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The Causal Links between Urbanization, Energy Use and Carbon Emissions: A Case of SADC Region

Pendo T Kivyiro
Institute of Finance Management, P.O. Box 3918, Dar es Salaam, Tanzania.
E-mail: pendo.kivyiro@ifm.ac.tz
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Abstract

The study aimed at examining the causal links between urbanization, energy consumption and carbon emissions in the case of selected SADC countries. The study employed annual time series data spanning from 1988 to 2020 extracted from the World Bank Development indicator Databank. A Pedroni cointegration test was employed to test whether the variables of interest move together in the long run. Granger causality backed with Full Modified Ordinary Least Squares (FMOLS) was used to detect the direction and the nature of causality among the variables of interest. The results from Pedroni cointegration test revealed that the variables move together in the long run. Granger causality results indicate bidirectional causality among the three variables in the short-run and one way Granger causality running from both energy consumption and urbanization to carbon emission in the long-run. Furthermore, the FMOLS shows the positive contribution of both energy consumption and urbanization to carbon dioxide emissions. The results from the empirical work make some significant contribution to the existing body of knowledge and to the policy makers and urban planners of SADC region. Policies in this region should focus on finding coherent ways of discouraging movements of people from rural areas to urban areas. This can be done by making rural environment conducive enough to motivate people to engage in agricultural activities.

Keywords: Urbanization; Energy Consumption; Carbon Emissions, SADC region.

Introduction

The persistent increase in the urban population has been acknowledged to be among of the trending issues of the twenty first century discussed by numerous scholars in the current era (See, e.g., Hossain 2011, Al-Mulali et al. 2012, 2013, Wang et al. 2016a, 2016b). The situation is tense in the vast majority of developing regions and countries in the Southern African Development Community (SADC) region are no exception. SADC has been experiencing rapid growth in some cities and megacities and the vast majority of the people are migrating from rural to urban areas for the sake of exploring some social and economic opportunities believed to be pervasive in urban areas as compared to rural areas. According to Brandt et al. (2017), more than 70% of Africa's population is expected to be living in cities (most specifically in slums) by the year 2025. So far, there are numerous emerging mega cities in the Sub Saharan region and these include among others Lagos, Kinshasa, Luanda, and Johannesburg (Chishakwe 2010, Businesswire 2016). A mega city is defined as an urban area with a population of more than 8 million and a gross domestic product (GDP) of at least $250 billion. However, the growth of mega cities places severe concerns on economic, social resources and on environment. Furthermore, the shift from agricultural activities to urban related activities is also linked to the persistent increase in energy use which may also lead to an increase in carbon emissions (Al-Mulali et al. 2015, Wang et al. 2016a, 2016b). Therefore, the study sought to examine the causal links among urbanization, energy consumption and carbon emissions in Southern African Development Community (SADC) countries. The main objective of the community among others is to strengthen economic cooperation among member states. Currently, the region consists of sixteen (16) member states; Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, United Republic Tanzania, Zambia and Zimbabwe. However, the present study is geared to examine the relationships among the variables of interest in a panel of only eight member states, which are undergoing rapid urbanization. Another coherent reason for the choice of these countries is due to data availability. To the best of the author's knowledge, this is the first study of its kind in this specific region. As it has been pointed our earlier, the main focus of interest of the current study is to examine the causal links among urbanization, energy consumption and carbon emissions. Specifically, the study sought to examine whether urbanization Granger cause energy consumption and vice versa but also whether there exists bi-directional Granger causality between urbanization and carbon emissions. Furthermore, the study examined whether energy consumption has significant positive impacts on carbon emissions and vice versa.

The results from this study and recommendations will assist policy makers and urban planners of this specific region to come up with appropriate and coherent policies and structures.

Literature Review

Due to predicament caused by climate change plaguing the globe in the current era, there has been paramount of research investigating the causes of this ordeal. Global warming has been singled out to be among the factors responsible for such massive changes in climate. On the other hand, numerous factors have also been mentioned to contribute to global warming. These factors include among others; greenhouse gases emissions, urbanization, energy use and economic growth. There have been numerous theories developed in the past to explain the nature of relationships between environmental degradation and some macroeconomic indicators. One of those theories is the so called Environment Kuznets Curve (EKC) which was developed by Grossman and Krueger (1991). The hypothesis proclaims an inverted U-shape relationship between environmental pollution and economic development. According to EKC, environmental degradation is pervasive at initial stages of economic development of a particular country. But after a certain threshold, a reverse can be revealed.

Ozatac et al. (2017) investigated the validity of Environmental Kuznets Curve for the case of Turkey using time series data spanning from 1960 to 2013. The sample employed four variables, namely energy consumption, trade, urbanization, and financial development. The results from this specific study indicated the validity of EKC, and Granger causality analysis indicated some causal relationships among the variables of interest. Katircioğlu and Katircioğlu (2018) investigated the role of urbanization in the conventional EKC framework. The results of this specific study indicated the energy consumption to be a significant factor that has contributed to air pollution. However, the results did not find the validity of EKC in the case of Turkey. Gungor and Simon (2017) investigated the relationships between energy consumption, financial development, economic growth, industrialization and urbanization in the case of South Africa for the period between 1970 and 2014. The study employed Johansen co-integration test, vector error correction model and Granger causality analysis. The results indicated a long equilibrium relationship between the variables of interest, and Granger causality showed bi-directional relationships between industrialization and energy utilization, financial development and energy consumption, and between financial development and industrialization.

