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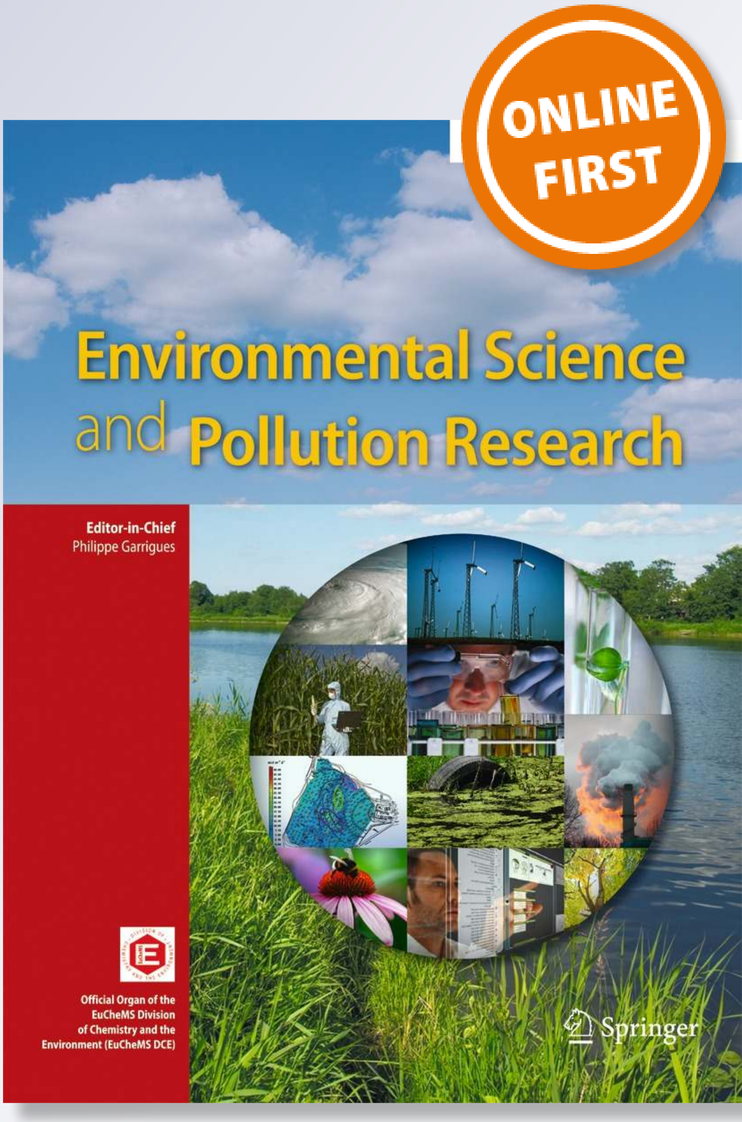

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RESEARCH ARTICLE

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Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded

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Abstract

The study explores the relationship between ecological footprint, urbanization, and energy consumption by applying the ARDL estimation technique on data spanning 1965–2014 for South Africa. After applying the unit root test that accounts for a break in the data, the Bayer and Hanck (J Time Ser Anal 34:83–95, 2013) combined cointegration test affirms cointegrating relationship among the variables. Findings further reveal that economic growth and financial development exact a deteriorating impact on the environment in the short run. However, the same was not true for both energy use and urbanization. While urbanization and energy use promote environmental quality in the long run, financial development and economic growth degrade it further. The long-run findings of our study are confirmed to be robust as reported by the fully modified OLS (FMOLS), dynamic OLS (DOLS), and the canonical cointegrating regression (CCR) estimates. The direction of causality supports the energy-led growth hypothesis for South Africa. Policy outcomes and directions, and the possibility of promoting sustainable growth without degrading the environment are discussed.

Keywords Ecological footprint · Energy use · Urbanization · Economic growth · South Africa

JEL classification Q43 · O13 · Q32

Introduction

Environmental degradation is now a major concern in global economies. The most challenging attack on humanity in this twenty-first century is not really terrorism or unemployment, but the dehumanizing effect of global warming (Charfeddine et al. 2018). This has become a serious concern to the world due to its increasing impact on human existence through increasing desertification, sea level rising, and damaging effects on agriculture especially in developing nations (Ross et al.

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2016). However, the increasing global warming has been attributed to many factors such as energy use which emits CO_2 emissions, the main greenhouse gas in terms of quantity, since IPCC (2007) estimated that CO_2 emission accounts for 76.7% of the whole greenhouse gas so far. This effect of CO_2 emissions is severed because it is accompanied by the growth of industries and increasing openness of economies (Martínez-Zarzoso and Maruotti 2011). Since industrial growth increases energy use as well as environmental degradation, trade openness coupled with improvement in the standard of living which has prolonged the life expectancy rate, reduction in average child mortality leading to a massive increase in the population of the world today. It has been inferred that the world is growing at the rate 1.5% annually with the estimation that by the year 2050, the population of the world will be over ten (10) billion.

