Urbanization-globalization-CO$_2$ emissions nexus revisited: empirical evidence from South Africa

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ABSTRACT

The environmental effects of urbanization and globalization are still subject to debate among scholars. South Africa is the most globalized, most urbanized and the most carbon-intensive economy in Sub Saharan Africa (SSA) region. Taking this into cognizance, this study examines the effects of urbanization and globalization on CO$_2$ emissions for South Africa using time series annual data for the period 1980–2017. Zivot and Andrews single and Bai and Perron multiple structural break unit root tests are employed to assess if all the series are stationary. This procedure follows ARDL cointegration test to check the presence of a long-run association among variables. Having been confirmed about such a cointegrating relation, ARDL short-run and long run coefficients indicate that urbanization induces CO$_2$ emissions while only long-run significant emissions effect of globalization was noted. Toda-Yamamoto non-causality test reports a bi-directional causal link between urbanization and CO$_2$ emissions. No causal link is observed between globalization and CO$_2$ emissions. Variance decomposition results do not rule out these effects in future. Policy implications are discussed.

1. Introduction

During the last two decades, both developed and developing countries experienced a spectacular growth in urbanization and globalization. However, the speed of urbanization is observed to have been faster in developing countries than in the developed world (Sadorsky, 2014; Shahbaz et al., 2016). Economies around the world have also become more globalized than ever before. Especially, during the last two decades, there have been a significant level of growth in the volumes of international trade and nations seemed to be increasingly integrated with the rest of the world. This is more evident when we observe that an economic earthquake in one part of the world immediately shakes the economies on the other side of the planet.

Globalization has generated increasing level of interdependence among national economies. This has also turned around the political dynamics of the world. Many historical foes turned into friends or at least moved to engage in trade collaboration as a consequence of globalization. However, no consensus is yet reached in the academia on the environmental consequences of such trade collaboration. As such, the debate goes on (Navarro, 1998; Jorgenson and Givens, 2014; Lv and Xu, 2018; You and Lv, 2018).

Globalization is said to impact CO$_2$ emissions through income effect, scale effect and composition effect (Antweiler et al., 2001). It causes emissions to rise emanating from the income effect as a consequence of increased foreign trade and foreign investment, *ceteris paribus*. Globalization potentially facilitates economies of scale through the integration of factors of production and the interaction among different markets beyond national boundaries. Such integration and the opportunities for increased interaction among market forces worldwide intensifies competition and enables product diversification and the availability of better quality products through unprecedented level of economies of scale that eventually results in productive efficiency. This is called scale

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effect of globalization. This scale effect may potentially cause emissions to rise via its income effect. When the scale and structure of an economy change as a result of globalization, the level of pollution may change through a transition towards a more carbon-intensive consumption. This is known as the composite effect of globalization.

South Africa is undisputedly the most urbanized and the most globalized economy in Sub-Saharan Africa region (SSA). It underwent a steady urbanization process during the last three decades. Its urbanization rate was 62.4% in 2012, the highest in SSA region (Wang et al., 2016). It is also the most globalized economy with the highest aggregate globalization rate (65.76%) in SSA region (Ajide et al., 2019). It represents the biggest economy in the region. It is also responsible for the highest level of CO_2 emissions in the region. It alone causes 42.8% of the Africa's total emissions (Ndoricimpa, 2017).

Globally, South Africa is the 14th largest CO_2 emitter and one of the most carbon intensive economies. To make things even worse environmentally, there has been a rising demand for fossil fuel energy in South Africa for non-renewable energy use for more than two decades now (Wang and Dong, 2019). Since it is a signatory to the 1992 UNFCCC and its Kyoto Protocol, it is under international pressure to reduce emissions. Despite the fact that South Africa has been pursuing various energy policies in order to enhance the concentration of renewable energy in its national energy composition for sometime now, 77% of its energy needs are still met by coal most of which is used for electricity production. It's investment in the sector of renewable energy as share of GDP was one of the highest in the world in 2012. The effectiveness of these policies warrants a call for scrutiny with such a dismal energy scenario still haunting the energy landscape of the country.

South Africa enjoys the blessings of several renewable energy sources including solar, wind, biomass, geothermal and hydropower with the highest potential in solar and wind energies. Most of its provinces are rich in these two renewables. In 2009, the National Energy Regulator of South Africa (NERSA) announced renewable energy feed-in-tariffs (REFIT) in private sector to increase electricity in the national grid. The government's commitment to promote renewable energy (RE) for sustainable development was further reflected through the release of White Paper on Renewable Energy (WPRE) in 2011 and the White Paper on National Climate Change Response Policy (WPNCCRP). The 2011 National Development Plan (NDP) also demonstrates Government's commitment to combat emissions through increased use of RE technologies. Through Renewable Energy Independent Power Producers Procurement Program (REIPPPP), the total capacity allocation of RE generation capacity was raised to 6300 MW (for details on these policies and programs, please refer to Jain and Jain, 2017).

South Africa also enjoys a high degree of sunshine blessed with a very good amount of radiation (4.5–6.6 kWh/m2 of radiation level) and its yearly rainfall is in the neighborhood of half of the global average. Promoting solar energy is meant for boosting the applications of both PV (photovoltaic) and thermal plants. Projects such as, Solar Energy Resource Maps (SERP), Solar Energy Technology Roadmap (SETRM), South African Solar Thermal Technology Roadmap (SA-STTRM) are being implemented to promote the application of solar thermal technologies for water heating, space heating and for cooling in residential, commercial and industrial sectors (Jain and Jain, 2017).

Based on above discussion, it is quite convincing that South Africa is an ideal candidate for an investigation of the effects of urbanization and globalization on its CO_2 emissions as it is the most urbanized and most globalized country in Sub-Saharan Africa region along with an alarming level of carbon emissions. The study is expected to be an enrichment of the literature on urbanization-globalization-emissions nexus. Another contribution of this study is that unlike most of the empirical studies, the current research uses a recently developed globalization index instead of the traditional measure of trade openness. Thus, this empirical exercise is a contribution to the scanty literature of globalization that used this index to measure it (Lv and Xu, 2018; You and Lv, 2018; Ajide et al., 2019).