Numerous studies have also been conducted to investigate the causal links among urbanization, energy use and carbon emissions in various regions (Liddle and Lung 2010, Zhu et al. 2012, Sadorsky 2013, 2014, Ponce de Leon Barido and Marsha 2014, Shahbaz et al. 2015, Chikaraishi et.al. 2015, Rafiq et al. 2016, Sheng and Guo 2016, Wang et al. 2016a, 2016b, Liddle and Sadorsky 2017, Effiong 2018). The results in these extant literatures are however mixed with regard to the direction of causality among the variables of interest (See, e.g., Zhu et al. 2012, Shahbaz et al. 2016, Rafiq et al. 2016, Wang et al. 2016a, 2016b).

Shahbaz et al. (2016) found a U-turn relationship between urbanization and carbon emissions whereby urbanization was found to Granger cause carbon emissions. Rafiq et al. (2016) analyzed the impacts of urbanization and trade openness on emissions and energy intensity in a sample of 22 increasingly urbanized emerging economies. The results indicated that population density and affluence increase emissions and energy intensity while renewable energy seems to be scant and urbanization was found to be insignificant in impacting emissions. Wang et al. (2016a) examined the relationships between urbanization, energy use and carbon dioxide emission for the case of ASEAN countries using time series data covering the period between 1980 and 2009. The results from this specific study indicated significant effects of urbanization on energy use and carbon emissions. Granger causality results indicated a bi-directional causality relationship between energy use and carbon dioxide emission. Zhu et al. (2012) examined the relationship between urbanization and CO_2 emissions in a sample of 20 emerging countries over the period between 1992 and 2008 using the semi-parametric panel data model with fixed effect model. The study found little evidence in support of an inverted-U curve, and thus the Kuznets hypothesis was not validated by the analysis. The study also found nonlinear relationship between urbanization and CO_2 emissions.

Shabhazi (2015) investigated the impact of urbanization on energy consumption by applying the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) in the case of Malaysia for the period between 1970Q1 and 2011Q4. The results validated the existence of long run relationships among the variables of interest and urbanization was found to be a major contributor of energy consumption. The causality analysis found that urbanization Granger causes energy consumption. The feedback effect was found between energy consumption and affluence and, energy consumption and capital. The bidirectional causality exists between trade openness and energy consumption. Chikaraishi et al. (2015) proposed an alternative conceptual and analytical framework to identify the environmental impacts of urbanization, where urbanization was treated as a moderating factor by employing the latent class STIRPAT model. The main empirical findings indicated that urbanization could make countries more environmentally friendly when the country's GDP per capita and the percentage share of service industries in GDP are sufficiently high. Ponce de Leon Barido and Marshall (2014) investigated how CO_2 emissions are affected by urbanization and environmental policy by employing the panel data for the period between 1983 and 2005. Random-and fixed-effects models indicated that, on the global average, the urbanization has a significant positive impact on carbon emissions. Cetin (2018) investigated the validity of EKC hypothesis and the effect of green energy on CO_2 emissions in the case of emerging economies. The sample consisted of data spanned from 1990 to 2011. The results from this specific study supported that validity of EKC in the case of developed economies and not in emerging economies. Furthermore, the results indicated that renewable energy is one of the viable options to mitigate persistence increase in greenhouse emissions.

Fujii and Managi (2016) analyzed the relationship between economic growth and emissions by using eight environmental pollutants. The results indicated the validity of environmental Kuznets curve to some of the industrial sectors, and at least ten individual industries do not have ECK relationships. Al-Mulali et al. (2016) employed a time series data covering the period between 1980 and 2012 to investigate the validity of EKC hypothesis. The study also used ARDL bound testing methodology to capture co-integration among the variables of interest. The results showed that fossil fuel energy consumption, GDP, urbanization and trade openness increases environmental pollution. Baek (2015) investigated the validity of EKC in the case of Arctic countries by using the data spanned from 1960 to 2010. The study employed ARDL bound testing methodology to investigate the long-run relationships between the variables of interest. The results indicated little evidence of the existence of EKC hypothesis in the selected sample. Furthermore, energy consumption was found to have adverse effects on the environment in most of the countries under investigation.

Balaguer and Cantavella (2016) performed structural analysis to investigate the validity of EKC for the case of Spain by using the time series data covering the period between 1874 and 2011. The study employed ARDL bounds testing approach to capture the long-run relationships among the variables of interest. The results supported the existence of EKC hypothesis and real oil prices showed to be a viable indicator of pollutant energy consumption. Poumanyvong and Kaneko (2010) examined empirically the impacts of urbanization and both energy use and CO_2 emissions by using a panel data set spanned between 1975 and 2005. The study employed the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT). The results showed that the impact of urbanization on energy use and emissions depends on stages of economic development. Urbanization is found to decrease energy use in the low-income group, while it increases energy use in the case of high-income countries.