Since the rate of urban development varies based on the geographical region, it is also pertinent to note that developing economies are fast growing in terms of population and it is presumed that a much bigger portion of the energy use will come from developing economies bearing in mind that CO_2 emissions in the developing economies is increasing greatly and will still be on the increase naturally (Hossain 2011; Okunola et al. 2018). According to Al-mulali and Binti Che Sab (2012), CO_2 emission of economies in this category may likely surpass that of the well-developed countries in the next 30 years, hence there is a need for affirmative action.

While developing economies have been slow to take curative measures towards reducing environmental degradation, arguing that the major culprits, the advanced economies, should take action first even when the developed economies are already working massively to reduce environmental degradation, hence there is need for greater attention on developing nations in a bid to explore the consequences of the increasing energy use.

Since a couple of decades ago, researchers of different origin have studied the factors that motivate environmental degradation applying the Kuznets Curve methodology, and a majority of the findings are in favor of the Kuznets projections (Perman and Stern 2003). Also, an attempt has been made recently to decompose the analysis by taking account of affluence and also technical and structural changes amidst energy intensity as (see Puzon 2012; Pen and Shi 2010; Çetin and Ecevit 2015). With all these different methodologies applied by the various studies in finding the influence of some factors on degradation with no concern for methodological blunders on some of the studies, perhaps, degradation still persists cause of poor methodology in studying the menace.

The choice of South Africa was based on the fact that it (South Africa) happens to be one of the largest economies in Africa. The immigration rate to the country, especially from other Africa countries, over the years has been unprecedented. This on its own has contributed to an increase in energy consumption which could also trigger environmental degradation since South Africa energy consumption (majorly coal) is largely non-renewable. Relatively, just a few attempts have been made to study the effect of urbanization and even energy use on environmental degradation (especially in South Africa). Also, most studies in this area have narrowed environment degradation to just CO_2 emission without putting into consideration the effect of individuals on the environment which can be expressed on the needed land space for sustainable use of natural resources. This individual effect on the environment largely referred to as ecological footprints (EF) is seen as the impact of humanity on the Earth's ecosystem and it reveals the dependence of the human economy on natural capital (Lin et al. 2015). However, this is the first attempt to study the South Africa economy in the framework of a leading developing economy considering the increasing energy use in South Africa. This study adds to the existing literature in the following ways: (i) To the best of our knowledge, this study is the first to explore the energy-environment nexus for South Africa with EF (which is a more aggregate indicator and captures environmental degradation better than CO_2 emissions) as a measure of environmental degradation, as opposed to previous studies which used CO_2 emissions. (ii) Economic episodes offer structural break dates in time series data especially our focus data energy use, financial development, urbanization, and real GDP per capita due to the implementation of economic policies. These structural breaks are enough to change the unit root results, causality, and the effect of each of the variables on the dependent variable (EF). Hence, structural break unit root test which was not considered, especially for studies in South Africa (Khobai and Le Roux 2017; Okafor 2012; Menyah and Wolde-Rufael 2010; Khobai 2017) is employed. (iii) The Bayer and Hanck (2013) recent cointegration test and Pesaran's ARDL bounds test were utilized while controlling for possible structural breaks over the period examined.

Therefore, the study aims to examine the impact of urbanization and energy use on environment degradation in South Africa by using the ARDL, FMOLS, DOLS, and CCR econometrics methodology combined with Bayer and Hanck (2013) cointegration tests to test for long-run relationship amidst structural break. Ecological footprints (EF) instead of CO_2 emissions are used to proxy environmental degradation. Following the works of Charfeddine (2017) and Jorgenson (2016), the ecological footprints variable is modelled in relation to per capita income level, energy use, urban population, and financial development.

The article is grouped into five sections: section one is the introduction, the second section presents a stylized fact of South Africa's energy use and a brief review of relevant literature. The third section shows the methodology and model specification; the fourth section is the analysis of the result and discussion of the findings, while section five presents the conclusion of the work with relevant policy direction.

Literature review

Stylized facts of energy use in South Africa

South Africa has the potential to be energy efficient, as well as, increase the share of renewable energy in its energy portfolio. About 93% of its energy is generated from coal. This goes to explain why South Africa is the 12th largest emitter of CO_2 in the world, and the 1st in Africa (USAID 2016). This has made the investment in renewable energy inevitable, not only to meet the country's energy needs but also to create jobs and abate emissions. This is in line with the country's National Development Plan to install 17,800 MW of renewable energies. This, the government plan to achieve by installing 8400, 1000, and 8400 MW of wind, concentrated solar and photovoltaic energies respectively by 2030.

The recent attention accorded to the use of renewable energy in South Africa was due to the energy crisis befell the country in 2008. Over the years, the country has found it difficult to meet the energy demand of its ever-increasing population. For instance, Fig. 1 shows the energy demand by sectors as of 2010. The industrial sector takes the lead, closely followed by transport, and then residential. However, a recent report by the Department of Energy (DoE) showed that, in 2015, residential demand for energy has since increased to 27%. That of agriculture reduced to 2%, while that of the industrial sector remained unchanged (36%). Over the years, coal has remained the major source of energy in South Africa (Maleka et al. 2010). As of 2016, the contribution of coal to total energy generation was 85.7%. There has also been an