The rest of the paper proceeds as follows; Section 2 provides an overview of literature while section 3 is dedicated to the discussion on methodology and data. Section 4 presents results and the paper comes to an end in section 5 offering discussions, conclusions and policy implications.

2. Background

Three theories: ecological modernization theory, urban environmental transition theory and compact city theory have explained the theoretical link between urbanization and environment (Poumanyvong and Kaneko, 2010). The ecological modernization theory is based on the premise that as an economy grows, the level of associated environmental damage at some point can't be ignored. It becomes imperative for economies to undertake measures such as, promoting technological advancement and well-planned urbanization. The theory also emphasizes the need for a transition from a manufacture-based economy to a service-based economy.

Urban environmental transition theory suggests that emissions effect of urbanization is rather ambiguous. One line of thought offers a couple of arguments in favor of urbanization's role to stimulate emissions. The first argument sheds light on the fact that urban cities are generally characterized by industrialization that causes emissions while the other one supports the view that the consumption pattern of urbanites is generally more carbon intensive than their rural counterparts.

The second line of thought generated from this theory is that, since urban people are relatively wealthier and more concerned about climate issues, various measures for a decline in pollution may be developed and implemented. One such measure is to enforce and increase the level of compliance with environmental regulations. More financial resources should be channeled towards exploiting emissions abatement potentials. Higher investment in modern technology is also important for achieving desired level of energy efficiency. The compact city theory underscores the importance of economies of scale that could be achieved through increased urbanization resulting in the potential expansion of public infrastructure such as water supply, health facilities, education and transport.

Two strands of empirical literature continue to evolve on CO_2 emissions-urbanization nexus. The first strand deals with time series country-specific studies while the other one is devoted to panel studies that included mostly countries of different regions. Ali et al. (2019) in one of the most recent studies probed the effect of urbanization on CO_2 emissions for Pakistan using time series data for the period 1972–2014. Through the application of ARDL (Autoregressive Distributed Lag) method, the study found that urbanization stimulated emissions in Pakistan both in the short-run and the long-run. Urbanization was also found to cause emissions in the short-run. The study offered the argument that one of the key contributing factors towards such a dismal emissions scenario in Pakistan is vehicular emissions.

Wang et al. (2019) undertook an interesting study to investigate the quality of urbanization on CO_2 emissions across different provinces in China. Using a geographically weighted regression model (GWR), the study observed heterogeneous effects of urbanization on emissions across different provinces. The study recommends that urban sprawling would be environmentally very expensive unless it is accompanied by province-specific environmental policies. Liu and Bae (2018) investigated the impacts of urbanization, industrialization, economic growth and energy consumption on CO_2 emissions in the context of China. The study analyzed time series data for the period 1970–2015 with the application of ARDL method and VECM (Vector Error Correction Model) to estimate short-run and long-run coefficients and the causal direction among the variables. Empirical results indicated that all explanatory variables including urbanization stimulated CO_2 emissions in China.

Exploiting census data for the period of 1901–2011 for India, Franco et al. (2017) probed the temporal, dynamic and causal link between

urbanization and CO_2 emissions. Findings indicated that rapid urbanization in India has caused a faster rise in emissions. A number of recommendations have been offered for more effective emissions-reduction measures. Bekhet and Othman (2017) studied the impact of urbanization on CO_2 emissions for Malaysia and analyzed time series data for Malaysia for the period 1971–2015 within an augmented Cobb-Douglas production function. The study found a U-shaped relationship between urbanization and CO_2 emissions in the long-run.

This finding is consistent with another earlier study for the same country by Shahbaz et al. (2016) who utilized time series quarterly data for the period 1970Q1-2011Q4. Using a STIRPAT model and through the application of ARDL method, the study found a U-shaped relation between urbanization and CO_2 emissions. Urbanization is also reported to have Granger-caused emissions as evident from VECM Granger causality test. This U-shaped relation between urbanization and CO_2 emissions has been corroborated by earlier findings of Zhang et al. (2015) which also exploited time series data for Beijing, the capital of China for the period 1980–2013.

Numerous panel studies have also studied the effects of urbanization on CO_2 emissions (Chen et al., 2019; Bai et al., 2019; Wang et al., 2018; Lin et al., 2017; Li et al., 2018; Zhang et al., 2017; Rafiq et al., 2016; Wang et al., 2016; Li and Lin, 2015; Sadorsky, 2013; Sadorsky, 2014; Poumanyvong and Kaneko, 2010; Sharma, 2011 among others). However, no unique effect is unanimously observed yet.

Two opposing theoretical views exist in literature with regards to the potential environmental effects of globalization-induced trade openness: the ''pollution haven'' hypothesis (Eskeland and Harrison, 2003) and the "California effect'' hypothesis (Vogel, 1995). The ''pollution haven'' argument suggests that trade openness potentially causes relocation of industries from developed countries to developing countries. As a consequence of a higher level of trade openness, high polluting industries from developed countries tend to avoid pollution tax by being relocated to pollution havens in developing countries with relatively flexible environmental regulations. These relocated industries aim to reduce production costs. This is how pollution in developing countries is likely to rise as a result of industry flight (Jaffe et al., 1995).

Another camp of scholars focus on the positive effects of trade on pollution in developing countries. Levinson (2010) analysis of US imports for the period 1972–2001 is in contrast with the pollution haven hypothesis. Scholars suggest that the cost savings generated from the relocation of firms to developing countries (pollution havens) are often outweighed by loss in reputation back in the country of origin. Firms importing from developing countries are likely to face growing pressure from their home countries to ensure environmental protection for the exporting countries (Prakash and Potoski, 2007). Thus, trade can be instrumental for boosting environmental standard of imported goods entering into the developed countries as exports from the developing countries. Thus developing countries may achieve a higher environmental standard in their key exports as a result of trade openness (Perkins and Neumayer, 2012).