Martínez-Zarzoso and Maruotti (2011) analyzed the impacts of urbanization on carbon emissions in the developing countries by using the data spanned from 1975 to 2003. The results indicated an inverted U-shaped relationship between urbanization and carbon emissions. Xu and Lin (2015) examined the impacts of industrialization and urbanization on carbon emissions in the case of China by using non-parametric additive regression models. The study employed provincial time series data covering the period between 1990 and 2011. The results indicated an inverted U-shaped non-linear relationship between industrialization and carbon emission in three regions. Urbanization indicated an inverted U-shaped relationship with emissions in the eastern region. The study recommended differential dynamics effect to be taken into consideration. Zhang and Lin (2012) investigated the impacts of urbanization on both energy use and carbon emission at the national and regional levels using STIRPAT approach. The span of the data ranged between 1995 and 2010. The results indicated that urbanization increases both energy consumption and carbon emissions in the case of China. However, the effect of urbanization on energy use varied across regions.

Al-Mulali et al. (2012) explored the relationships between urbanization, energy use, and carbon emissions in the case of MENA region by using panel data set spanned between 1980 and 2009. The results indicated long-run bi-directional positive relationships between urbanization, energy use and carbon emissions. But the long-run relationships among the variables of interest were found to depend on the level of economic development. However, to the best of our knowledge, no empirical studies have devoted time to examine the causal relationships among urbanization, energy use and carbon emissions in SADC region. For the past decade, urbanization has continued to spur in the region where the proportion of urban to total population in SADC member states has increased from 17% in year 2010 to 43% in the year 2020. It is anticipated that this figure might continue to rise as the varsity majority of people are aspiring to relocate in big cities for the sake of improving their living standards. It is against this backdrop that the current study sought to examine the impacts of urbanization on carbon emissions in region. It is expected that, results from this current study will assist the policy makers and urban planners to come up with viable policies that will reduce adverse impacts of urbanization, energy use on carbon emissions in the region. Therefore, the empirical findings will add value and fill the knowledge gap and hence contribute to the extant literature.

Data and Methodology

To investigate the causal links among urbanization, energy use and carbon emissions, the multivariate time series model was employed whereby the urbanization variable was considered to influence both emissions and energy consumption. The model was initially used by Al-Mulali et al. (2013) and later employed by other researchers such as Wang et al. (2016a). The specification of the model is as indicated in following Equations (1) and (2):

$$CO_{2t} = f(UG_t, EC_t) \quad (1)$$

$$EC_t = f(UG_t, CO_{2t}) \quad (2)$$

Where CO_2 denotes emission level, EC represents the total energy consumption, and UG stands for growth rate of urban population. As it has been pointed out earlier, the main objective of this study was to examine causal links among urbanization, energy consumption and CO_2 emissions for the case of Tanzania mainland. The study employed the annual data spanning from 1988 to 2016 taken from the World Bank Development indicator Databank (World Bank 2020). The emission level which is measured by carbon emissions is measured in metric tons per capita. This variable has been used by other previous studies as an indicator for environmental degradation (See, e.g., Kivyiro and Arminen 2014). Energy consumption is captured by kg of oil equivalent per capita, and the level of economic growth was captured by GDP growth rate. Urbanization is measured by urban population growth rate.

Panel unit root tests

Since the study employed panel data techniques to investigate relationships among the variables of interest, we start by embarking on checking some preliminary diagnostic tests of the data before further analysis. This is done by first examining the stationarity of the data. This is very imperative because some of the econometric techniques require the data to be stationary before they can be used. There are myriad techniques that have been employed by different researchers to test stationary of the panel data. Some of these approaches among others include IPS tests (Im et al. 2003), LLC test (Levin et al. 2002), Breitung tests (Breitung 2001) and Fisher-type tests (Maddala and Wu 1999). However, in the current study three methods were employed; IPS, LLC and Breitung tests which are categorized as the first generation panel unit root tests and were designed for cross-sectional independent panels. Levin et al. (2002) proposed a panel based ADF test as depicted in the following model specification:

$$\Delta Y_{it} = \alpha_i + \delta Y_{it-1} + \sum_{L=1}^{p_i} \theta_{iL} \Delta Y_{it-L} + \sigma_{mi} d_{mt} + \varepsilon_{it} \qquad m = 1,2,3 \ldots.. \quad (3)$$

Where the subscript $i = 1,2,\cdots,N$ denotes the countries and $t = 1,2,\cdots,T$ indexes the time, δ is considered to be identical across individual countries, Y_{it} is the series of variables whose stationarity is to be tested, p_i denotes the number of lags to be included in the first difference of the model specification and this is allowed to vary across countries, d_{mt} are the deterministic variables, and ε_{it} are the error terms which are assumed to be independent and normally distributed with a zero mean and constant variance.

Panel cointegration tests

There are several approaches that have been suggested and used in the extant literature to test for panel cointegration and among others are: Pedroni (1999, 2004), Fisher type test which is simply the transformation of Johansen co-integration tests (Maddala and Wu 1999). However, the current study has adopted the Pedroni cointegration test which has been claimed to be superb as compared to other cointegration tests. The Pedroni test is based on Engle-Granger (1987) two-step co-integration tests (Engle and Granger 1987) and is also based on the assumption of cross-section dependence. The approach proposes several tests statistics for cointegration that allow for heterogeneous intercepts and trend coefficients across cross-sections and the model may be as indicated in the following specification:

$$y_{it} = \alpha_i + \gamma_i t + \sum_{k=1}^{K} \beta_{ki} x_{kit} + \varepsilon_{it} \qquad (4)$$

Where k is the number of predictor variables, $t = 1,2,\cdots,T$ denoted the number of observation over time dimension, and $i = 1,2,\cdots,N$ represent each individual cross-section within the panel, γ_i stands for coefficient of trend term. The intercept term α_i and the slope coefficients $\beta_{1i},\cdots,\beta_{ki}$ are assumed to vary across countries. The residuals in the above equation are assumed to be integrated of order 1 based on the null hypothesis of no cointegration.

