

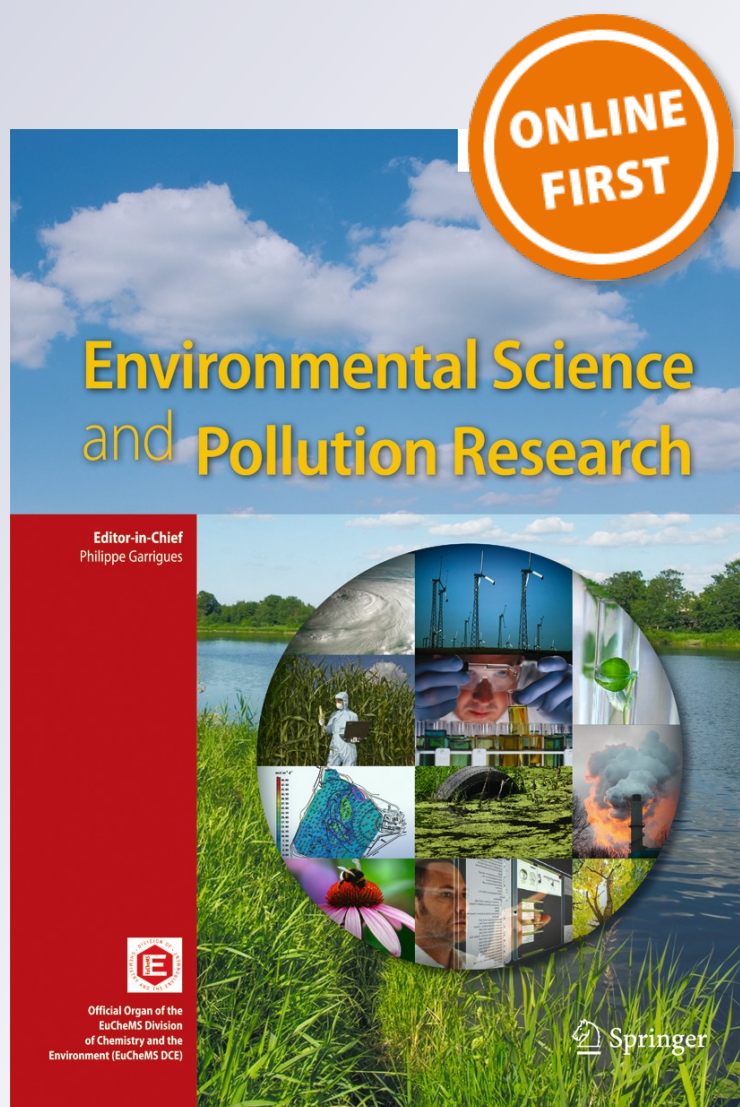
# *Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded*

**Solomon Nathaniel, Ozoemena Nwodo, Abdulrauf Adediran, Gagan Sharma, Muhammad Shah & Ngozi Adeleye**

**Environmental Science and Pollution Research**

ISSN 0944-1344

Environ Sci Pollut Res  
DOI 10.1007/s11356-019-05924-2



**Your article is protected by copyright and all rights are held exclusively by Springer-Verlag GmbH Germany, part of Springer Nature. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at [link.springer.com](http://link.springer.com)".**



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

Solomon Nathaniel<sup>1</sup> · Ozoemena Nwodo<sup>2</sup> · Abdulrauf Adediran<sup>3</sup> · Gagan Sharma<sup>4</sup> · Muhammad Shah<sup>5</sup> · Ngozi Adeleye<sup>6</sup>

Received: 24 April 2019 / Accepted: 8 July 2019  
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

## 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.

---

Responsible editor: Muhammad Shahbaz

---

✉ Solomon Nathaniel  
nathaniel\_solomon21@yahoo.com

Ozoemena Nwodo  
nwodo.ozoemena.pg68442@unn.edu.ng

Abdulrauf Adediran  
Addabd001@myuct.ac.za

Gagan Sharma  
angrishgagan@gmail.com

Muhammad Shah  
ibrahimecondu@gmail.com

Ngozi Adeleye  
ngozi.adeleye@covenantuniversity.edu.ng

<sup>1</sup> Department of Economics, University of Lagos, Akoka, Nigeria

<sup>2</sup> Department of Economics, University of Nigeria, Nsukka, Nigeria

<sup>3</sup> Department of Finance and Investment Management, College of Business and Economics, University of Johannesburg, Johannesburg, South Africa

<sup>4</sup> University School of Management Studies, Guru Gobind Singh Indraprastha University, New Delhi, India

<sup>5</sup> Department of Economics, University of Dhaka, Dhaka, Bangladesh

<sup>6</sup> Department of Economics, Covenant University, Ota Ogun State, Nigeria

2016). However, the increasing global warming has been attributed to many factors such as energy use which emits CO<sub>2</sub> emissions, the main greenhouse gas in terms of quantity, since IPCC (2007) estimated that CO<sub>2</sub> emission accounts for 76.7% of the whole greenhouse gas so far. This effect of CO<sub>2</sub> emissions is severe 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions) as a measure of environmental degradation, as opposed to previous studies which used CO<sub>2</sub> 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 (Khubai and Le Roux 2017; Okafor 2012; Menyah and Wolde-Rufael 2010; Khubai 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<sub>2</sub> 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<sub>2</sub> 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.