Some recent panel studies (e.g., Lv and Xu, 2018; Le et al., 2016; Li et al., 2015; Lim et al., 2015; Jorgenson and Givens, 2014) have exploited globalization data from KOF index to assess its impact on CO_2 emissions. However, no consensus on such effect could yet be drawn from these studies. From this discussion, it is crystal-clear that an investigation into the empirical link of urbanization and globalization with CO_2 emissions is absent in the context of South Africa and as such, this empirical exercise seems to be a worthy contribution to the existing time series literature in the area. Findings from such a study are potentially likely to render South Africa with a better direction towards a more contextual and more pragmatic formulation of energy policies which is very important for a country plagued with high rates of urbanization, globalization and carbon intensity.

3. Methodology

3.1. Model

Based on the premises that South Africa far exceeded the initial stages of urbanization and globalization quite a while ago and that this study does not aim at testing the EKC hypothesis, the relation of per capita CO_2 emissions with urbanization, globalization, energy poverty and per capita GDP is anticipated to be linear. Unlike studies testing for conventional EKC hypothesis, this study does not incorporate the non-linear terms of explanatory variables also to avoid potential threats from multicollinearity. Instead, it examines the relationship between CO_2 emissions and economic growth and other variables through comparing the short and long-run effects. Thus, a base-line model with the dependent and independent variables is constructed for this study as follows:

$$CO_{2t} = ln\alpha_0 + \alpha_1 lnURB_t + \alpha_2 lnGLO_t + \alpha_3 lnGDPPC_t + \alpha_4 lnENPOV_t + v_i + \varepsilon_t$$

$$(1)$$

where, subscript t represents time period (1984–2016) and ε represents stochastic error term.

3.2. Data

Annual time series data for South Africa are sourced for the period 1984 to 2016. The variable, CO_2 is the total CO_2 emissions measured in metric tons and divided by population to obtain per capita emissions, real GDP per capita measured at constant 2010 US is considered to represent economic growth (GDPPC). The percentage of population with access to electricity is taken as energy poverty (ENPOV) while data for the variable urbanization (URB) is constructed with percentage of total population living in urban areas. Data on globalization variable (GLO) is obtained from KOF Swiss Economic Institute (2018) developed by Dreher (2006). All other data were sourced from the World Bank Development Indicators database (World Bank, 2018). Logarithmic transformation of all variables but per capita CO_2 emissions was performed in order to scale down values that reduces heteroscedasticity. Table 1 provides summary statistics of the variables. The data demonstrated considerable level of homogeneity as evidenced by small standard deviations in all series. VIF results from Table 2 confirm that multicollinearity is not a serious concern for the choice of explanatory variables in this study and as such, it allows for proceeding with the dataset of the current study for further analysis.

3.3. Estimation procedures

3.3.1. Unit root tests

Despite significant positive developments on several fronts, South Africa's economy has been characterized by numerous elements that potentially cause uncertainties. The key factors that may potentially contribute towards such uncertainties include rising income inequality, rampant corruption, and poverty. Nevertheless, various global shocks might also have some spill-over and trickle-down effects on South African economy. Therefore, it is not unlikely that South African macro data on these variables would potentially be characterized by structural breaks during the sample period. In the first instance, this study exploits Zivot and Andrews (2002) unit root test which takes into account only one structural break in data. For a variable X, the functional forms of the unit root tests can be written as;

$$\Delta X_t = \varphi + \varphi X_{t-1} + bT + cDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \qquad (2)$$

Table 1

Data sources and summary statistics.

Source	Definition	Variables	Obs.	Mean	Std. Dev.	Min	Max
World Bank, 2018	CO_2 emissions (metric tons per capita)	CO_2	33	8.8259	0.6049	7.5838	9.8706
	GDP per capita (constant 2010, US$)	lnGDPPC	33	8.3151	0.3707	7.6489	8.9945
	Access to electricity (% of population)	lnENPOV	33	4.2655	0.1473	4.0535	4.4543
	Urban population (% of total)	lnURB	33	4.0403	0.0868	3.8936	4.1789
KOF Swiss Economic Institute (2018)	Globalization index	lnGLO	33	4.0046	0.2084	3.7113	4.2353

Source: own calculations.

Table 2

Variance inflation factor (VIF).

Variable	VIF	1/VIF
lnENPOV	1.17	0.851551
lnGDPPC	1.15	0.870431
lnGLO	1.23	0.816151
lnURB	1	0.996075
Mean VIF	1.14	

$$\Delta X_t = \delta + \delta X_{t-1} + cT + bDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \quad (3)$$

$$\Delta X_t = \psi + \psi X_{t-1} + cT + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \quad (4)$$

$$\Delta X_t = \omega + \omega X_{t-1} + cT + dD_t + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \quad (5)$$

where D stands for dummy variable demonstrating mean shift at each point and DT_t depicts trend in data. Under this test, the null hypothesis is in support of the presence of a unit root with a single structural break while the alternative hypothesis rules out any such possibility.

3.3.2. Multiple structural breaks unit root test

3.3.2.1. Bai and Perron (2003) multiple structural break test. Since macro time series data are likely to be exposed to various local and external shocks in the economy over time, the possibility of multiple breaks in such data can't be ruled out. Therefore, this study conducts another structural break test (Bai, 1999; Bai and Perron, 2003) which allows for multiple breaks in data. This method gained popularity due to its simplicity and ease in application.

3.3.2.2. Unit root test under multiple structural break points. The multiple structural break test described above unravels five structural break points in the series. As such, an appropriate unit root test provided by Carrion-i-Silvestre et al. (2009) is conducted. This test applies quasi-generalized least squares (GLS) technique which is an extension of the detrending of data advocated by Elliott et al. (1996). A key feature of this test is that it can accommodate random shocks at both level and slope of the trend. The null hypothesis of the Carrion-i-Silvestre et al. (2009) tests state that five structural breaks exist in the data with a unit root (Carrion-i-Silvestre et al., 2009).

The presence of five structural breaks are determined through the critical values of five statistics which are PT (Gaussian point optimal statistic), MPT (modified feasible point optimal statistic) MZα MSB and MZt. The critical values are obtained through the bootstrap method.