Panel Granger causality

The current study adopted Granger causality analysis to examine the causal links among urbanization, energy use, and CO_2 emission. Granger causality analysis can be carried out using either vector autoregressive (VAR) model or Vector Error Correction Model (VECM). VAR model is normally adopted when the variables of interest are found to be stationary at their level form but also when the variables are integrated of order one but not cointegrated. On the other hand, VECM is employed when the variables are found to be integrated of order (i.e., $I(1)$) and cointegrated. The VECM can be used to detect short-run causality through F-statistics on independent variables and the long-run causality test through t-statistics on lagged error correction term. The VECM specification on the variables of interest is as shown Equations (5) to (7).

$$\Delta UG_{it} = \alpha_{it} + \sum_{L=1}^{pi} \beta_{it} \Delta UG_{it-L} + \sum_{L=1}^{pi} \gamma_{it} \Delta EC_{it-L} + \sum_{L=1}^{pi} \delta_{it} \Delta CO_{2it-L} + \rho_{it} ECT_{it-1} + \mu_{it} \qquad (5)$$

$$\Delta EC_{it} = \alpha_{it} + \sum_{L=1}^{pi} \beta_{it} \Delta EC_{it-L} + \sum_{L=1}^{pi} \gamma_{it} \Delta UG_{it-L} + \sum_{L=1}^{pi} \delta_{it} \Delta CO_{2it-L} + \rho_{it} ECT_{it-1} + \mu_{it} \qquad (6)$$

$$\Delta CO_{2it} = \alpha_{it} + \sum_{L=1}^{pi} \beta_{it} \Delta CO_{2it-L} + \sum_{L=1}^{pi} \gamma_{it} \Delta EC_{it-L} + \sum_{L=1}^{pi} \delta_{it} \Delta UG_{2it-L} + \rho_{it} ECT_{it-1} + \mu_{it} \qquad (7)$$

Where pi denotes the maximum lag length to be used, α_{it} is the constant term, Δ is the first difference operator, β_{it} , γ_{it} , δ_{it} and ρ_{it} are the parameters to be estimated, ECT_{it-1} is the first lagged error correction term deduced from the cointegration equation, and μ_{it} is the stochastic or random error term. However, as it has been pointed out earlier, VECM is used when the variables of interest are cointegrated, if the not VAR model which captures only the short run causality is adopted and its general structure is as indicated below.

$$\Delta UG_{it} = \alpha_{it} + \sum_{L=1}^{pi} \beta_{it} \Delta UG_{it-L} + \sum_{L=1}^{pi} \gamma_{it} \Delta EC_{it-L} + \sum_{L=1}^{pi} \delta_{it} \Delta CO_{2it-L} + \mu_{it} \qquad (8)$$

$$\Delta EC_{it} = \alpha_{it} + \sum_{L=1}^{pi} \beta_{it} \Delta EC_{it-L} + \sum_{L=1}^{pi} \gamma_{it} \Delta UG_{it-L} + \sum_{L=1}^{pi} \delta_{it} \Delta CO_{2it-L} + \mu_{it} \qquad (9)$$

$$\Delta CO_{2it} = \alpha_{it} + \sum_{L=1}^{pi} \beta_{it} \Delta CO_{2it-L} + \sum_{L=1}^{pi} \gamma_{it} \Delta EC_{it-L} + \sum_{L=1}^{pi} \delta_{it} \Delta UG_{2it-L} + \mu_{it} \qquad (10)$$

Empirical Results

Descriptive statistics

The analysis commenced by computing the descriptive statistics of the variables used in this study, which are CO_2 emissions, energy use and urbanization. The results for the descriptive statistics are reported in Table 1. The results indicate that there was a steady increase in the CO_2 emissions for the entire period under the study. Emissions which were measured by metric tons per capita ranged between 0.017 and 9.87 and the average value stands to be 1.593. Energy use which was measured by kg of oil equivalent per capita had the mean of 797.201 and its values range between 295.409 and 2913.130 for the entire period under the study. There is a steady increase in urbanization as well, the results show that the mean value of urbanization stood to be 4.173 and the series range between -0.107 and 10.299. In general the results indicate a remarkable increase in all the three series under the study.