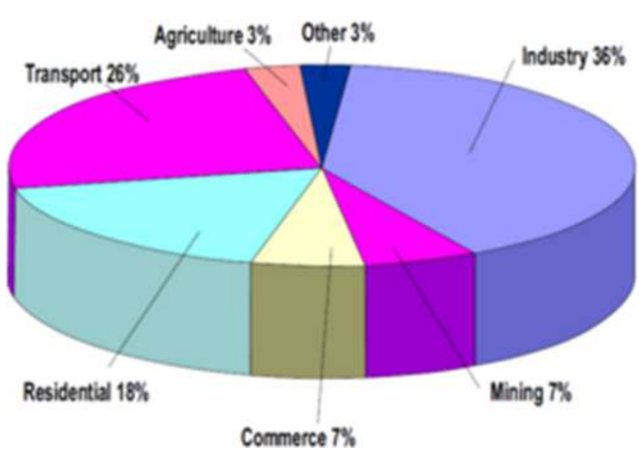

Fig. 1 Sectoral energy demand in South Africa. Source: Department of Energy, South African Energy Synopsis 2010

increase in the contributions of nuclear energy as it sails to 5.2%. Natural gas contributes 3.2%, while 1.7%, 0.9%, 0.9%, and 2.4% were contributed by diesel, solar, wind, and others, respectively. According to the DoE, in their Energy Balances report in 2015, the residential energy demand for renewables and waste was 80% of the total energy demand, while that of electricity, coal, petroleum products, and gas were 17%, 1%, 2%, and 0%, respectively. In the same year, energy demand in the agricultural sector for coal, petroleum product, and electricity was 2%, 66%, and 32%, respectively. The case was slightly different for the commercial and public sector as electricity demand sailed to 83%, while the sectors demand for coal, gas, and petroleum products were 9%, 1%, and 7%, respectively.

Empirical review

The energy sector in South Africa accounts for 15% of the nation's energy-driven economy (Bekun et al. 2019a; DME 2016) with coal contributing 70% energy supply and 93% electricity (World Bank 2017). South Africa's reputation as the 7th largest greenhouse gas emitter is attributed to her over-dependence on coal energy (Bekun et al. 2019a; Winkler 2007), a major contributor of environmental degradation (Shahbaz et al. 2013b). The impacts of several factors on the environment is well-documented in the empirical literature of which has been expansively reviewed by (Bello et al. 2018; Al-Mulali et al. 2016a; Li and Lin 2015; Poumanyvong and Kaneko 2010; Martínez-Zarzoso and Maruotti 2011; Shafiei and Salim 2014; Feng 2017; York et al. 2003; Sadorsky 2013; Shahbaz et al. 2014a; Asumadu-Sarkodie and Owusu 2016a; Shahbaz et al. 2015; Onafowora and Owoye 2014; Menyah and Wolde-Rufael 2010; Odhiambo 2011; Farhani et al. 2014; Shahbaz et al. 2014b; Shahbaz and Lean 2012; Osabuohien et al. 2014; Asumadu-Sarkodie and Owusu 2016b) amidst CO_2 emissions as a measure of environmental degradation.

Among the recent works focusing on sub-Saharan Africa, South Africa has received some attention with studies such as Bekun et al. (2019a), Onafowora and Owoye (2014), Kohler (2013), and Shahbaz et al. (2013b). Studies have also concentrated on the African continent (Osabuohien et al. 2014; Shahbaz et al. 2015) or other individual African countries such as Kenya (Al-Mulali et al. 2016b) and Tunisia (Farhani et al. 2014; Shahbaz and Lean 2012; Shahbaz et al. 2014b). In Kenya, evidence of EKC has also been reported with urbanization, non-renewable energy consumption, trade openness, and GDP as the culprits of environmental degradation while financial development mitigates CO_2 emissions (Al-Mulali et al. 2016b). Still focusing on Sub-Saharan countries between 1980 and 2012, Shahbaz et al. (2015) validated the EKC hypothesis for Congo Republic, South Africa, Ethiopia, and Togo; and also affirm that energy use drives CO_2 emissions.

A vast majority of studies that have estimated the energy-environment relationship for South Africa, with the same methodology (ARDL), have consistently reported that energy use drives growth (see Gungor and Simon 2017; Bekun et al. 2019a; Kohler 2013; Shahbaz et al. 2015). Also, these studies resorted to CO_2 emissions as a measure for environmental degradation. Using data from 1960–2009 in South Africa, Kohler (2013) found a feedback causality between energy use and income, energy use and carbon dioxide emissions, trade flow and energy use, and between trade flow and income; however, trade openness did not contribute to higher emission levels in the long run. Kohler (2013) observed that the specific relationship between South Africa's emissions and economic growth was difficult to discern while accounting for foreign trade; therefore, the presence of EKC is inconclusive. Gungor and Simon (2017) explored the link between financial development, urbanization, industrialization, and energy consumption in South Africa using annual data from 1970 to 2014. Findings revealed a feedback causality between energy utilization and financial development. Same was true for urbanization and economic growth. Similarly, for South Africa, Bekun et al. (2019a) examined how energy use impacts growth while accounting for the role of labor and capital. They discovered that energy use, CO_2 emissions, and labor drive growth while capital formation and CO_2 emissions have a feedback causality.