3.3.3. Cointegration test: ARDL bounds testing approach to cointegration

Because, the unit root tests have uncovered the fact that variables in this study are integrated with mixed order of integration [I(0) and I(1)], the Autoregressive Distributed Lag (ARDL) bounds test is preferred to verify the existence of cointegration as well as ARDL estimation method

for estimating short-run and long-run coefficients. ARDL technique has some other advantages also over other traditional methods. First, it can be performed using simple reduced form equation (Duasa, 2007). Second, the ARDL method provides both reliable and robust results even for data with small sample. Fifth, it also estimates an error correction term (ECT) which shows the speed at which short-run disequilibrium would be converging towards the long-run equilibrium. This ECT coefficient provides with an insight into how short-run polices could be more effective towards achieving long-run policy goals set by a government. Finally, this method provides with the liberty of altering optimal lags as required. All these advantages prompted this study pick ARDL method for the estimation of data.

Next, ARDL equations constructed from the baseline model are presented below as:

$$\Delta CO_{2t} = \beta_0 + \alpha_1 CO_{2t-1} + \alpha_2 lnURB_{t-1} + \alpha_3 lnGLO_{t-1} + \alpha_4 lnGDPC_{t-1}$$
$$+ \alpha_5 lnENPOV_{t-1} + \sum_{i=1}^{n} \beta_{1i} \Delta lnCO_{2t-i} + \sum_{i=0}^{n} \beta_{2i} \Delta lnURB_{t-i}$$
$$+ \sum_{i=0}^{n} \beta_{3i} \Delta lnGLO_{t-i} + \sum_{i=0}^{n} \beta_{4i} \Delta lnGDPPC_{t-i} + \sum_{i=0}^{n} \beta_{5i} \Delta lnENPOV_{t-i} + \mu_{1t}$$

$$(6)$$

Where $\beta_{1i} - \beta_{5i}$, $\alpha_1 - \alpha_5$ are coefficients, β_0 is a constant and, μ_{1t} is white noise error term. Next, the error correction model is specified as follows:

$$\Delta CO_{2t} = \beta_0 + \sum_{i=1}^{n} \beta_{1i} \Delta CO_{2t-i} + \sum_{i=0}^{n} \beta_{2i} \Delta lnURB_{t-i} + \sum_{i=0}^{n} \beta_{3i} \Delta lnGLO_{t-i}$$
$$+ \sum_{i=0}^{n} \beta_{4i} \Delta lnGDPPC_{t-i} + \sum_{i=0}^{n} \beta_{5i} \Delta lnENPOV_{t-i} + \mu_t \quad (7)$$

ARDL bounds test is a Wald Test or an F-test that determines the joint significance of the coefficients of the lagged variables. The null hypothesis, H_0 indicates the absence of a cointegrating vector against the alternative hypothesis in favor of its presence. The upper and lower bounds critical values are obtained from Pesaran et al. (2001). If and when a cointegrating association among variables is observed, obtaining short-run and long-run coefficients of the explanatory variables becomes imperative.

3.3.4. Toda-Yamamato (TY) causality test

A key weakness of Granger causality test (Granger, 1969) is that it is not indifferent to the change in the order of integration. Therefore, this study conducts TY causality test (Toda and Yamamoto, 1995) that can assess the causal association among variables regardless of the order of integration. The following multivariate Eqs. (8), (9), and (10) demonstrate the causality pattern among variables when we consider only core independent variables, urbanization and globalization along with the dependent variable, CO_2 emissions;

$$CO_{2t} = \alpha_1 + \sum_{i=1}^{m} \varphi_i CO_{2(t-i)} + \sum_{i=m+1}^{m+d_{max}} \varphi_{2i} CO_{2(t-j)} + \sum_{i=1}^{m} \delta_i lnURB_{t-i}$$
$$+ \sum_{i=m+1}^{m+d_{max}} \delta_{2i} lnURB_{t-j} + \sum_{i=1}^{m} \varphi_i lnGLO_{t-i} + \sum_{i=m+1}^{m+d_{max}} \varphi_{2i} lnGLO_{t-j} + \varepsilon_{1t} \quad (8)$$

Table 3
Zivot and Andrews Unit root test.

Variables	Levels			1st Difference		
	T-statistic	Time break	Decision	T-statistic	Time break	Decision
CO_2	−3.886	2003	Unit root	−6.684***	2010	Stationary
lnENPOV	−3.463	2002	Unit root	−12.611***	1997	Stationary
lnGDPPC	−4.394	2003	Unit root	−7.204***	2003	Stationary
lnURB	−5.301**	2011	Stationary			
lnGLO	−3.442	1997	Unit root	−6.115***	1993	Stationary

Note: *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

$$lnURB_t = \alpha_2 + \sum_{i=1}^{m} \beta_i lnURB_{t-i} + \sum_{i=m+1}^{m+d_{max}} \beta_{2i} lnURB_{t-j} + \sum_{i=1}^{m} \gamma_i lnGLO_{t-i}$$
$$+ \sum_{i=m+1}^{m+d_{max}} \gamma_{2i} lnGLO_{t-j} + \sum_{i=1}^{m} \psi_i CO_{2t(t-i)} + \sum_{i=m+1}^{m+d_{max}} \psi_{2i} CO_{2(t-j)} + \varepsilon_{2t} \quad (9)$$

$$lnGLO_t = \alpha_3 + \sum_{i=1}^{m} \chi_i lnGLO_{t-i} + \sum_{i=m+1}^{m+d_{max}} \chi_{2i} lnGLO_{t-j} + \sum_{i=1}^{m} \kappa_i lnURB_{t-i}$$
$$+ \sum_{i=m+1}^{m+d_{max}} \kappa_{2i} lnURB_{t-j} + \sum_{i=1}^{m} \mu_i CO_{2(t-i)} + \sum_{i=m+1}^{m+d_{max}} \mu_{2i} CO_{2(t-j)} + \varepsilon_{3t} \quad (10)$$

3.3.5. Variance decomposition analysis

With a view to assessing the potential future influence of variables urbanization and globalization on CO_2 emissions, this study employs variance decomposition method (Pesaran and Shin, 1998). Variance decomposition estimates the percentage of influence of each independent variable on the error variance of the dependent variable (Pesaran and Shin, 1998) for a period beyond the sample. It is argued that variance

Table 4
Bai-Perron tests of multiple breakpoints.