Table 1: Results for descriptive statistics

Statistics	CO_2 emission	Energy	Urbanization
Mean	1.593	797.201	4.173
Standard error	0.144	34.824	0.119
Standard deviation	2.697	653.361	2.233
Sample variance	7.272	426880.914	4.985
Kurtosis	2.868	2.704	-0.196
Skewness	2.096	1.993	0.239
Range	9.853	2617.721	10.407
Minimum	0.017	295.409	-0.107
Maximum	9.870	2913.130	10.299
Count	**352**	**352**	**352**

Results for unit root tests

The study then embarked on testing the stationarity of the variables used by using Eviews statistical package and the results are as reported in Table 2. Three tests approaches were employed; LLC, Breitung and IPS tests. The test equations in the level series included both intercept and trend components, whereby in the case of the first difference series only the intercept term was incorporated. From the results, CO_2 emissions were found to be stationary at level form in the case of LLC test technique. But, the same variable was found to be non-stationary in the remaining two techniques. The other two variables; energy consumption and urbanization are found to be non-stationary at their level form in all three approaches. Stationarity is induced in the first difference whereby all three series are found to be stationary at 1% level of significance.

Table 2: Panel unit root tests results

Variable	LLC tests		Breitung tests		IPS tests	
	Level series	Difference series	Level series	Difference series	Level series	Difference series
CO_2	-2.146	-11.201***	5.648	-7.935***	2.766	-12.362***
Energy	-0.809	-7.095***	-1.445	-11.445***	-1.408	-11.446***
Urbanization	3.658	-14.127***	4.739	-3.203***	4.300	-14.123***

Notes: 1) LLC indicates the Levin, Li and Chu unit root test. 2) represents Im et al. (2003) unit root test. 3) The optimal lag was selected automatically based on Schwarz Information Criterion. 4) ***,**,* Denote significance at 1%, 5% and 10% levels of significance, respectively.

Results for cointegration tests

Since all the variables of interest are found to be integrated of order one I(1), we proceed testing whether the given non-stationary variables are to some extent related in the long run. Therefore, we employed Pedroni cointegration test to test whether the variables are cointegrated. The results are as reported in Table 3. It can be observed that all the test statistics (within-dimension and between-dimension) reject the null hypothesis of no cointegration at 1%, 5% and 10% levels of significance. Therefore, we conclude that the variables move together in the long run. However, since cointegration does not reflect causality we proceed testing whether there exists a causal link among the variables by employing the Granger causality analysis approach. This is employed based on VECM approaches.

Table 3: Pedroni cointegration tests

Pedroni tests	Statistic	Prob.
Panel v-statistic	1.390*	0.0822
Panel rho-statistic	-4.145***	0.0000
Panel PP-statistic	-4.406***	0.0000
Panel ADF-statistic	-4.108***	0.0000
Panel v-statistic (Weighted statistic)	1.764**	0.0389
Panel rho-statistic (Weighted statistics)	-2.543***	0.0055
Panel PP-statistic (Weighted statistics)	-2.729***	0.0032
Panel ADF-statistic (Weighted statistics)	-2.392***	0.0084
Group rho-statistic	-2.357***	0.0092
Group PP-statistic	-2.878***	0.0020
Group ADF-statistic	-2.210**	0.0135

Lag selected criteria

The results for VAR lag order selection criteria are as reported in Table 4. The results show that the four criterion which are; the sequential modified LR test statistics, the final prediction error, the Akaike information criterion, the Schwarz information criterion and the Hannan-Quinn information criterion suggest the number of lags to be included in the model to be eight (8). Therefore, lag eight (8) of all the variables was incorporated in estimating the VECM and the results for Granger causality analysis based on VECM are as reported in Table 5.

Table 4: VAR lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	402.864	NA	8.40e-06	-3.174	-3.132	-3.157
1	1093.306	1358.965	3.76e-08	-8.582	-8.414	-8.514
2	1154.250	118.502	2.49e-08	-8.994	-8.699	-8.876
3	1196.752	81.631	1.91e-08	-9.259	-8.840	-9.091
4	1254.666	109.852	1.30e-08	-9.648	-9.102	-9.428
5	1324.848	131.452	7.98e-09	-10.134	-9.461	-9.863
6	1382.520	106.648	5.42e-09	-10.520	-9.722	-10.199
7	1519.201	249.497	1.97e-09	-11.533	-10.608	-11.161
8	1631.710	202.693*	8.67e-10*	-12.354*	-11.304*	-11.932*

Notes: 1) *Indicates lag order selected by the criterion. 2) LR indicates the sequential modified LR test statistics. 3) Denotes final prediction error. 4) AIC stands for Akaike information criterion. 5) SC denotes the Schwarz information criterion. 6) HQ indicates the Hannan-Quinn information criterion.

Results for Granger causality analysis

Pedroni cointegration test results confirm the existence of long term equilibrium relationships among the variables of interest. However, since cointegration does not indicate the direction of causality, the Granger causality test based on VECM is used to put more insight on the direction of causality among the three variables. Table 5 reports the results of both short term and long-term causal relationships among the variables of interest within the VECM approach. The *t*-statistics for the coefficients of the lag one error correction term (ECT_{t-1}) are used to test whether there are significance long term relationships among the variables of interest. The *F*-test on the lagged predictor variables of the VECM is employed to capture the short-term causal relationships among the variables. In the short-run the results indicate the bi-directional causality among all the three variables. That is to say; there is a bi-directional Granger causality between energy consumption and carbon dioxide emission; there exists a bidirectional Granger causality between energy consumption and urban growth and also we observe a bi-directional causality between carbon dioxide emission and urban growth in the SADC region. In the long-run however, the results indicate a uni-direction Granger causality from both urban growth and energy consumption to carbon emission. The effect is vindicated by the coefficient of error correction term in the carbon equation which is found to be negative as expected but also significant. The coefficient of error correction term in the energy equation though significant at 1%, the sign is negative which contradicts the theory and this indicates that the process is not converging in the long-run. Generally, the results show that changes in both energy consumption and urbanization precede changes in the carbon emissions in the short and long-run terms.