The wide range of empirical literature on CO_2 emissions that exist for China is not surprising since it has been the world's biggest emitter of CO_2 in recent decades. Therefore, the studies have been done at both national and regional level for China. For example, using data from 1970 to 2015, Liu and Bae (2018) studied the causal linkage among energy intensity, renewable energy, industrialization, and CO_2 emissions per capita in China. Their long-run estimate showed that energy intensity and industrialization both simultaneously increase CO_2 emissions. Their Granger causality result showed evidence of bidirectional causality linkage among industrialization, real GDP, and CO_2 emissions. Using thirty Chinese cities and three regional panel data from 2000 to 2016 and following the same approach used by Sadorsky (2013), Ahmad and Zhao (2018) recently found out that unidirectional causality runs from coal energy consumption to CO_2 emissions, and from urbanization to CO_2 emissions and coal consumption. According to their findings, urbanization and industrialization drive CO_2 emissions. Also, Tian et al. (2014) used the input-output model to explore the effect of gross regional product and structural industrial change on CO_2 emissions in China. The study discovered that the later impacts CO_2 substantially. However, no evidence of EKC hypothesis exist.

From the foregoing literature, various econometrics techniques have been adopted amidst various explanatory variables like financial development, energy use, trade flow, urbanization, and industrialization. The results from South African studies relatively converged with most validating the EKC hypothesis. Moreover, most of these studies have used CO_2 emission to proxy environmental degradation. However, evidence suggests that CO_2 emissions have a limited indication of the impact of energy consumption (Zhang et al. 2017; Solarin et al. 2019) and resource stocks (Ulucak and Lin 2017; Bello et al. 2018). Recently, ecological footprint (EF) has become one of the most widely used indicators to measure environmental impacts of consumption (Jóhannesson et al. 2018) and the pressure of economic activity on the environment (Yang and Fan 2019; Kaltenegger et al. 2017). For instance, Destek and Sarkodie (2019) examined the role of energy use, growth, and financial development on environmental quality (measured with EF) for 11 countries from 1977 to 2013. The study reported a feedback causality between economic growth and EF. On the flipside, a unidirectional causality also flows from economic growth to energy consumption.

Hassan et al. (2019) explored the effect of natural resources, urbanization, and economic growth on EF in Pakistan from 1970 to 2014 using the ARDL technique. Results revealed natural resource positively influence EF. This suggests that natural resources encourage environmental degradation in Pakistan. The study further reported a bidirectional causality between natural resources and EF. The same direction of causality also exists between biocapacity and EF. The impact of economic growth on EF was also well pronounced. Baloch et al. (2019) examined the effects of financial development, urbanization, energy consumption, and FDI on environmental degradation (proxy by EF) in fifty-nine (59) Belt and Roads countries from 1990 to 2016. Findings confirmed that FDI, economic growth, energy consumption, and urbanization deteriorate the environment by adding to EF.

Ajayi and Ajayi (2013) explored the policies related to energy issues in Nigeria with a special focus on the country's Vision 20:2020 agenda. The study highlighted poor government motivation and economic incentives, multiple taxations, inappropriate excise, and customs duty as factors that drive renewable energy technology in Nigeria. Akadiri et al. (2019) examined the causal linkage between economic growth, energy consumption, and CO_2 emissions in Iraq from 1972 to 2013 relying on the Toda-Yamamoto test. Findings suggested that growth and CO_2 emissions drive energy consumption. The study did not, however, show any form of feedback causality among the aforementioned variables. Following the studies of Akadiri et al. (2019), but for the case of Pakistan, Balcilar et al. (2019) explored the growth-electricity nexus from 1971 to 2014 while accounting for multiple structural breaks in the series. From their findings, growth drives electricity consumption. Also, electricity consumption triggers CO_2 emissions.

Bekun and Agboola (2019) examined the energy-growth nexus for Nigeria from 1971 to 2014 adopting the same set of variables and estimation technique with Balcilar et al. (2019) though complemented with FMOLS and DOLS. Just like the studies of Balcilar et al. (2019), they also discovered that electricity consumption triggers CO_2 emissions in Nigeria. The authors suggested that policymakers in Nigeria concentrate on clean energy sources, such as renewables, to ensure a sustainable environment. Bekun et al. (2019b) discovered that economic growth and fossil fuel consumption add to environmental deterioration in 16-EU countries. Just as Emir and Bekun (2018) reported that growth in Romania is dependent on renewable energy consumption.