	Levels				Break years
	F-statistic	Scaled F-statistic	Weighted F-statistic	Critical Value	
CO_2	20.91***	20.91	50.34	4.91	1990; 1999; 2003; 2007; 2011
lnENPOV	203.14***	203.14	508.47	4.91	1992; 1997; 2002; 2007; 2011
lnGDPPC	66.49***	66.49	166.44	4.91	1988; 1998; 2004; 2009; 2013
lnURB	195.11***	195.11	488.36	4.91	1989; 1994; 2000; 2005; 2011
lnGLO	329.13***	329.13	823.83	4.91	1988; 1995; 1999; 2004; 2011
	First differences				
ΔCO_2	3.51	3.51	8.78	4.91	1989; 1993; 1998; 2003; 2009
ΔlnENPOV	5.45***	1.45	3.64	4.91	1993; 1997; 2001; 2005; 2013
ΔlnGDPPC	4.08	4.08	10.21	4.91	1990; 1998; 2003; 2007; 2012
ΔlnURB	3.58***	2.90	7.26	4.91	1992; 1997; 2002; 2008; 2013
ΔlnGLO	4.43	4.43	11.10	4.91	1990; 1995; 2000; 2004; 2008

*** shows 1% level of significance.

decomposition provides more reliable results about such influence of the independent variables on the dependent variable than other methods (Engle and Granger, 1987; Ibrahim, 2005).

4. Results and discussion

Table 3 reports results obtained from Zivot and Andrews (2002) single structural break unit root test which demonstrates a mixed order of integration for variables. Variable urbanization is reported to be stationary at levels [I(0)] while all other variables are reported to be first difference stationary [I(1)]. Most of the series are characterized by a single structural break during the period of early and late 1990s and 2000s.

Given the continuously evolving dynamics in both global and local economic and political landscapes, it was imperative to detect the potential presence of multiple structural breaks in the series of variables. As such, Table 4 presents Bai and Perron (2003) multiple structural breaks test results which confirm the detection of a total of five structural break points in the data. The presence of such structural breaks imply that South Africa may have continued to bear the scars of the downsides of the apartheid era even after it was dismantled in early 1990s. Besides, its struggle to cope with the spill-over and trickle-down effects of global shocks such as the global financial crisis in late 2000s may also be attributed to such breaks in data. Table 5 reports results from the Carrion-i-Silvestre et al. (2009) unit root test which confirm that all variables are integrated of order 1, [I(1)], i.e. first difference stationary.

Table 6 reports results from ARDL cointegration. The F-statistics is 16.266 at 1% level of significance. The calculated F-statistics is compared to the Pesaran et al. (2001) critical values. The calculated F statistics found to be greater than the upper critical bounds (UCB) values. This confirms a highly significant presence of cointegration among the variables. Once such cointegrating association is established, estimating short-run and long-run coefficients of the variables are in order. However, such estimations precede the selection of optimal lag length. This study prefers Bayesian Information Criteria (BIC) for the selection of the optimal lag length. BIC is believed to produce more parsimonious results than the Akaike Information Criteria (AIC) based models. The optimal lag length selected for the Model is ARDL (3, 3, 1, 2, 1).

Table 7 provides the short- and the long-run coefficients of explanatory variables. The regression results show that urbanization stimulates CO_2 emissions both in the long-run and the short-run. Such effects in both short-run and long-run are statistically significant. Toda-Yamamoto non-causality test reports a bi-directional causal link between urbanization and CO_2 emissions. The finding of the positive stimulating long-run causal effect of urbanization on CO_2 emissions is supportive of the urban environmental transition theory.

From the perspective of this theory, such a finding is based on a couple of arguments; a) urban cities are generally characterized by rapid industrialization that causes emissions and b) the consumption pattern of urbanites is generally more carbon intensive than their rural counterparts. Both these arguments corroborate the realities in South Africa which has experienced a rapid urban sprawling in the last two decades. Large cities (such as Johannesburg, Cape Town, Pretoria and Durban) which are at a post-industrial phase, are exposed to severe emissions due

Table 5
The quasi-GLS based unit root tests under multiple structural breaks.

	Levels					Break years
	P_T	MP_T	MZ_α	MSB	MZ_T	
CO_2	17.47 [6.54]	18.08 [6.54]	−20.67 [−41.75]	0.14 [0.10]	−4.13 [−4.66]	1990; 1999; 2003; 2007; 2011
lnENPOV	19.32 [9.09]	20.45 [9.09]	−21.15 [−43.44]	0.16 [0.10]	−4.42 [−3.27]	1992; 1997; 2002; 2007; 2011
lnGDPPC	18.66 [8.33]	28.89 [8.33]	−20.37 [−45.26]	0.21 [0.12]	−3.57 [−4.83]	1988; 1998; 2004; 2009; 2013
lnURB	17.65 [8.17]	17.13 [8.17]	−21.54 [−44.17]	0.15 [0.11]	−3.30 [−4.66]	1989; 1994; 2000; 2005; 2011
lnGLO	20.21 [9.23]	19.88 [9.23]	−20.73 [−43.77]	0.14 [0.10]	−3.30 [−4.15]	1988; 1995; 1999; 2004; 2011
	First differences					
ΔCO_2	4.24* [5.54]	5.35* [5.54]	−18.38* [−23.15]	0.13* [0.18]	−3.25* [−3.89]	–
ΔlnENPOV	4.36* [5.54]	5.37* [5.54]	−20.46* [−21.56]	0.14* [0.16]	−3.22* [−3.89]	–
ΔlnGDPPC	5.59* [5.54]	4.74* [5.54]	−20.33* [−18.66]	0.14* [0.17]	−3.13* [−4.18]	–
ΔlnURB	5.44* [5.54]	5.38* [5.54]	−19.64* [−32.31]	0.15* [0.16]	−3.44* [−3.89]	–
ΔlnGLO	4.34* [5.54]	4.55* [5.54]	−18.49* [−22.31]	0.14* [0.16]	−3.26* [−4.37]	–

Note: i. Break years are obtained through using the quasi GLS-based unit root tests of Carrion-i-Silvestre et al. (2009). Ii. * denotes the rejection of the null hypothesis of a unit root at the customary 0.05 level of significance. Iii. Numbers in brackets are critical values from the bootstrap approach by Carrion-i-Silvestre et al. (2009).