Table 5: Granger causality results

	Dependent variable		
	ΔCO_2	ΔEN	ΔUG
ΔCO_2	-	50.547*** (0.000)	61.012*** (0.000)
ΔEN	79.459*** (0.000)	-	58.932*** (0.000)
ΔUG	113.227*** (0.000)	26.183*** (0.000)	-
ECT_{t-1}	-0.5217*** (0.000)	0.0007 (0.894)	0.0988*** (0.000)

Notes: 1) The numbers in parentheses are the p-values. 2)***Denotes rejection of the null hypotheses of no Granger causality at 1% level.

Results for FMOLS

Since the Granger causality does indicate the direction of causality but not the magnitude of causality, therefore in addition to the results from Granger causality analysis, the current study also employed the Fully Modified Ordinary Least Squares (FMOLS) technique to estimate the long-run equilibrium relationships among the variables of interest. The results for FMOLS for both individual countries and as a panel are as indicated in Table 6. It can clearly be observed that the long-run coefficients for energy consumption for all the eight countries have the expected signs and the variables are statistically significant at 1% level of significance. In the case of Angola, the results show that a unit increase in energy consumption is linked with 0.004 increase in CO_2 emissions. A unit increase in energy consumption is likely to increase carbon emissions by 0.001 in the case of DRC. Furthermore, the results indicate that a unit increase in energy consumption is linked with an increase of 0.004 carbon emissions in the case of Mauritius. Similar trends can be vindicated in the remaining five countries. A unit increase in energy consumption with trigger an upsurge of carbon by 0.004 unit in the case of Mozambique. In the case of South Africa, a unit increase in energy consumption is linked to 0.003 increase in carbon dioxide emissions. A unit increase in energy consumption is likely to increase emissions by 0.009 in the case of Tanzania. In the case of Zambia, a unit increase in energy consumption is linked with an increase of 0.002 carbon dioxide emissions. Likewise, in the case of Zimbabwe, a unit increase in energy consumption increases carbon emissions by 0.009 units. Generally, in the case of panel of all the countries, the results indicate that energy consumption has a positive impact on the level of carbon dioxide emissions. For the case of the second variable, that is, urbanization, the results indicate that the variable is statistically significant, however, its sign for some countries is negative and this contradicts the theory. However, for the case of South Africa, Zambia and Zimbabwe, the sign is positive and statistically significant at 1% level as well. A unit increase in urbanization is linked with an increase of 0.319 increase in the carbon dioxide emissions in the case of South Africa, a unit increase in urbanization is linked with an increase of 0.0125 in the case of Zambia, unit in urbanization is linked with 0.086 in the case of Zimbabwe. However, in the case of the panel of countries, again the coefficient is negative.

Table 6: Results for FMOLS Dependent variable: CO_2 emissions

Country	Variable	Coefficient	Prob.
Angola	Energy use	0.004***	0.0000
	Urbanization	-0.220***	0.0000
DRC	Energy use	0.001***	0.0000
	Urbanization	-0.067***	0.0002
Mauritius	Energy use	0.004***	0.0000
	Urbanization	0.032	0.2535
Mozambique	Energy use	0.0009***	0.0000
	Urbanization	-0.013**	0.0429
South Africa	Energy use	0.003***	0.0000
	Urbanization	0.319***	0.0018
Tanzania	Energy use	0.0009***	0.0000
	Urbanization	-0.008***	0.0096
Zambia	Energy use	0.002***	0.0000
	Urbanization	0.0125*	0.1010
Zimbabwe	Energy use	0.0009***	0.0000
	Urbanization	0.086***	0.0000
Panel	Energy use	2.896***	0.0000
	Urbanization	-1.566***	0.0000

Notes: ***, **, * Denote significance at 1%, 5% and 10% levels of significance, respectively.

Discussion

The results obtained from the selected countries of SADC indicate positive contributions of both energy consumption and urbanization towards explaining the variability of carbon dioxide emissions. Although the countries in Southern Africa region emit almost 3% of the total carbon dioxide emissions which is minimal as compared to the rest of the world, but the adverse effects of climate changes attributed to global warming are more pervasive in the region. Emissions in this region are attributed to land degradation and deforestation and therefore reducing deforestation in this region is crucial and it should be the first priority in their agenda for developing climate change mitigation and adaptation policies. Majority of the people in this region use energy from firewood for the purpose of cooking and heating which make them cut down trees more often. Furthermore, traditional cooking stoves are also common in the region and most of them are low efficient and hence cause more emission. Therefore, member states in SADC region need to find coherent and efficient ways of reducing low efficient cooking and heating appliances. The results are consistent with some of the previous studies in the extant literature (See, e.g. Wang et al. 2016a, 2016b, Khobai and Le Roux 2017, Abbas et al. 2020, Sufyanullah et al. 2022)