Katircioğlu and Katircioğlu (2018) investigated the role of urbanization while trying to establish the EKC for Turkey. The study reported that the EKC does not exist for Turkey. The authors, through their findings, attributed the rise in emissions in Turkey to urban development and fossil fuel consumptions. Katircioglu et al. (2018) further examined if the role of urbanization in the EKC of the globe. The study controlled for both overall and rural population. Again, the EKC failed to exhibit an inverted U-shaped, similar to the findings reported in Katircioğlu and Katircioğlu (2018). However, the curve was downward slopping when the urban population was added to the model and assumed an inverted U-shaped when both overall and rural population were included. Samu et al. (2019) also examined the electricity-growth nexus for Zimbabwe from 1971 to 2014. Their findings were similar to those of Bekun and Agboola (2019) and Balcilar et al. (2019). They discovered that electricity consumption drives CO_2 emissions in Zimbabwe. Shahbaz and Sinha (2019) in their literature survey of EKC for CO_2 emissions from 1991 to 2017 discovered that results are inconclusive for all the contexts examined. These discrepancies in results were attributed to the nature of explanatory variables, time period, methodology, and the choice of contexts. Shahbaz et al. (2014b) investigated the EKC for Tunisia from 1971 to 2010 adopting both the innovative accounting approach and the VECM. Both approaches confirmed the existence of EKC, and a feedback causality exists between energy consumption and CO_2 emissions. Shahbaz et al. (2012) discovered that energy consumption drives CO_2 emissions in Pakistan. A similar result was also discovered by Shahbaz et al. (2013a), Nathaniel (2019), and Nathaniel and Iheonu (2019) for Romania, Nigeria, and Africa, respectively. Sinha et al. (2017) explored the EKC for CO_2 emissions for the Next 11 (N-11) economies from 1990 to 2014 with trade flow and urbanization as additional variables. Findings revealed that renewable energy consumption inhibits growth, while non-renewable energy consumption performs the exact opposite. Rehman et al. (2019) discovered a feedback causality between economic growth and CO_2 emissions for Pakistan. This was arrived at through the VECM causality test applied on annual data spanning 1990–2017. The study recommended the adoption of clean energy sources to resolve the energy crisis in Pakistan.

Improving on the study of Bekun et al. (2019a, b), our study differs from others by utilizing EF which is a robust accounting tool that measures the amount of the earth's biocapacity demanded by a given activity, in this case, urbanization-induced energy consumption and ecological pressure in South Africa. In addition to ecological footprint, the current study incorporates urbanization, energy use, and financial development.

Data and methodology

The time period of the study spans over four decades from 1965 to 2014. The availability of data informed the time period. All data were derived from the World Development Indicators (WDI 2017), apart from ecological footprint obtained from Global Footprint Network (GFN) (2017) (Table 1).

Unit root test

To make sure our regression is not spurious, the unit root properties of variables were first examined with the Dickey and Fuller (ADF) (1981) and the Phillip and Perron (PP) (1988) tests. To make up for the criticism levelled against both tests, in terms of their sensitivity to size, low power, and inability to consider break(s) in the series, the variables were further subjected to the Zivot and Andrews (1992), (ZA, hereafter) test to account for a structural break.

Cointegration

The Bayer and Hanck (2013) cointegration test would be used to investigate the cointegrating relationship of the variables. The beauty of this test is in its ability to combine other relevant tests (Banerjee et al. 1998; Johansen 1991; Boswijk 1995; Engle and Granger 1987) and give a robust result. The Fisher equation is provided as:

$$EG{-}JOH = -2\left[\ln\left(\rho_{EG}\right) + (\rho_{JOH})\right] \quad (1)$$

$$EG{-}JOH{-}BO{-}BDM = -2\left[\ln\left(\left(\rho_{EG}\right) + (\rho_{JOH}) + (\rho_{BO}) + (\rho_{BDM})\right]\right. \quad (2)$$

ρ_{BDM}, ρ_{BO}, ρ_{JOH}, and ρ_{EG} are the test probability of individual cointegration tests.

Table 1 Variable definition

S/N	Indicator name	Measurement	Source	Code
1	Energy use	Kilogram of oil equivalent per capita	WDI	EUSE
2	Ecological footprint	Global hectares per capita	GFN	TEFP
3	Urbanization	Percentage of total population	WDI	URB
4	Financial development	% of GDP	WDI	FD
5	Real GDP per capita	In constant 2010 USD	WDI	GDP

Sources: Author's compilation 2019.

Estimation techniques

Apart from the Bayer and Hanck (2013) test, the ARDL bounds test to cointegration of Pesaran et al. (2001) was also used. The general form of the model is specified in Eq.3.

$$\Delta Y_t = \Psi_0 + \sum_{i=1}^{k} \Psi_1 \Delta y_{t-i} + \sum_{i=0}^{k} \delta_1 \Delta x_{t-i} + \gamma_1 y_{t-1} + \gamma_2 x_{t-1} + \mu_t \quad (3)$$

where $\Psi_1$and δ_1 are the short-run coefficients, γ_1 and γ_2 are the long-run coefficients. The number of lags and the error term are respectively k and μ_t.

Empirical findings and discussion of results

Before embarking on any analysis, a graphical representation of the series is important since it will help in deciding the direction of analysis for accurate results (Rana and Sharma 2018). Therefore, the study proceeds with the trend of each of the variables in the study (see Fig. 2 below.)

A mere look at the plots shows that the variables failed to evolve around zero means. They evolve around other means. All variables exhibit a largely or slightly upward moving trend. These trends and breaks are accounted for in our study.