Table 6
ARDL cointegration results and critical values.

Independent variables	Function		F-statistic		Cointegration Status	
CO_2	F (lnENPOV, lnGDPPC, lnURB, lnGLO)		16.266***		Cointegrated	
Assymptotic Critical Values (unrestricted intercept and no trend)						
Pesaran et al. (2001:300) critical values (Table CI(iii) Case III)	10%		5%		1%	
	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
	2.62	3.35	2.26	3.79	3.41	4.68

Note: *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

to higher level of energy consumption emanating from massive growth in private residential housing sector and public utility services such as public transport, health, water supply, sanitation and so on. In small cities, the emissions-enhancing effect of urbanization may be associated with gradual industrial development that causes higher energy consumption and subsequent larger emissions. The finding of this study is consistent with almost all previous time series studies (Liu and Bae, 2018; Franco et al., 2017; Shahbaz et al., 2016; Wang et al., 2016, 2018; Zhang et al., 2015) on urbanization-CO_2 emissions nexus.

Table 7
ARDL long and short runs results.

Dependent Variable = CO_2			
Long run analysis			
Variables	Coefficient	Standard Error	T-statistics [Prob]
Constant	37.2762	20.6558	1.8046 [0.083]
lnENPOV	6.3010	5.5919	1.1268 [0.270]
lnGDPPC	1.5633	1.1049	1.4148 [0.169]
lnURB	−18.4742	9.4526	−1.9544 [0.061]
lnGLO	1.5680	3.4787	0.45073 [0.656]
R^2	0.62561		
Adjusted R^2	0.61137		
Short run analysis			
Variables	Coefficient	Standard Error	T-statistics [Prob]
Constant	15.2927	9.8961	1.5453 [0.134]
ΔlnENPOV	2.5851	2.0401	1.2671 [0.216]
ΔlnGDPPC	0.64134	0.53242	1.2046 [0.239]
Δ lnURB	−7.5791	4.2043	−1.8027 [0.083]
ΔlnGLO	0.64327	1.4788	0.43499 [0.667]
ECMt-1	−0.41025	0.14110	−2.9075 [0.007]
R^2	0.30655		
Adjusted R^2	0.29543		
F-statistic	8.5986 [.000]		
D. W	1.9230		
Short Run Diagnostic Tests			
Test	F-statistic	Prob. value	
χ^2SERIAL	0.0023448	0.962	
χ^2ARCH	0.62675	0.453	
χ^2RAMSEY	0.20915	0.651	

Another core independent variable, globalization is reported to exert a negative significant effect on CO_2 emissions in the long-run but no significant effect is observed in the short-run from ARDL estimates. No causal association between them is reported from the Toda-Yamamoto non-causality test results. The long-run significant coefficient implies that higher level of globalization induces a decline in CO_2 emissions. This study attributes such a long-run effect of globalization on CO_2 emissions to the fact that South Africa has already reached a post-take off stage of globalization with its economy being increasingly integrated into the global economy during the last two decades. This long-run result partially corroborates the neo-liberal argument of positive effects of globalization (Navarro, 1998).

Such a positive effect of globalization on CO_2 emissions reduction is corroborated by Porter's Hypothesis which states that with a rise in income from globalization, developing countries experience a more successful implementation of environmental regulations that enable them adopt a more environment-friendly production pattern which eventually reduces pollution and intensifies competitiveness (Porter and Van der Linde, 1995; Mani and Wheeler, 1998). The finding of CO_2 emissions-reduction effect of globalization is highly consistent with those of several recent empirical studies (Haseeb et al., 2018; Lv and Xu, 2018; You and Lv, 2018). However, such a finding sharply contrasts with the that of Shahbaz et al. (2015) for India.

Another possible explanation for a potentially CO_2 emissions-reduction effect of globalization is that a highly globalized country like South Africa is potentially more likely to benefit from globalization-induced new technologies than those relatively less globalized. Furthermore, as globalization facilitates a greater and faster flow of and access to information and knowledge, it is likely that South Africa would not squander these information and knowledge capital to achieve positive environmental effects from increased and more liberalized international trade. This supposition is very true based on the premise that corporate globalization is widespread now-a-days and as such, corporations are more actively engaged than ever before in transferring clean technologies from developed to developing countries.

Table 8
Toda-Yamamoto causality test.

	Chi-sq	Prob.		Chi-sq	Prob.
$\Delta CO_2 \rightarrow \Delta lnENPOV$	5.464	0.243	$\Delta lnENPOV \rightarrow \Delta CO_2$	0.931	0.920
$\Delta CO_2 \rightarrow \Delta lnGDPPC$	64.072	0.000	$\Delta lnGDPPC \rightarrow \Delta CO_2$	6.490	0.165
$\Delta CO_2 \rightarrow \Delta lnGLO$	2.129	0.712	$\Delta lnGLO \rightarrow \Delta CO_2$	0.703	0.951
$\Delta CO_2 \rightarrow \Delta lnURB$	7.261	0.123	$\Delta lnURB \rightarrow \Delta CO_2$	8.146	0.086
$\Delta lnENPOV \rightarrow \Delta lnGDPPC$	53.698	0.000	$\Delta lnGDPPC \rightarrow \Delta lnENPOV$	8.944	0.063
$\Delta lnENPOV \rightarrow \Delta lnGLO$	7.130	0.129	$\Delta lnGLO \rightarrow \Delta lnENPOV$	13.198	0.010
$\Delta lnENPOV \rightarrow \Delta lnURB$	9.443	0.051	$\Delta lnURB \rightarrow \Delta lnENPOV$	2.263	0.688
$\Delta lnGDPPC \rightarrow \Delta lnGLO$	10.550	0.032	$\Delta lnGLO \rightarrow \Delta lnGDPPC$	95.414	0.000
$\Delta lnGDPPC \rightarrow \Delta lnURB$	5.794	0.215	$\Delta lnURB \rightarrow \Delta lnGDPPC$	136.416	0.000
$\Delta lnGLO \rightarrow \Delta lnURB$	9.146	0.058	$\Delta lnURB \rightarrow \Delta lnGLO$	16.229	0.003

