Effect of Economic Growth on Greenhouse Emission

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Abstract

This study employs the panel cointegration and Pooled Mean Group technique to examine the effects of economic growth on greenhouse emissions using the panel data from the period of 1970 to 2014 for five Southern African Development Community groups of countries. The Pooled Mean Group demonstrated mixed results in the study's regressions, monotonic relationship was found between carbon dioxide and economic growth. The existence of relationship between economic growth and energy consumption was found to be significant at the 1% level. These results are in line with the EKC hypothesis, which assumes that as the income level increases the society will start to be environmentally friendly and the technology advancement will decrease the emission of pollutants. In addition, to confirm the causal relationship between variables, the study used the Granger causality test, with the results from this test revealing mainly bi-directional relationship between all the chosen variables. These results are important for policy makers.

Keywords: Economic growth, Environmental Kuznets Curve, Energy Consumption, Carbon Dioxide, Pooled Mean Group.

1. Introduction

Every country wants to maximise its economic activities to maintain and achieve the highest level of sustainable economic development to improve the social welfare of its population (Alabdulrazag & Alrajhi, 2016). However, the maximisation of these economic activities leads to outcomes that can be viewed with positive and negative externalities to the country's' economy. The country's growth negative externalities include but are not limited to air pollution, land pollution, water pollution, and noise pollution, among others. This study focused on examining the effects of economic growth and environmental inequality as a consequence of greenhouse emission. The study focused on selected countries in the Southern African Development Countries region, namely South Africa being the largest emitter of greenhouse gas in the region, Zimbabwe, Mauritius, Botswana and Namibia. Countries were selected based on their economic activities, emission levels and data availability.

Economic growth must be achieved at a time were the environmental impacts trigger negative externalities. During the past decades, countries have been increasing their economic growth rates as this is used to determine the expansion of a country. To this end, countries are aiming for high economic growth, but growth of a country is subject environmental effects. With the significant increase of economic growth reported between the period 1960–2014 across the globe, per capita pollution has shown a major increase of 65% that contributed to the global emission (Jebli & Youssef, 2015). Greenhouse emissions from fossil fuel combustion associated with different economic activities are the major drivers that lead the global climate change (Kohler, 2013). Climate change is the greatest environmental threat to humanity, and it is caused by the build-up of greenhouse gasses from the burning fossil fuels and the destruction of areas that store massive amounts of a carbon like the world's rainforests. For the past two decades, the growth rate of emissions showed a massive increase, and when comparing the two decades the world fossil.

As we enter the era of the most disruptive technology such as the Internet of Things (IOT), Fourth Industrial Revolution (4IR), Smart Cities, 5G, Blockchain technology, amongst others, many countries have tried to develop their economies and move from an agricultural-based economy to an industrialised one. Diffusion of technology, especially in developing countries, is very important as it has the potential to prevent the economies from requiring the same level of resources and same energy inputs per unit of gross domestic product (GDP) (Dinda, 2004). The increase in economic development has led to global warming with carbon dioxide as the main polluter at the centre of the environmental degradation debate (Adu & Denkyirah, 2017). One can conclude that in the presence of advanced technology, environmental inequality can be eliminated while the countries are maintaining economic development.

Achieving sustainable economic growth and promoting economic development calls upon all countries and people of Southern Africa to develop a vision of a shared future, a future within a regional community (Chinyanga, 2019). The Southern African Development Community (SADC) encompasses 16 members that grouped together with the aim of promoting sustainable and equitable economic growth and economic development through efficient productive systems, deeper co-operation and integration, good governance and durable peace and security the among 16 Southern African countries (Southern African Development Community [SADC], 2015). To this end, the SADC region is still believed to be struggling with a high level of land deterioration, high pollution, deforestation and access to clean water. Despite the 5.1% increase in economic growth in the SADC region, it is still believed that environmental effects remain a threat that needs sustainable environmental polices (SADC, 2015).

2. Literature review

The economic literature on the subject of economic growth, energy consumption and environmental pollution is well established. Empirically, relationship between economic growth and environmental inequality have emerged over the last few decades. The first area of research which focuses on pollutant emissions and income is related to testing the validity of the environmental Kuznets curve (EKC) hypothesis. The EKC theoretical model was developed by Simon Kuznets in 1955 in evaluation of the changes between income inequality and per capita income as an inverted U-shape curve. The origin of Kuznets (1955) stated that in the early stages of economic growth the distribution of income is highly unequal but tends to become more equal as the economy develops (Dinda, 2004). Second area, there has been evidence that the environmental degradation and per capita income follows the same U-shape curve of per capita income and income inequality. In the early 1990s, Kuznets extended the hypothesis of per capita income and income inequality by looking at the relationship between environmental quality and per capita income (Sarkodie & Strezov, 2019). Kuznets (1955) became the environmental economist pioneer in formulating the relationship between economic growth and environmental inequality, and the theory which is known as EKC.