Table 2 Descriptive statistic and correlation results

	TEFP	EUSE	FD	URB	GDP
Panel A					
Mean	1.270	2355	96.06	53.32	2.350
Median	1.260	2424	75.44	51.50	2.180
Maximum	1.930	2913	160.1	64.31	4.130
Minimum	6033	1745	53.96	47.24	1.070
Std. Dev.	3656	312.6	35.35	5.584	8.530
Skewness	0.064	− 0.418	0.409	0.543	0.579
Kurtosis	2.113	2.061	1.555	1.847	2.351
Jarque-Bera	1.638	3.229	5.627	5.126	3.605
Probability	0.440	0.198	0.059	0.077	0.164
Panel B					
TEFP	1				
EUSE	0.875	1			
FD	0.889	0.672	1		
URB	0.944	0.743	0.966	1	
GDP	0.973	0.834	0.904	0.971	1

Source: Authors computation

Descriptive statistic

Table 2 concentrates on the properties of the variables (panel A) and the correlation matrix (panel B). Findings revealed that the mean and the median of each of the variables are almost equal. With the exception of energy use, the remaining variables are positively skewed.

All the variables are platykurtic since their kurtosis value is less than three. Evidence of normality exists, which is desirable. This can be deduced from their various probability values which is greater than 5%. Also, a strong positive correlation exists among the variables considered for the study.

Unit root

Since the ARDL technique breaks down when a variable(s) is/are $I(2)$, these tests were carried out to avoid $I(2)$ variable(s) in the series. The study proceeded with ADF and PP tests which do not account for a break(s) and complemented with the ZA test which accounts for a break (Table 3).

The three-unit root tests (ADF, PP, and ZA) are in harmony. They confirmed all variables to be $I(1)$. With this result, the precondition for cointegration is met. We proceed with the bounds test (see Table 4).

Since the F statistic of 6.973817 is greater than 4.57 at 5%, the finding suggests cointegration. This means that our variables (TEFP, EUSE, GDP, FD, and URB) have a long-run relationship.

The Fisher statistic for EG-JOH-BO-BDM and EG-JOH are far beyond the 5% critical values of 20.143 and 10.576, respectively (Table 5). In this case, we can conclude that the variables (TEFP, GDP, EUSE, FD, and

Table 3 ADF and PP tests (without break) and ZA unit root test (with break)

Variables	ADF *T* statistic	PP *T* statistic	ZA *T* statistic	Break date Time break
Panel A				
AT levels				
TEFP	−1.0220	−1.0412	−3.6656	2003
EUSE	− 1.7189	− 1.7200	−3.0821	1989
FD	0.0130	0.5721	−3.6427	1991
URB	−0.4105	−3.8284	−3.2520	2002
GDP	1.2970	−2.0174	−3.0999	2004
Panel B				
AT first difference				
TEFP	−7.5834***	−7.8227***	−8.2976	1975
EUSE	−6.6307***	−6.6309***	−7.3487	1989
FD	−6.9214***	−7.6425***	−7.1740	1981
URB	−6.2021***	−5.0061***	−6.7871	1985
GDP	−4.2607***	−4.2984***	−5.5907	1994

Source: Authors computation. * stands for 1% significance rejection level

URB) are cointegrated. These findings complement the bounds test in Table 4.

The findings from Table 6 suggests that energy use increases environment degradation in the short run, though its impact is not strongly related to TEFP. The results further revealed that the signs of the coefficients of *ln*GDP, *ln*FD, and *ln*URB are all positive. The intuition here is that a unit increase in GDP, financial development, and urbanization will trigger a rise in TEFP by 1.57%, 0.22%, and 3.20%, respectively. Interestingly, urbanization appears to have the greatest impact on TEFP in the short run. This finding corroborates that of Wang and Dong (2019) who discovered the same for a panel of 14 SSA countries. Also, in tandem with Poumanyvong and Kaneko (2010), Liddle and Lung (2010), Cole and Neumayer (2004) and Kasman and Duman (2015), findings further affirm that financial development and growth witnessed in South Africa take place at a cost. For the country to improve its environmental quality in the short run, it had to trade-off economic growth. South Africa's energy consumption is largely non-renewable and this has a detrimental and deteriorating effect on the environment. There is an urgent need for the country to adjust its energy portfolio by shifting its attention to non-renewable energy sources (wind, solar, thermal, geothermal, etc.) which are clean and low in emissions. Findings further

Fig. 2 Plots of the series. Sources: Author's compilation 2019

Table 4 ARDL bounds test

Estimated model	Lower bound	Upper bound	Significance levels
F_c *(lneuse, lngdp, lnfd, lnurb)*	3.03	4.06	10%
$F = 6.973817$	3.47	4.57	5%
$K = 4$	3.89	5.07	2.5%
	4.40	5.72	1%

Source: Authors computation

revealed that energy use and urbanization will reduce environmental degradation by 1.80% and 7.41% respectively in the long run. However, these findings for both GDP and financial development are consistent with their short-run results. Both variables still exact a detrimental effect on the environment, as a unit increase in economic growth and financial development deteriorate the environment further by 3.27% and 1.01%, respectively.

We discovered that GDP reduces environmental quality in both time periods while Bekun et al. (2019a, b) discovered the exact opposite. These contradictions could be as a result of the variables used to proxy environmental degradation. They used CO_2 emissions while we used ecological footprint to proxy environment degradation. The ecological footprint is a more aggregate indicator (Wang and Dong 2019; Stern 2014) and captures environmental degradation better than CO_2 emissions (Charfeddine 2017; Bello et al. 2018; Ulucak and Lin 2017; Stern 2014). The long-run findings of our study are confirmed to be robust as reported by the FMOLS, DOLS, and CCR estimates with similar signs as the ARDL long-run coefficient (see Table 7).