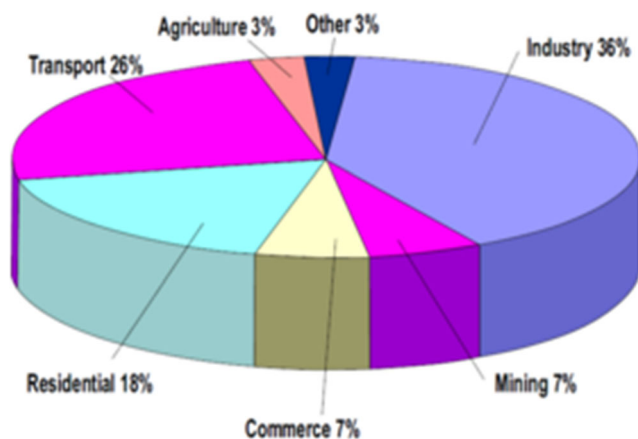
The recent attention accorded to the use of renewable energy in South Africa was due to the energy crisis befell the country in 2008. Over the years, the country has found it difficult to meet the energy demand of its ever-increasing population. For instance, Fig. 1 shows the energy demand by sectors 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

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; Poumanyong 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions.



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

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<sub>2</sub> 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<sub>2</sub> emissions, and labor drive growth while capital formation and CO<sub>2</sub> emissions have a feedback causality.

The wide range of empirical literature on CO<sub>2</sub> emissions that exist for China is not surprising since it has been the world's biggest emitter of CO<sub>2</sub> 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<sub>2</sub> emissions per capita in China. Their long-run estimate showed that energy intensity and industrialization both simultaneously increase CO<sub>2</sub> emissions. Their Granger causality result showed evidence of bidirectional causality linkage among industrialization, real GDP, and CO<sub>2</sub> 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<sub>2</sub> emissions, and from urbanization to CO<sub>2</sub> emissions and coal consumption. According to their findings, urbanization and industrialization drive CO<sub>2</sub> 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<sub>2</sub> emissions in China. The study discovered that the later impacts CO<sub>2</sub> 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<sub>2</sub> emission to proxy environmental degradation. However, evidence suggests that CO<sub>2</sub> 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<sub>2</sub> emissions in Iraq from 1972 to 2013 relying on the Toda-Yamamoto test. Findings suggested that growth and CO<sub>2</sub> 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, Balçilar 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<sub>2</sub> 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<sub>2</sub> 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. Katircioğlu 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<sub>2</sub> emissions in Zimbabwe. Shahbaz and Sinha (2019) in their literature survey of EKC for CO<sub>2</sub> 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<sub>2</sub> emissions. Shahbaz et al. (2012) discovered that energy consumption drives CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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:

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

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

$\rho_{BDM}$ ,  $\rho_{BO}$ ,  $\rho_{JOH}$ , and  $\rho_{EG}$  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.

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

where  $\Psi_1$  and  $\delta_1$  are the short-run coefficients,  $\gamma_1$  and  $\gamma_2$  are the long-run coefficients. The number of lags and the error term are respectively  $k$  and  $\mu_t$ .

### 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.

### 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.

**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

### 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 <i>T</i> statistic	PP <i>T</i> statistic	ZA <i>T</i> 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 *lnGDP*, *lnFD*, and *lnURB* 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 Poumanyong 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
$F_c$ ( <i>lneuse, lngdp, lnfd, lnurb</i> )	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<sub>2</sub> 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<sub>2</sub> 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
$\ln\text{TEFP} = f(\ln\text{GDP}, \ln\text{EU}, \ln\text{FD}, \ln\text{URB})$	13.631**	31.100**	Yes
$\ln\text{GDP} = f(\ln\text{TEFP}, \ln\text{EU}, \ln\text{FD}, \ln\text{URB})$	23.683**	49.283**	Yes
$\ln\text{EU} = f(\ln\text{GDP}, \ln\text{TEFP}, \ln\text{FD}, \ln\text{URB})$	14.053**	31.085**	Yes
$\ln\text{FD} = f(\ln\text{GDP}, \ln\text{TEFP}, \ln\text{EU}, \ln\text{URB})$	20.431**	27.617**	Yes
$\ln\text{URB} = f(\ln\text{GDP}, \ln\text{TEFP}, \ln\text{EU}, \ln\text{FD})$	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.
<b>Short-run results</b>			
$\Delta \ln EUSE$	0.3757*	0.1965	1.9110
$\Delta \ln EUSE(-1)$	0.6951***	0.1926	3.6081
$\Delta \ln GDP$	1.5738***	0.2954	5.3266
$\Delta \ln FD$	0.2271**	0.0872	2.6027
$\Delta \ln URB$	3.2016	5.4511	0.5873
$\Delta \ln URB(-1)$	18.125**	6.2153	2.9162
ECT(-1)	-0.5987***	0.0943	-6.3429
$R^2$	0.7182		
F stat.	6.3374***		
<b>Long-run results</b>			
$\ln EUSE$	-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
<b>Diagnostic tests</b>			
<b>Test</b>	<b>Prob.</b>		
Normality (Jarque-Bera)	0.2954		
Serial correlation (LM test)	0.7155		
Heteroskedasticity (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 uni-directional 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