The narrow conceptual framework of EKC lies in environmental inequality and economic growth, of which it indicates that at the early stages of economic growth, pollution increases as there is high demand for increasing use of resources and this contributes to the environmental pressure of a country, but when a certain level of income per capita is reached, the environmental inequality starts to decrease at a higher economic development stage, with further economic growth leading to the improvement of the environment inequality (Ginevičius, Lapinskienė & Peleckis, 2016). Kuznets (1955) hypothesised that income inequality first rises and then falls as there is development in the country's economy (Stern, 2004).

The EKC phenomenon has raised many questions amongst economists' contributors and as a result, many studies (Pearson, 1994; Arrow et al., 1995; Stern, Common & Barbier, 1996; Ansuategi, Barbier & Perrings, 1996) have been conducted in reviewing the EKC origin. The main critique that has been raised by many researchers is the weakness in the econometrics techniques that are used to find the U-shape relationship between environmental quality and economic growth. The inverted U-shape relationship has been found in a few subsets of environmental indicators such as carbon dioxide, methane, air pollution. Stern et al. (1996) identified some problems in the basic EKC model and in the interpretation of the model – some of the problems include econometrics techniques used, data availability of environmental indicators, mean and median income, aggravations of other environmental problems, and ambient concentrations versus emissions.

Testing EKC has been increasing over the years as the theory predicts that economic growth is the solution for environmental impacts with no policy or regulation being implemented. The various studies of Panayotou (1993), Stern (2004) and Dinda (2004) conducted on finding the existence of EKC have contributed to the theoretical framework of the EKC model by finding the existence between income inequality and environmental quality. Numerous writers used different econometric methodologies and different data sets to find the existence the EKC model. However, it has been found that many studies employed cross-sectional (Kasman & Duman, 2015; Das, Chowdhury & Akhtaruzzaman, 2012; Kohler, 2013), and time-series (Pikoko & Phiri, 2019; Kohler, 2013; Benavides, Ovalle, Torres & Vinces, 2017) data sets to evaluate the relationship between income inequality and environmental pollutants.

In examining the environmental quality nexus economic growth in the developed countries, studies by Iwata, Okada and Samreth (2009) for France, Halicioglu (2009) for Turkey, Shahbaz, Dube, Ozturk and Jalil (2015) for Portugal, Bildirici (2016) for

USA, Benavides et al. (2017) for Austria, Baek (2015) for Arctic countries, and Cho, Chu and Yang (2014) for 22 OECD countries, confirmed the presence of the Environment Kuznets Curve hypothesis in their surveyed countries and these findings confirm the Environmental Kuznets Curve hypothesis.

In addition, many studies (Hamit-Haggar, 2012; Farhani, Chaibi & Rault, 2014; Lean & Smyth, 2010; Ahmad et al., 2016) that support the existence of EKC have been carried out for the past years focusing on the greenhouse gas emissions and economic development. These studies have been conducted using the time series data to test the economic relationship between energy consumption and economic growth. The EKC model was confirmed in these studies in a long-run relationship. The results reveal a positive impact in the short run and long run of economic growth and carbon emissions.

On the other hand, most developing countries failed to validate the EKC hypothesis, as proven by the research work of Inglesi-Lotz and Bohlmann (2014) for South Africa, Hilaire and Fotio (2015) for Cameroon, Congo, Gabon and Democratic Republic of Congo and Adu and Denkyirah (2017) for West Africa countries.

However, work by Farhani et al. (2014) for Tunisia; Osabuohien, Efobi and Gitau (2014) for 50 African countries; Hilaire and Fotio (2015) for Cameroon, Congo, Gabon and Democratic Republic of Congo; Zambrano-Monserrate, Valverde-Bajaña, Aguilar-Bohórquez and Mendoza-Jiménez (2016) for Brazil; Ahmad and Du (2017) for Iran; Mapapu and Phiri (2018) for South Africa; and Sunde (2018) for Namibia, support the presence of the EKC hypothesis in the developing countries.