Figure 3 presents the cumulative sum control chart (CUSUM) which shows that all fitted model is stable, parsimonious, and helpful for policy implication since the blue lines fall within the red bandwidth.

We discovered a unidirectional causality flowing from GDP to ecological footprint, and from energy use to GDP (Table 8). This supports the energy-led growth hypothesis and further suggests that growth causes environmental degradation and that the South Africa economy, in terms of growth, is energy dependent. This is a more reason why the country should concentrate on clean energy sources to enhance sustainable growth since it is pretty difficult to trade-off one for the other. This finding complements those of Bekun et al. 2019a, b), Khobai and Le Roux (2017), and Menyah and Wolde-Rufael (2010) who also discovered a similar direction of causality for South Africa. Energy use was also found to drive environmental degradation (TEFP). However, shifting attention to clean energy sources may not impede growth, but rather sustain it as revealed by a recent study carried out by Khobai and Le Roux (2018) on the South African economy where they reported that renewable energy consumption drives economic growth.

Conclusion and policy directions

This work focused on environmental degradation, urbanization, and energy use in South Africa. The focus was on South Africa because of the critical role South Africa plays as a leading economy in sub-Saharan Africa and the most industrialized economy in the region. The work estimated the impact of urbanization and energy use on environmental degradation in South Africa using ecological footprints instead of carbon emission as a proxy for environmental degradation in line with the works of Jorgenson (2016). For the regression analysis, we used variables such as energy use, ecological footprints, urban population, financial development, and per capita GDP in the models which followed the works of Wang and Dong (2019) and Poumanyvong and Kaneko (2010). The study applied the ARDL model to address the objectives together with the ADF, PP, and ZA tests to ascertain the level of stationarity. A Granger causality analysis was carried to test

Table 5 The result of Bayer-Hanck test for cointegration

Estimated models	EG-JOH	EG-JOH-BO-BDM	Cointegration
*ln*TEFP = f(*ln*GDP,*ln*EU,*ln*FD,*ln*URB)	13.631**	31.100**	Yes
*ln*GDP = f(*ln*TEFP,*ln*EU,*ln*FD,*ln*URB)	23.683**	49.283**	Yes
*ln*EU = f(*ln*GDP,*ln*TEFP,*ln*FD,*ln*URB)	14.053**	31.085**	Yes
*ln*FD = f(*ln*GDP,*ln*TEFP,*ln*EU,*ln*URB)	20.431**	27.617**	Yes
*ln*URB = (*ln*GDP,*ln*TEFP,*ln*EU,*ln*FD)	26.147**	31.196**	Yes
5% critical value	10.576	20.143	

**indicate significance at 5% levels. Source: Author's computation

Table 6 ARDL results

Dependent variable: *ln*TEFP			
Independent variables	Coefficients	Std. errors	*T* stat.
Short-run results			
Δ*ln*EUSE	0.3757*	0.1965	1.9110
Δ*ln*EUSE(-1)	0.6951***	0.1926	3.6081
Δ*ln*GDP	1.5738***	0.2954	5.3266
Δ*ln*FD	0.2271**	0.0872	2.6027
Δ*ln*URB	3.2016	5.4511	0.5873
Δ*ln*URB(-1)	18.125**	6.2153	2.9162
ECT(-1)	− 0.5987***	0.0943	-6.3429
R^2	0.7182		
F stat.	6.3374***		
Long-run results			
*ln*EUSE	− 1.8012***	0.5626	− 3.2012
*ln*GDP	3.2722***	0.6767	4.8353
*ln*FD	1.0194***	0.2387	4.2699
*ln*URB	− 7.4162***	1.3410	-5.5300
Diagnostic tests			
Test	**Prob.**		
Normality (Jarque-Bera)	0.2954		
Serial correlation (LM test)	0.7155		
Heteroskedaskticity (Breusch-Pagan-Godfrey)	0.3483		
Functional form (Ramsey RESET)	0.4208		

***, *, and ** stands for 0.01, 0.10, and 0.05 significance level respectively. Source: Author's computation

for the direction of causality between economic growth and ecological footprint, while the Bayer and Hanck (2013) cointegration tests in addition with the ARDL bound test was used to test for long-run relationship.