Conclusions and Policy Implications

The persistence increase in global warming has triggered enormous amounts of researches for the past three decades. Some of the factors which have been attributed to such predicament as explicated in the extant literature are among others; urbanization and energy consumption. The rapid growth in urbanization and energy consumption in emerging economies has attracted much attention in academic circles and from policy makers to seek and find out how the variables contribute to the global warming and hence climate change. Furthermore, in other developing regions such as SADC, the rapid increase in urbanization has been pointed out to be pervasive in the current era and hence pose threats to the strategies that have been so far put in place to offset the effects of global warming. Therefore, the current study devotes time to find out the causal links among, urbanization, energy consumption and carbon dioxide emissions. The study employs Granger causality analysis to detect the causality among the variables of interest. In addition, the study uses the FMOLS to show the direction of causality for both individual countries and as a panel of countries. The results indicate bidirectional causality among the three variables in the short-run and one way Granger causality from both energy consumption and urbanization to carbon emissions. Furthermore, the FMOLS show the positive contributions of both energy consumption and urbanization to carbon dioxide emissions. These results are consistent with the study by Wang et al. (2016a, 2016b) who found urbanization to Granger cause carbon emissions.

The results from the empirical work make some significant contributions to the existing body of knowledge and to the policy makers. First, to the best of author's knowledge, this is the only study that has investigated the causal link among these variables of interest in the case of SADC region. But also, the results pose some policy implications to the policy makers and to the governments of SADC region. In order to slow down urbanization which has been pointed out to trigger energy use and hence more carbon emissions, the SADC member states should be able to find coherent ways to discourage people from moving in the cities. First of all, attention should be focused on fostering modern agricultural practices to encourage the varsity majority of people to stay in the villages to do farming rather than moving to urban areas. In addition, the governments in the region should be able to find strategies to commercialize agriculture in order to boost living conditions of farmers. This will help to get rid of mentality in the minds of people who normally claim that agricultural activities are for poor people, hence the varsity majority of people and most specifically youths do not value agricultural activities and therefore they tend to migrate to the cities for the purpose of seeking better jobs leaving old ones in the village to practice farming. We should learn from developed world where farming activities contribute significantly to the economy of respective countries. The energy-efficient tools to replace conventional cooking stoves and charcoal should be encouraged, and public transport system should be improved.

References

Abbasi MA, Parveen S, Khan S and Kamal, MA 2020 Urbanization and energy consumption effects on carbon dioxide emissions: evidence from Asian-8 countries using panel data analysis. *Environ. Sci. Pollut. Res.* 27(15): 18029-18043.

Al-Mulali U, Sab CNBC and Fereidouni HG 2012 Exploring the bi-directional long run relationship between urbanization, energy consumption, and carbon dioxide emission. *Energy* 46(1): 156-167.

Al-Mulali U, Fereidouni HG, Lee JY and Sab CNBC 2013 Exploring the relationship between urbanization, energy consumption, and CO_2 emission in MENA countries. *Renew. Sustain. Energy Rev.* 23: 107-112.

Al-Mulali U, Ozturk I and Lean H 2015 The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. *Nat. Hazards* 79(1): 621-644.

Al-Mulali U, Solarin SA and Ozturk I 2016 Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. *Nat. Hazards* 80(3): 1729-1747.

Baek J 2015 Environmental Kuznets curve for CO_2 emissions: the case of Arctic countries. *Energy Econ.* 50: 13-17.

Balaguer J and Cantavella M 2016 Estimating the environmental Kuznets curve for Spain by considering fuel oil prices (1874–2011). *Ecol. Indicat.* 60: 853-859.

Brandt M, Rasmussen K, Peñuelas J, Tian F, Schurgers G, Verger A, Mertz O, Palmer JR and Fensholt R 2017 Human population growth offsets climate-driven increase in woody vegetation in sub-Saharan Africa. *Nat. Ecol. Evolut.* 1(4): 0081.

Breitung J 2001 The local power of some unit root tests for panel data. In: Baltagi BH, Fomby TB and Carter Hill R (Ed) *Nonstationary Panels, Panel Cointegration, and Dynamic Panels* (*Advances in Econometrics, Vol. 15*), Emerald Group Publishing Limited, Bingley, pp. 161-177.

Businesswire 2016 Burgeoning Mega Cities in Sub-Saharan Africa-Lagos, Kinshasa, Luanda, and Johannesburg-Where are the Opportunities for ICT Providers?-Research and Markets.

Cetin MA 2018 Investigating the environmental Kuznets curve and the role of green energy: emerging and developed markets. *Int. J. Green Energy* 15(1): 37-44.

Chikaraishi M, Fujiwara A, Kaneko S, Poumanyvong P, Komatsu S and Kalugin A 2015 The moderating effects of urbanization on carbon dioxide emissions: A latent class modeling approach. *Technol. Forecast. Soc. Change* 90: 302-317.

Chishakwe NE 2010 Southern Africa sub-regional framework on climate change programmes report. Draft working document. SADC-UNEP.

Effiong EL 2018 On the urbanization-pollution nexus in Africa: a semi parametric analysis. *Quality and Quantity* 52(1): 445-456.

Engle RF and Granger CWJ 1987 Co-integration and error correction: representation, estimation, and testing. *Econometrica* 55: 251-276.