It is evident from the reviewed studies that the Kuznets hypothesis relationship between the environmental inequality and per capita incomes reveals mixed results. A vast number of studies conducted found the existence of the EKC model while other studies did not confirm the existence of the EKC model, because of the different methodologies that the researchers employed in conducting their different studies and also in terms of the data sets used by different authors.

3. Research methodology

3.1 Data

The yearly panel data for the years 1970 to 2014 from the World Bank Development Indicators was collected to test the hypothesis of EKC, reliability, and validity of the econometrics model. The data sets used in this study to test the regression model are the secondary. The study utilised a quantitative approach because it deals with numerical analysis of data (Wiid & Diggines, 2013).

Description of variables and Data Sources

Variables	**Units**	**Description**	**Source**	**Notation**	**Expected Outcomes**
Carbon dioxide	Metrics tons per capita	Carbon Emission (CO2kt) carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement.	World bank	CO_2	Depended variable

GDP	GDP per capita (LCU)	The GDP per capita in 2012, measured in 2016 value US dollars.	World bank	GDP	+
GDP Squared	Measured in local currency	The variable GDP squared.	World bank	GDP^2	-
Energy consumption	Fossil fuel energy consumption (matt-hours)	Fossil fuel energy consumption comprises of oil, coal, petroleum and natural gas products.	World bank	EN	+

3.2 Data Analysis Method

Before estimating the Pooled Mean Group (PMG) cointegration model, it is important to test for unit roots. This is an important step since the PMG model can only be used if all the time series variables being modelled are integrated in the order of I (0) and I (1), and not integrated in the order higher than I (2). Panel unit root tests are designed to evaluate the null hypothesis that each individual in the panel has integrated time series versus the alternative hypothesis that all individual time series are stationary. Therefore, this study employed three panel unit root tests, namely Levin, Lin & Chu (LLC), Im, Pesaran & Shin (IPS) and Fisher-ADF to verify whether variables have a unit root. Moreover, the normality test is used to check the normal distribution of the collected data. After the stationary test the study proceeded by attempting to establish the existence of a long-term cointegration among the variables. For this exercise, the study used the Pedroni (2004) cointegration test and Kao (1999) cointegration test.
Hence, after the authors confirmed the stationarity of variables and normality test the log-linear quadratic form is employed to analyse the effects of economic growth and greenhouse emissions. In this context, two regressions are used to determine the relationship between economic growth and greenhouse emissions.

$$CO_{2,it} = \alpha_0 + \beta_1 GDP_{it} + \beta_2 GDP^2{}_{it} + \beta_3 EN_{it} + \varepsilon_{it} \quad \text{.........1}$$

$$EN_{it} = \alpha_0 + \beta_1 GDP_{it} + \beta_2 GDP^2{}_{it} + \beta_3 CO_{2,it} + \varepsilon_{it} \quad \text{.........2}$$

The above equations were then transformed into a natural logarithmic form. The log-linear specification is superior, interprets elasticities directly and gives better, efficient and consistent results and helps in overcoming the heteroscedasticity problems (Ahmad & Du, 2017; Benavides et al., 2017; Sunde, 2018).

$$LCO_{2,it} = \alpha_0 + \beta_1 LGDP_{it} + \beta_2 LGDP^2{}_{it} + \beta_3 LEN_{it} + \varepsilon_{it} \quad \text{.........3}$$

$$LEN_{it} = \alpha_0 + \beta_1 LGDP_{it} + \beta_2 LGDP^2{}_{it} + \beta_3 LCO_{2,it} + \varepsilon_{it} \quad \text{.........4}$$

As per the EKC hypothesis, it is expected that the GDP will positive, square root of GDP will be negative and energy consumption will be positive. This implies that as the economy grows, emissions/pollutions also rise initially, but later as the economy continues to grow the environmental quality improves (Shahbaz et al., 2015; Baek, 2009; Ali et al., 2017; Sunde, 2018).
In this study the Pooled Mean Group was presented in the following models.