Conceptual literature like ecological footprints as it relates to environmental degradation was defined, as well as many related empirical works of literature were equally reviewed. From the result obtained, we discovered a unidirectional causality flowing from economic growth to ecological footprint, and from energy use to economic growth and that though energy use increases environment degradation in the short run, urbanization appears to have the greatest impact on TEFP in the short run while GDP and financial development also exact a detrimental effect on the environment both in the short and long run. One policy implication from the findings of this study is that it is obvious that rapid growth witnessed in South Africa over the years is at a huge cost since South Africa's energy consumption is largely non-renewable and this has a detrimental and deteriorating effect on the environment. Hence,

Table 7 Sensitivity check with FMOLS, DOLS, and CCR

Dependent variable: *ln(TEFP)*						
Variables	FMOLS		DOLS		CCR	
	Coefficient	*T* Stat.	Coefficient	*T* Stat.	Coefficient	*T* Stat.
ln(GDP)	1.1748***	4.6981	1.9322***	6.6578	1.1870***	4.7383
ln(EUSE)	− 0.4945**	− 2.0837	− 1.0339**	2.2618	− 0.4798**	− 2.0403
ln(FD)	0.3137**	2.3448	0.4839***	2.9155	0.3236**	2.3375
ln(URB)	− 3.7683***	− 4.4486	− 4.7472***	− 4.3154	− 3.7070***	− 4.6079

***, *, and ** stands for 0.01, 0.10, and 0.05 significance level respectively. Source: Author's computation 2019

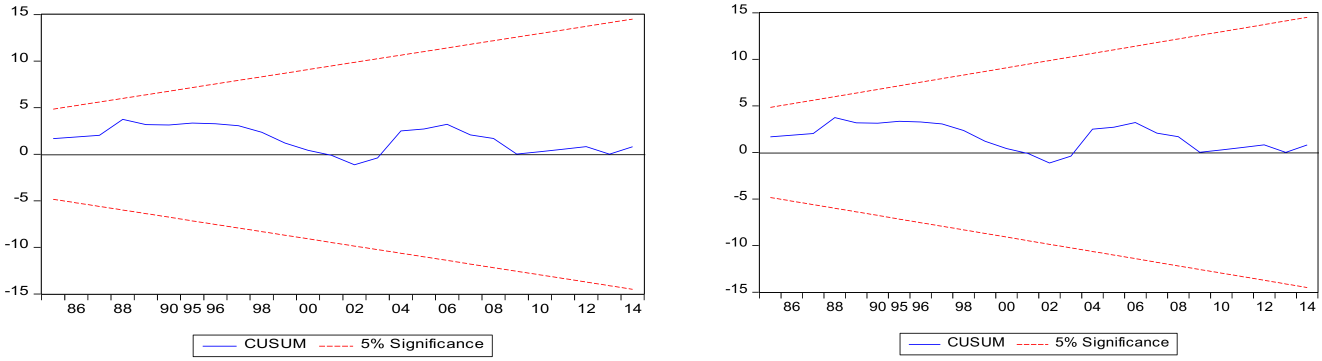

Fig. 3 CUSUM and CUSUM (sq) graphs

there is a need to diversify the energy portfolio of South Africa to renewable energy sources. This entails that government at all level should fashion out policies that will encourage the use of renewable energy sources. There is also a dire need for the country to engage in aggressive development of rural infrastructures, since inadequate infrastructure in the rural areas is largely culpable for rural-urban drift. Once this is done, problems associated with urban anomalies like waste management, congestion, and even environmental degradation would be minimized. This also applies to other Africa countries. Also, another major finding of this study was that energy use and urbanization will reduce environmental degradation in the long run, posing a positive environment in future for South Africa by exposing the current efforts of the government towards a sustainable development. These efforts of the government should be sustained and even enhanced.

Table 8 Granger causality results

Null hypothesis	Direction of causality	*F* statistic	Probability
*ln*EUSE ≠> *ln*TEFP	EUSE → TEFP	6.2850**	0.0260
*ln*TEFP ≠> *ln*EUSE		2.2616	0.1394
*ln*FD ≠> *ln*TEFP	FD ≠ TEFP	3.7006*	0.0609
*ln*TEFP ≠> *ln*FD		2.1197	0.1525
*ln*URB ≠> *ln*TEFP	TEFP → URB	3.7653*	0.0585
*ln*TEFP ≠> *ln*URB		6.4606**	0.0145
*ln*GDP ≠> *ln*TEFP	GDP → TEFP	5.7817**	0.0203
*ln*TEFP ≠> *ln*GDP		2.5427	0.1177
*ln*FD ≠> *ln*EUSE	FD ≠ EUSE	0.0068	0.9342
*ln*EUSE ≠> *ln*FD		2.8343*	0.0994
*ln*URB ≠> *ln*EUSE	URB ≠ EUSE	0.3024	0.5850
*ln*EUSE ≠> *ln*URB		27.515	4.E-06
*ln*GDP ≠> *ln*EUSE	EUSE → GDP	2.3635	0.1310
*ln*EUSE ≠> *ln*GDP		9.2872**	0.0038
*ln*URB ≠> *ln*FD	URB ≠ FD	3.8340*	0.0566
*ln*FD ≠> URB		1.6427	0.2067
*ln*GDP ≠> *ln*FD	FD → GDP	2.5533	0.1172
*ln*FD ≠> *ln*GDP		7.0236**	0.0111
*ln*GDP ≠> *ln*URB	GDP ↔ URB	4.8408**	0.0329
*ln*URB ≠> *ln*GDP		10.983***	0.0018

***, *, and ** stands for 0.01, 0.10, and 0.05 significance level. ≠>symbolized "does not Granger cause". ↔ represents feedback causality. ≠ represents no causality, and → represents unidirectional causality. Sources: Author's computation 2019

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