Although, no short-run and long-run significant coefficients on energy poverty and economic growth with CO_2 emissions are obtained from ARDL estimates, unidirectional causal associations running from energy poverty and economic growth to CO_2 emissions are observed as evident from Table 8. Predominant use of non-renewable fossil fuels such as coal in electricity generation might be attributed to such findings for South Africa. Also, these results send a clear signal that South Africa needs to boost its ongoing efforts and their effectiveness to achieve environmental sustainability. Its energy efficiency goal is yet to be accomplished.

Fig. 1 demonstrates plots of CUSUM and CUSUMSQ for the estimated model in this study. The CUSUM and CUSUMSQ plots show that the ARDL parameters in this model are stable at 5% bounds. The graphical plots of CUSUM and CUSUM sum of squares (Fig. 1A, and 1B respectively) reveal that the parameters of the model are stable over time.

Results from the variance decomposition analysis are reported in Table 9. It is evident that all explanatory variables will continue to have some effects on future CO_2 emissions in South Africa. The findings indicate that a 1% variation in urbanization and globalization will lead to a variation in CO_2 emissions by 0.13% and 2.42% respectively during a 10-year period horizon behind the sample period. The highest variation in CO_2 emissions however is forecasted to be explained by economic growth seconded by energy poverty during the same period.

5. Discussion & conclusions

South Africa is the most urbanized and the most globalized country in SSA region. It is also one of the most carbon intensive countries in the world. Despite many good achievements on the economic front since the debacle of apartheid almost three decades back, South Africa is still struggling with high levels of income inequality, corruption, poverty, and climate change risk. The literature on urbanization and globalization reveal how these two factors have been linked to environmental concerns. In the light of this background, this study analyses time series data of South Africa (1984–2017) in order to examine the effects of urbanization, globalization, economic growth and energy poverty on CO_2 emissions.

After detecting structural breaks through Zivot and Andrews and Bai and Perron unit root tests, this study applied ARDL estimation technique to first of all, assess cointegration and then estimate the short run and long-run coefficients on the relevant variables. Toda-Yamamoto causality test and variance decomposition analysis were also performed on the data. Findings suggest that urbanization stimulates CO_2 emissions both in the short-run and the long-run. A bi-directional causal link between urbanization and CO_2 emissions is also reported. Although, no causal effect between globalization and CO_2 emissions is reported, globalization is observed to negatively affect CO_2 emissions in the long run as evident from its significant long-run coefficient from ARDL estimates. Both economic growth and energy poverty cause CO_2 emissions regardless of their insignificant coefficients from ARDL estimates. Variance decomposition results revealed that all the independent variables are expected to continue to stimulate CO_2 emissions in the future also.

Such a set of findings offer a number of policy implications for South Africa. First of all, despite insignificant short-run and long-run effects of economic growth on CO_2 emissions, the presence of a causal link between them deserves attention. Nevertheless, such a causal link also lends support to the argument that South Africa's stable economic growth over the years has an environmental opportunity cost. This claim is further reinforced with energy poverty causing a rise in CO_2 emissions endorsing energy-led emissions for South Africa-a phenomenon that is observed in majority of the countries. South Africa which already confronts a number of challenges including poverty, income inequality, corruption and a deteriorating health system can't simply afford to compromise its pro-growth policies for combating emissions. Therefore,
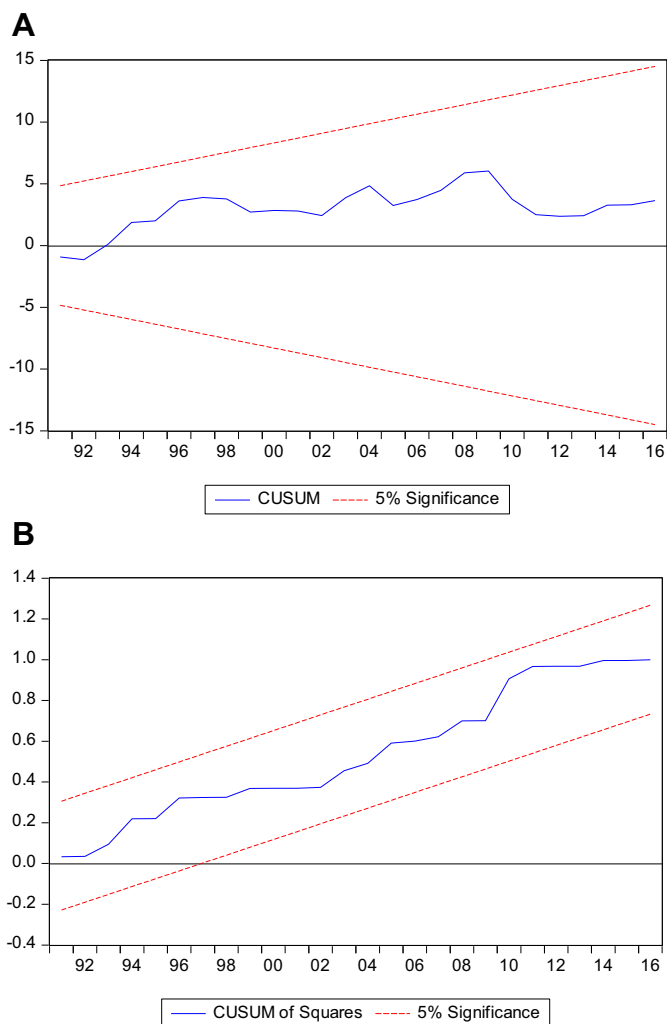
Fig. 1. A: Plot of cumulative sum of recursive residuals. B: Plot of cumulative sum of squares of recursive residuals.