$$\Delta LCO_{2,t} = \alpha_1 + \sum_{i=1}^{n} \beta_{1i} \Delta LCO_{2t-i} + \sum_{i=0}^{n} \beta_{2i} \Delta LGDP_{t-i} + \sum_{i=0}^{n} \beta_3 \Delta LGDP^2{}_{t-i} + \sum_{i=0}^{n} \beta_4 \Delta LEN_{t-i} + \delta_1 \Delta LCO_{2t-1} + \delta_2 \Delta LGDP_{t-1} + \delta_3 \Delta LGDP^2{}_{t-1} + \delta_4 \Delta LEN_{t-1} + \varepsilon_{1t} \quad \text{.........5}$$

$$\Delta LEN_t = \alpha_1 + \sum_{i=1}^{n}\beta_{1i}\Delta LEN_{t-i} + \sum_{i=0}^{n}\beta_{2i}\Delta LGDP_{t-i} + \sum_{i=0}^{n}\beta_3\Delta LGDP^2{}_{t-i} + \sum_{i=0}^{n}\beta_4\Delta LCO_{2t-i} + \delta_1\Delta LEN_{t-1} + \delta_2\Delta LGDP_{t-1} + \delta_3\Delta LGDP^2{}_{t-1} + \delta_4\Delta LCO_{2t-1} + \varepsilon_{1t}$$

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Where, Δ represents the first difference operator, α_1 represents the constant, n shows the number of optimal lag order, and ε_{1t} is the white noise error term. β_1 and β_4 represent the error correlation dynamics. The second part in the equation from δ_1 to δ_4 drift is drift components which explain that the long run dynamics among the variables in the model and the short error correction are represented by the summation sign.

The study included the ECT in the models.

$$\Delta LCO_{2,t} = \alpha_1 + \sum_{i=1}^{n}\beta_{1i}\Delta LCO_{2t-i} + \sum_{i=0}^{n}\beta_{2i}\Delta LGDP_{t-i} + \sum_{i=0}^{n}\beta_3\Delta LGDP^2{}_{t-i} + \sum_{i=0}^{n}\beta_4\Delta LEN_{t-i} + \phi LECT_{t-1} + \varepsilon_{it}$$

$$\Delta LEN_t = \alpha_1 + \sum_{i=1}^{n}\beta_{1i}\Delta LEN_{t-i} + \sum_{i=0}^{n}\beta_{2i}\Delta LGDP_{t-i} + \sum_{i=0}^{n}\beta_3\Delta LGDP^2{}_{t-i} + \sum_{i=0}^{n}\beta_4\Delta LCO_{2t-i} + \delta_1\Delta LEN_{t-1} + \delta_2\Delta LGDP_{t-1} + \delta_3\Delta LGDP^2{}_{t-1} + \delta_4\Delta LCO_{2t-1} + \phi LECT_{t-1} + \varepsilon_{1t}$$

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The Granger causality test was applied in the study to identify the causal relationship among the series in the model. The empirical equations of the VECM model are expressed in the following form:

$$\Delta LCO_{2,t} = \alpha_1 + \sum_{i=1}^{n}\beta_{1i}\Delta LCO_{2t-i} + \sum_{i=0}^{n}\beta_{2i}\Delta LGDP_{t-i} + \sum_{i=0}^{n}\beta_3\Delta LGDP^2{}_{t-i} + \sum_{i=0}^{n}\beta_4\Delta LEN_{t-i} + \phi_1 LECT_{t-1} + \varepsilon_{it}$$

$$\Delta LGDP_t = \alpha_2 + \sum_{i=1}^{n}\beta_{1i}\Delta LGDP_{t-i} + \sum_{i=0}^{n}\beta_{2i}\Delta LCO_{2t-i} + + \sum_{i=0}^{n}\beta_3\Delta LGDP^2{}_{t-1} + \sum_{i=0}^{n}\beta_4\Delta LEN_{t-i} + \phi_2 LECT_{t-1} + \varepsilon_{it}$$

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$$\Delta LGDP^2{}_t = \alpha_3 + \sum_{i=1}^{n}\beta_3\Delta LGDP^2{}_{t-i} + \sum_{i=0}^{n}\beta_{1i}\Delta LCO_{2t-i} + \sum_{i=0}^{n}\beta_{2i}\Delta LGDP_{t-i} + \sum_{i=0}^{n}\beta_4\Delta LEN_{t-i} + \phi_3 LECT_{t-1} + \varepsilon_{it}$$

$$\Delta LEN_t = \alpha_4 + \sum_{i=1}^{n}\beta_{1i}\Delta LEN_{t-i} + \sum_{i=0}^{n}\beta_{2i}\Delta LCO_{2t-i} + \sum_{i=0}^{n}\beta_{3i}\Delta LGDP_{t-i} + \sum_{i=0}^{n}\beta_{4i}\Delta LGDP^2{}_{t-i} + \phi_4 LECT_{t-1} + \varepsilon_{it}$$

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4. Estimation and interpretation of the results

This section presents the estimation and interpretation of results: summary of statistics, unit root, cointegration tests, pooled mean group, granger causality test.