Fujii H and Managi S 2016 Economic development and multiple air pollutant emissions from the industrial sector. *Environ. Sci. Pollut. Res.* 23: 2802-2812.

Gungor H and Simon AU 2017 Energy consumption, finance and growth: the role of urbanization and industrialization in South Africa. *Int. J. Energy Econ. Policy* 7(3): 268-276.

Grossman GM and Krueger AB 1991 Environmental impacts of a North American free trade agreement.

Hossain MS 2011 Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy* 39(11): 6991-6999.

Im KS, Pesaran MH and Shin Y 2003 Testing for unit roots in heterogeneous panels. *J. Econometr.* 115: 53-74.

Katircioğlu S and Katircioğlu S 2018 Testing the role of urban development in the conventional environmental Kuznets curve: evidence from Turkey. *Appl. Econ. Lett.* 25(11): 741-746.

Khobai HB and Le Roux P 2017 The relationship between energy consumption, economic growth and carbon dioxide emission: The case of South Africa. *Int. J. Energy Econ. Policy* 7(3): 102-109.

Kivyiro P and Arminen H 2014 Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: Causality analysis for Sub-Saharan Africa. *Energy* 74: 595-606.

Levin A, Lin CF and Chu CSJ 2002 Unit root tests in panel data: asymptotic and finite-sample properties. *J. Economet.* 108(1): 1-24.

Liddle B and Lung S 2010 Age-structure, urbanization, and climate change in developed countries: revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Popul. Environ.* 31(5): 317-343.

Liddle B and Sadorsky P 2017 How much does increasing non-fossil fuels in electricity generation reduce carbon dioxide emissions? *Appl. Energy* 197: 212-221.

Maddala GS and Wu S 1999 A comparative study of unit root tests with panel data and a new simple test. *Oxford Bull. Econ. Statist.* 61(S1): 631-652.

Martínez-Zarzoso I and Maruotti A 2011 The impact of urbanization on CO_2 emissions: Evidence from developing countries. *Ecol. Econ.* 70(7): 1344-1353.

Ozatac N, Gokmenoglu KK, and Taspinar N 2017 Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: The case of Turkey. *Environ. Sci. Pollut. Res.* 24(20): 16690-16701.

Pedroni P 1999 Critical values for cointegration tests in heterogeneous panel with multiple regressors. *Oxford Bull. Econ. Statist.* 61: 653-670.

Pedroni P 2004 Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Economic Theory* 20: 597-625.

Ponce de Leon Barido D and Marshall JD 2014 Relationship between urbanization and CO_2 emissions depends on income level and policy. *Environ. Sci. Technol.* 48(7): 3632-3639.

Poumanyvong P and Kaneko S 2010 Does urbanization lead to less energy use and lower CO_2 emissions? A cross-country analysis. *Ecol. Econ.* 70(2): 434-444.

Rafiq S, Salim R and Nielsen I 2016 Urbanization, openness, emissions, and energy intensity: a study of increasingly urbanized emerging economies. *Energy Economics* 56: 20-28.

Sadorsky P 2013 Do urbanization and industrialization affect energy intensity in developing countries? *Energy Econ.* 37: 52-59.

Sadorsky P 2014 The effect of urbanization on CO_2 emissions in emerging economies. *Energy Econ.*41: 147-153.

Shahbaz M, Loganathan N, Sbia R and Afza T 2015 The effect of urbanization, affluence and trade openness on energy consumption: A time series analysis in Malaysia. *Renew. Sustain. Energy Rev.* 47: 683-693.

Shahbaz M, Loganathan N, Muzaffar AT, Ahmed K and Jabran MA 2016 How urbanization affects CO_2 emissions in Malaysia? The application of STIRPAT model. *Renew. Sustain. Energy Rev.* 57: 83-93.

Sheng P and Guo X 2016 The long-run and short-run impacts of urbanization on carbon dioxide emissions. *Econ. Model.* 53: 208-215.

Sufyanullah K, Ahmad, KA and Ali MAS 2022 Does emission of carbon dioxide is impacted by urbanization? An empirical study of urbanization, energy consumption, economic growth and carbon emissions- Using ARDL bound testing approach. *Energy Policy* 164: 112908.

Wang Y, Chen L and Kubota J 2016a The relationship between urbanization, energy use and carbon emissions: evidence from a panel of Association of Southeast Asian Nations (ASEAN) countries. *J. Clean. Product.* 112: 1368-1374.

Wang Y, Li L, Kubota J, Han R, Zhu X and Lu G 2016b Does urbanization lead to more carbon emission? Evidence from a panel of BRICS countries. *Appl. Energy* 168: 375-380.

World Bank 2020 *World Development Indicators Database 2020* [online] http://data.worldbank.org/data-catalog/world-development-indicators (accessed 3 September 2020).

Xu B and Lin B 2015 How industrialization and urbanization process impacts on CO_2 emissions in China: evidence from nonparametric additive regression models. *Energy Economics* 48: 188-202.

Zhang C and Lin Y 2012 Panel estimation for urbanization, energy consumption and CO_2 emissions: A regional analysis in China. *Energy Policy* 49: 488-498.

Zhu HM, You WH and Zeng Z F 2012 Urbanization and CO_2 emissions: A semi-parametric panel data analysis. *Econ. Lett.* 117(3): 848-850.