Table 9
Variance decomposition of CO_2.

Period	CO_2	lnENPOV	lnGDPPC	lnURB	lnGLO
1	100	0.0000	0.0000	0.0000	0.0000
2	94.2567	0.6457	3.5658	0.0197	1.5120
3	91.4005	1.2513	4.8522	0.0621	2.4340
4	90.2328	2.3918	4.8427	0.1144	2.4183
5	89.0520	3.6135	4.7876	0.1340	2.4129
6	88.8874	3.7846	4.7793	0.1341	2.4146
7	88.7640	3.8754	4.8059	0.1355	2.4192
8	88.7186	3.9220	4.8035	0.1361	2.4198
9	88.6878	3.9516	4.8022	0.1374	2.4210
10	88.6855	3.9538	4.8024	0.1374	2.4209

it must opt for other options for reducing emissions and the most promising such option is undisputedly none other than invigorating its efforts for promoting the use of renewables in its energy production gradually switching from a mostly coal-fired generation of energy to a renewables-based energy production method. Understandably, there is no other optimum choice for South Africa for a transition to a low-carbon economy at this point.

Massive growth in urban sprawling and its adverse effect on emissions is not unexpected for a fast growing upper-middle income economy like South Africa. Growth in public and private infrastructure as a result of increased urbanization is a key contributor to increased emissions. Construction, maintenance and operation of such infrastructures always involve energy-intensive resources that contribute to raise the level of emissions. Such an adverse emissions effect of urbanization for South Africa corroborates the findings of Wang et al. (2018). Since, for a growing economy like South Africa, decelerating the speed of urbanization can not be a viable option to reduce or offset its negative environmental consequences, one potential way to mitigate such urbanization-led emissions may be through a planned and organized urbanization. To do so, it is important that a threshold point of urbanization is identified where urbanization-led CO_2 emissions start to decline from. In other words, a point of divorce between urbanization and CO_2 emissions needs to be singled out for appropriate actions to potentially reduce the emissions effect of urbanization.

The positive long-run effect of globalization in reducing CO_2 emissions contradicts with the "pollution haven'' hypothesis which states that trade openness induced by globalization results in industry flight that causes emissions to rise but supports the "California effect'' hypothesis that highlights the positive role of globalization in reducing emissions (Vogel, 1995). According to this hypothesis, globalization-induced trade openness potentially acts as a vehicle for transmission of new technologies, faster spread and exchange of knowledge, rapid information dissemination and thus enables countries adopt environment-friendly cleaner technologies replacing those based on non-renewable fossil-fuels. South Africa can also enhance its emissions-abatement potential by exploiting advantages from its integration with BRICS (Brazil, Russia, India, China and South Africa). Its other partners in BRICS especially Brazil, India and China are also some of the leading CO_2 emitters in the world. The formation of BRICS brings to these countries an opportunity to share their energy strategies and work to improve their energy scenarios through coordinated efforts.

From the various energy policies currently being implemented, it is evident that South African government is strongly dedicated towards promoting RE use in its energy mix but unfortunately, the outcomes from the implementation of such policies are not yet up to the desired level. In other words, the effectiveness of such policies in combating emissions is far from being satisfactory. What is missing then? Unlike most of the previous works, this study tends to attribute such a failure to its poor governance.

The country miserably suffers from poor law and order, rampant corruption, lack of accountability, high rates of poverty and inequality. To address these concerns, the quality of governance must be improved.

Once the quality of governance is improved, the implementation and the effectiveness of government's renewable energy policies and other policies are expected to be more outcomes-oriented. With improved quality of governance, it is also likely to be much easier for the government to ratchet-up its efforts to build a strong public-private partnership to promote investment in renewable energy sector. Since South Africa boasts a highly developed financial market system (Haseeb et al., 2018), the financial institutions may motivate investment in less-polluting industries by facilitating loans on soft and flexible conditions while de-motivating high polluting industries by constraining loanable funds through stringent and tough conditions.

The findings of this study are expected to provide a direction to many other developing emerging countries in different regions especially in SSA. Apart from South Africa, many other SSA countries are blessed with significant potential in renewable energy sources such as wind, solar energy, biofuel and hydro power (Salahuddin et al., 2018). Despite various policy initiatives to promote RE use in their energy mix, the outcomes from the implementation of such policies in these countries are not satisfactory perhaps due to poor governance pertaining to these countries. Many other emerging but yet developing economies in other parts of the world characterized by high growth potentials while simultaneously plagued with poor governance might also be benefitted from the findings of this study with regards to their policy-pursuits for a renewable energy-based sustainable environment.

Last but not the least, this study undoubtedly suffers from certain limitations. First of all, findings from this study should not be treated unique as they are not expected to be invariant across a spectrum of other econometric specifications than the ones used in here. Nevertheless, due to uncommon country-specific characteristics, even similar renewable energy policies are likely to exert heterogeneous effects on the energy landscapes of different countries even with comparable RE potentials and as such, this constrains the generalizability of the findings of this study. Another potential weakness is that the sample period of data analysed in this study is only 36 years (n = 33) due to non-availability of data for longer period. Certainly data with longer sample period is expected to provide more reliable results. Finally, the model estimated in this study suffers from another caveat. The study is still likely to be plagued with omission bias despite the inclusion of two additional variables; economic growth and energy poverty. There is highly likely that some excluded potential variables can also influence CO_2 emissions of a country. One such important variable may be quality of governance. Poor governance might potentially undermine the effectiveness of RE policies in many emerging countries like South Africa. Therefore, it may be interesting to investigate how lack of good governance affects quality of environment in these countries. This may be a worthy panel investigation. This is left to be dug in future research.

Declarations

Author contribution statement

Mohammad Salahuddin: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Jeff Gow: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Md. Idris Ali: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Md. Rahat Hossain: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Khaleda Shaheen Al-Azami, Ayfer Gedikli: Contributed reagents, materials, analysis tools or data.

Delwar Akbar: Analyzed and interpreted the data.

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