4.1 SUMMARY OF STATISTICS PER COUNTRY

The table below is a summary of the descriptive statistics for carbon dioxide (LCO2), gross domestic product (LGDP), energy consumption (LEN) and gross domestic product square (LGDPSQ). The results from the Jarque-Bera test show that the data is normally distributed which indicates that the data has skewness and kurtosis matching a normal distribution.

	LCO2	LGDP	LGDPSQ	LEN
Mean	9.236680	8.996704	84.41985	4.075456
Median	8.350363	9.264821	85.83711	4.153269
Maximum	13.12857	12.64732	159.9548	4.505419
Minimum	6.219355	5.876876	34.53768	3.164291
Std. Dev.	2.112358	1.870340	33.65319	0.351007
Skewness	0.727568	-0.044187	0.231794	-0.640037
Kurtosis	2.167824	1.849201	2.078512	2.441206
Sum	1699.549	1655.394	15533.25	749.8839
Sum Sq. Dev.	816.5560	640.1653	207254.3	22.54665
	Probability	Jarque-Bera	Std-dev.	Observation
Normality test	0.00000	133.7771	0.021159	169

4.2 Correlation

The table below represents the correlation matrix among the coefficients of the variables. Correlation measures the degree of association between the variables. It measures the direction and strength among the variables. The coefficients of the variables in the table range between negative 1 and positive 1, demonstrating that the variables may not cause a severe multicollinearity problem and showing the diagnose line across the table.

Correlation

Variables	**LEN**	**LGDP**	**LGDPSQ**	**LCO2**
LEN	1.000000	0.631963**	0.609864**	0.457030*
LGDP	0.631963**	1.000000	0.995437***	-0.133479*
LGDPSQ	0.609864**	0.995437***	1.000000	-0.136248*
LCO2	0.457030*	-0.133479*	-0.136248*	1.000000

*Notes: *** significant at level 1%, ** significant at level 5%, and * significant at level 10%*

Source: Author's computation based on EViews9

4.3 Panel unit root test

The results for LLC, IPS and Fisher-ADF unit root test are presented in the table below, showing that at levels not all the variables are stationary. The null hypothesis of non-stationary at levels in the variables is not rejected at levels, and therefore, it was important to check the stationarity of all the variables at first difference.

Variables	**Levin, Lin & Chu**	**Im, Pesaran & Shin**	**Fisher-ADF**
	Intercepts and Trends	**Intercepts and Trends**	**Intercepts and Trends**
Carbon Dioxide	0.0000	0.0000	0.0000
	(13.0748)***	(14.9985)***	(288.019)***

Variables	Levin, Lin & Chu	Im, Pesaran & Shin	Fisher-ADF
	Intercepts and Trends	**Intercepts and Trends**	**Intercepts and Trends**
GDP	0.8525	0.9987	0.9151
	(1.04723)	(3.02236)	(4.61890)
GDP^2	0.9793	0.9604	0.5788
	(2.03866)	(1.75484)	(8.51410)
Energy Consumption	0.2939	0.4490	0.3644
	(0.54216)	(0.12819)	(10.9120)

Note: statistics are given in parenthetic
*Notes: *** significant at level 1%, ** significant at level 5%, and * significant at level 10%*
Source: Author's computation based on EViews 9

Unit root test at first difference

The panel unit root tests at levels failed to reject the null hypothesis and thus the first difference was employed to check the stationarity of all the variables. With all the panel unit root tests performed, the variables show stationarity in both intercepts and intercepts & trends in LLC, IPS and Fisher-ADF. All the variables are stationary and significant at the 1% level. Therefore, the null hypothesis is rejected, and the alternative null hypothesis accepted. The results suggest that none of the variables are integrated in order I (2) or the higher level of integration. Therefore, we could proceed to test the long-run cointegration test and check the short-run and long-run relationship in Pooled Mean Group.

