035	0.0281**
lnenergy	1.3028	0.0867	15.0286	0.0000***
lnpop	0.2313	0.0471	4.9120	0.0000***

*, **, *** represents 1%, 5% and 10% respectively

Table 7: Error correction models results

Model 1		
Variable	Coefficient	Prob.
ECT	0.8943	0.0000***
C	0.5419	0.0000***

*, **, *** represents 1%, 5% and 10% respectively

Table 8: Diagnostic tests

Model 1	LM	F	Model 2	
			LM	F
Test stat	Prob.	Prob.	Prob.	Prob.
Serial correlation	0.2549	0.3676	0.2080	0.2668
Heteroskedacity	0.7562	0.6988	0.9742	0.9761
Normality	0.8111		0.8975	

*, **, *** represents 1%, 5% and 10% respectively

no heteroscedasticity cannot be rejected. Therefore, all the models are free from heteroscedasticity, serial correlation and the model is normally distributed, implying that the results of the study are robust and reliable.

The stability tests are shown in Figure 2. Figure 2(a) (CUSUM) and 2 (b) (CUSUMQ) is for the model used in the study. The results reveal that CUSUM and CUSUMQ are within the bounds of a 5% level of significance. This implies that the coefficients of the model are stable. Therefore, the models used in this study are stable.

6. CONCLUSION

Does energy use cause carbon dioxide emissions? This question has caused many discussions on the effects of energy use. At the center of this discussion is the ability of energy use to undermine the environment by producing unwanted gases that provide negative externalities to third parties. Simply put, energy use causes carbon emission that causes diseases, drought and deaths. As such the government has embarked on implementing fiscal policies to reduce this epidemic. Among all the fiscal policy instruments, carbon tax has proven to be the most effective and efficient way of minimizing emissions. The association among carbon tax, energy use and carbon dioxide emissions is entangled and cannot be overlooked. Thus, the study investigated the relationship among carbon emission, energy use, carbon pricing in South Africa. Since the connection among energy use, carbon dioxide emissions and carbon tax cannot be ignored, the study investigated the link among these variables from 1970 to 2018 using an autoregressive distributed lag model. The results reveal that population growth and energy use is positively related to carbon emission, while carbon tax reduces carbon emissions.

Based on the study`s results the government should move towards the use of clean energy and set a carbon emission cap. The study can further be extended by adding the inequality variable. Income inequality tends to be influenced by carbon tax.

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