Unit root test at first difference

Variables	Levin, Lin & Chu	Im, Pesaran & Shin	Fisher-ADF
	Intercepts and Trends	Intercepts and Trends	Intercepts and Trends
	Null hypothesis: Unit root (assume common unit root process	Null hypothesis: Unit root (assumes individual unit root process)	
Δ Carbon Dioxide	0.0000	0.0000	0.0000
	(20.4060)***	(19.2308)***	(358.914)***
ΔGDP	0.0000	0.0000	0.0000
	(6.91943)***	(7.93350)***	(69.8075)***
ΔGDP^2	0.0000	0.0000	0.0000
	(7.12709)***	(7.82546)***	(68.4127)***
Δ Energy Consumption	0.0000	0.0000	0.0000
	(10.6071) ***	(10.0510)***	(91.9530)***

Note: statistics are given in parenthetic

*Notes: *** significant at level 1%, ** significant at level 5%, and * significant at level 10%*

Source: Author's computation based on EViews 9

4.4 Cointergration test

The study employed the cointegration test proposed by Pedroni (2004) and Kao (1999) to test the long -run relationship between the variables. The Pedroni (1999) cointegration test is based on seven statistics of which the first four are based within-dimension and the last three statists are based between-dimension. Tables 8 and 9 show the cointegration results from Pedroni and Kao. In regression (A) the results from the Pedroni cointegration test reveals that the null hypothesis of no cointegration in both panel-ADF statistics and group-ADF statistics is rejected. The Kao residual cointegration in regression (A) also shows that the null hypothesis of no cointegration at 1% level of significance is rejected and this tells us that the variables have a strong evidence of long-run relationship.

Pedroni cointegration test

Regression A: $LCO = LGDP + LGDP2 + LEN$ Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	0.539698	0.2947	0.469593	0.3193
Panel rho-Statistic	-1.990724	0.0233	-1.802342	0.0357
Panel PP-Statistic	-3.937943	0.0000	-3.610036	0.0002
Panel ADF-Statistic	-3.882426	0.0001	-3.460955	0.0003
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	-0.807133	0.2098		
Group PP-Statistic	-3.482072***	0.0002		
Group ADF-Statistic	-3.443955***	0.0003		

Notes: ***, ** and * imply significance level at 1%, 5% and 10% respectively

Kao test regression A

Series	ADF-Statistics	
	Statistics	Prob
LCO2= LGDP+ LGDPSQ + LEN	-3.069128***	0.0011

Notes: ***, ** and * imply significance level at 1%, 5% and 10% respectively

In regression (B) both the Pedroni (2004) and Kao (1999) cointegration tests reveals that the null hypothesis at 1% level of significance is rejected and thus the variables have a long run relationship. It is concluded that the variables have a long-run relationship based on the Pedroni cointegration test and Kao test. The study further employed the PMG approach to determine the appropriate signs and size of the coefficient and check the magnitude of the relationship between the variables.

Pedroni cointegration test regression 2

Regression B: $LEN = LGDP + LCO2 + LGDP2$				
Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	-0.382135	0.6488	0.434591	0.3319
Panel rho-Statistic	-0.449892	0.3264	-1.164008	0.1222
Panel PP-Statistic	-2.956449***	0.0016	-2.928353***	0.0017
Panel ADF-Statistic	-2.946110***	0.0016	-2.882335***	0.0020
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	-0.537747	0.2954		
Group PP-Statistic	-2.971796***	0.0015		
Group ADF-Statistic	-2.940746***	0.0016		

Notes: ***, ** and * imply significance level at 1%, 5% and 10% respectively

Kao test regression 2

Series	ADF-Statistics	
	t-Statistics	Prob
EN= GDP + CO2 + GDP2	-2.390523***	0.0084

Notes: ***, ** and * imply significance level at 1%, 5% and 10% respectively

4.5 Pooled Mean Group Results

4.5.1 PMG regression (A) results

The table below represents the long-run and short-run estimations for regression (A). In the long-run estimation GDP is positively related with carbon emissions but statistically insignificant. The positive relation between the GDP and CO2 suggests that more economic activities are performed that lead to a higher level of carbon emissions which consequently leads to a higher level of environmental pollution. Similarly, these results were found in the study conducted by Muftau, Iyoboyi and Ademola (2014). The positive relationship between GDP and greenhouse gas emissions is expected to be positive more in developing countries where most production takes place and contributing to dangerous gas emissions.

Furthermore, the negative sign of the GDP square coefficient is supported by Kuznets (1955) in his hypothesis that various indicators of environmental pollution tend to worsen as the economy develops until it reaches a certain threshold and starts to decrease. In this regression, it can be concluded that the monotonic relationship exists. This means that CO2 increases or decreases monotonically with regard to GDP. The turning point is 34.94% which is greater than the maximum 13% CO2 per capita in statistics.

The long-run coefficient of the energy consumption is positively related with carbon emissions and is statistically significant at 1% level. This indicates that the higher energy consumption will lead to higher carbon emissions. These results are consistent with the study conducted by Saboori and Sulaiman (2013). In addition, energy consumption contributes to carbon emission more in the long run than in the short run. If the energy consumption in the short run increases by 1%, the carbon emission will increase by 0.91%, and it will increase by 2.03% in the long run. These findings support the ongoing empirical evidence that energy consumption has a positive impact on carbon emission and causes greater potential damage in environmental quality especially in developing countries because of the increasing rate of industrialisation (Sasana & Eka Putri, 2018). Thus, this implies that the carbon emission level as a consequence of energy consumption is found to be increasing over time in this study's selected countries – South Africa, Zimbabwe, Namibia, Mauritius and Botswana.

PMG results

Dependent variables D(LCO2)		
Exploratory variables	**Coefficient**	**Prob**
Long-run coefficient		
LGDP	0.224169	0.2940
LGDPSQ	-0.00321	0.7653
LEN	2.036461	0.0000
Turning point Turning point: $Y^* = -\frac{\beta_1}{2\beta_2} Y^* = -\frac{\beta_1}{2\beta_2}$	34.92%	
Short-run coefficient		
COINTEQ01	-0.445087	0.0001
D(LGDP)	-5.66054	0.026
D(LGDPSQ)	0.333455	0.0201
D(LEN)	0.913521	0.0035
C	-0.798383	0.1081
Akaike info criterion (AIC)		

4.5.2 PMG regression B results

The PMG results for regression (B) are shown Table 13 below. The long-run estimations of GDP show that it is positively related with the energy consumption and is statistically significant at the 5% level. In effect, ceteris paribus, a 1% change in GDP will lead to a 20% change in the energy consumption. The GDP square coefficient is negative and statistically significant at the 5% level. This follows the EKC hypothesis model which states that at the initial stages of economic development there is income inequality but as the economy grows it will reach a certain level and turn down. This shows an inverted U-shaped EKC curve as proposed by Kuznets (1955), an extension of EKC supported by (Grossman & Krueger, 1991). The carbon emission as exploratory variable shows the positive relationship with energy consumption and is statistically significant at the 1% level. Consequently, this indicates that as the greenhouse emission occurs, the energy consumption increases at the same time. The turning point is 12.85% which is greater than the mean value of 4.3% of energy consumption. The error term in the short-run estimations shows a negative sign and is statistically significant at the 5% level. This indicates an adjustment of about 45% in a year when the disequilibrium takes place.

POOLED MEAN GROUP REGRESSION RESULTS

Dependent variables (LEN)		
Exploratory variables	**Coefficient**	**Prob**
Long-run coefficient		
LGDP	0.200184	0.0312
LGDPSQ	-0.007789	0.0410
LCO2	0.236903	0.0000
Turning point: $Y^* = -\frac{\beta_1}{2\beta_2} Y^* = -\frac{\beta_1}{2\beta_2}$	12.85	
Short-run coefficient		
COINTEQ01	-0.453358	0.0332
D(LGDP)	1.113758	0.4627
D(LGDPSQ)	-0.077455	0.3087
D(LCO2)	0.053187	0.5617
C	0.469791	0.0685
Model section method: Akaike info criterion (AIC)		

Granger causality test

Uni-directional causality exists between GDP and carbon dioxide – the results support the growth hypothesis and other similar studies (Benavides et al., 2017; Minihan & Wu, 2012; Akbostanci et al., 2011). This means that as GDP increases it also causes the carbon emission to increase, which was mentioned earlier in this study, namely that an increase in economic growth of a country is subject to a negative environmental effect. From the empirical results, there is no evidence that an increase in carbon emissions causes an increase in GDP. Between GDP square and CO2, the null hypothesis is rejected, and it can be concluded that unidirectional causality exists between the variables, with no causality between CO2 and GDP square.

There is evidence of bidirectional causality between energy consumption and carbon dioxide. These results confirm that any change in the degree of pollution has a significant influence on the trends of the combustion of fossil fuels in a country. Regarding uni-directional causality found between GDP and energy consumption, the feedback from these variables means that the economic growth has a strong influence on the amount of energy consumption, which is consistent with findings from Kasman and Duman (2015) and Hamit-Haggar (2012). The absence of no causality from energy consumption to GDP suggests that the clean energy policy measures can be implemented without jeopardising economic growth plans. The null hypothesis is rejected, and it can be concluded that there is unidirectional causality between GDP squared and energy consumption.

GRANGER CAUSALITY TEST

Null Hypothesis	F-Statistic	Prob.	Type of causality
LGDP →LCO2	6.34358	0.0022***	Unidirectional
LCO2 → LGDP	0.73316	0.4818	No causality
LGDPSQ →LCO2	4.31204	0.0148***	Unidirectional
LCO2 →LGDPSQ	0.86574	0.4225	No causality
LEN →LCO2	5.95013	0.0032***	Bidirectional
LCO2 →LEN	2.56494	0.0798	Bidirectional
LGDPSQ →LGDP	0.03320	0.9674	No causality
LGDP →LGDPSQ	0.81816	0.4428	No causality
LEN →LGDP	0.74049	0.4784	No causality
LGDP →LEN	5.74364	0.0039***	Unidirectional
LEN →LGDPSQ	0.54268	0.5822	No causality
LGDPSQ →LEN	5.65153	0.0042***	Unidirectional

Notes: ***, ** and * imply significance level at 1%, 5% and 10% respectively

5. Conclusion

This study investigated the effects of economic growth on greenhouse emissions in five selected SADC countries, namely South Africa, Zimbabwe, Mauritius, Botswana and Namibia. The studies that have examined this relationship between economic development and environmental quality showed mixed empirical evidence. Based on the empirical results, the variables were found to be stationary at levels and statistically significance at 1%. The results from Pedroni (2004) and Kao (1997) demonstrated a long-run relationship between the variables.

Specifically, the study tested the existence of the EKC hypothesis. The results from Pooled Mean Group reveal two relationships that exists, namely 1) the monotonic relationship was found in the first regression which suggests that the origin of the EKC will not hold in the long run. Rather, beyond a certain income level, increased income might once again lead to a positive relationship between economic development and environmental inequality.

Of interest, the second model the EKC has been confirmed and is statistically significant at the 5% level. Indeed, these results show that the increase of economic growth has a significant negative effect on greenhouse emission. This means these results support the phenomenon developed by Simon, and hence the energy consumption increases as the economy grows, then stabilises, and then starts to decrease. The results from Granger causality test indicate that bidirectional and unidirectional causality has been found between the variables and the null hypothesis is rejected. Unidirectional causality was found between GDP, GDPSQ to CO2, GDP, and GDP squared to energy consumption. The bidirectional causality was found only between energy consumption and carbon dioxide.

Several policies can be deduced from the outcomes of this study. The amount of emissions that contribute to the environmental inequality needs strong institutions to enact effective policies, rules and regulations that will support sustainable development and will contribute to reduction of environmental degradation as this imposes global environmental threats. Policy makers need to have productive processes for firms and citizens in the quest for being more environmentally conscious. Moreover, there is a need for strict enforcement of environmental laws and companies need to see this as a corporate social responsibility. Government also needs to find ways of incentivising those industries that adopt emission efficient techniques. The results of energy consumption contributing to environmental inequality calls for policy makers to reform their energy polices to promote renewable energy polices and other energy-efficient polices to reduce environmental pollution. By doing, the implication of these effective polices would bring about an eco-friendlier environment while maintaining sustainable economic growth.

Finally, this study found that a positive relationship exists between economic growth and greenhouse emissions, which raises the alarm for policy makers to promote an eco-friendly environment while maintaining economic growth. In this way, advanced technology can play a significant role in reducing greenhouse emissions. The policy makers need to devise proper strategic energy investment planning to control the effects of environmental degradation in our economies over the long-term period.

The researcher of this study used carbon emission and energy consumption as the indicators of environmental inequality. The fact is nitrous oxide and methane have shown a significant contribution to the percentage of pollutants that contribute to the global carbon. A greater contribution can thus be made if other researcher uses these environmental indicators in their studies. The major gap in the evaluation of environmental threats is the observation of the sample from sea level, ocean temperature, atmospheric temperature, snow and ice reduction as these variables are seen as the prominent indicators of global warming. The use of these variables would have drawn conclusions that are not in line with the objectives of this study. Therefore, for future studies focusing on environmental threats these variables can be used to bring greater evidence of the contribution of climate change.

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