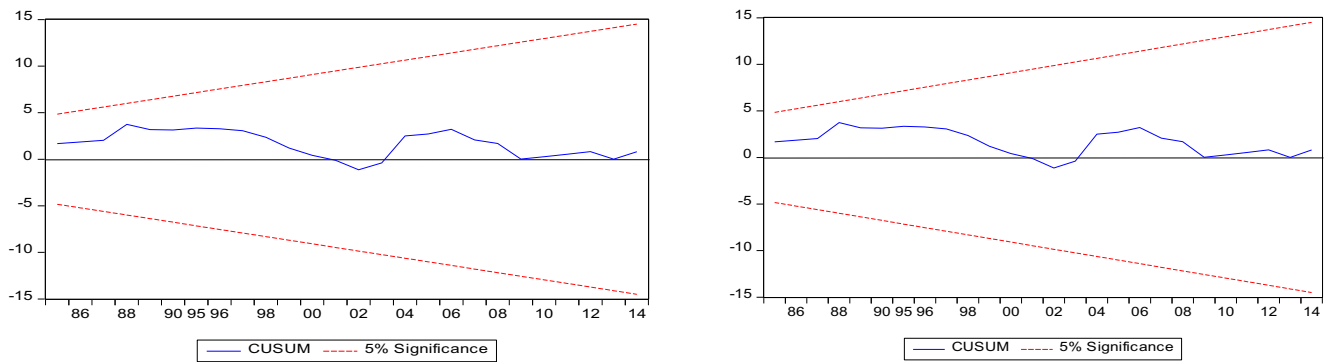


Fig. 3 CUSUM and CUSUM (sq) graphs

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
$\ln EUSE \nRightarrow \ln TEFP$	$EUSE \rightarrow TEFP$	6.2850**	0.0260
$\ln TEFP \nRightarrow \ln EUSE$		2.2616	0.1394
$\ln FD \nRightarrow \ln TEFP$	$FD \neq TEFP$	3.7006*	0.0609
$\ln TEFP \nRightarrow \ln FD$		2.1197	0.1525
$\ln URB \nRightarrow \ln TEFP$	$TEFP \rightarrow URB$	3.7653*	0.0585
$\ln TEFP \nRightarrow \ln URB$		6.4606**	0.0145
$\ln GDP \nRightarrow \ln TEFP$	$GDP \rightarrow TEFP$	5.7817**	0.0203
$\ln TEFP \nRightarrow \ln GDP$		2.5427	0.1177
$\ln FD \nRightarrow \ln EUSE$	$FD \neq EUSE$	0.0068	0.9342
$\ln EUSE \nRightarrow \ln FD$		2.8343*	0.0994
$\ln URB \nRightarrow \ln EUSE$	$URB \neq EUSE$	0.3024	0.5850
$\ln EUSE \nRightarrow \ln URB$		27.515	4.E-06
$\ln GDP \nRightarrow \ln EUSE$	$EUSE \rightarrow GDP$	2.3635	0.1310
$\ln EUSE \nRightarrow \ln GDP$		9.2872**	0.0038
$\ln URB \nRightarrow \ln FD$	$URB \neq FD$	3.8340*	0.0566
$\ln FD \nRightarrow URB$		1.6427	0.2067
$\ln GDP \nRightarrow \ln FD$	$FD \rightarrow GDP$	2.5533	0.1172
$\ln FD \nRightarrow \ln GDP$		7.0236**	0.0111
$\ln GDP \nRightarrow \ln URB$	$GDP \leftrightarrow URB$	4.8408**	0.0329
$\ln URB \nRightarrow \ln GDP$		10.983***	0.0018

\*\*\*, \*, and \*\* stands for 0.01, 0.10, and 0.05 significance level.  $\nRightarrow$  symbolized “does not Granger cause”,  $\leftrightarrow$  represents feedback causality.  $\neq$  represents no causality, and  $\rightarrow$  represents unidirectional causality. Sources: Author’s computation 2019

## References

Ahmad M, Zhao ZY (2018) Empirics on linkages among industrialization, urbanization, energy consumption, CO2 emissions and economic growth: a heterogeneous panel study of China. *Environ Sci Pollut Res* 25(30):30617–30632

Ajayi OO, Ajayi OO (2013) Nigeria’s energy policy: inferences, analysis and legal ethics toward RE development. *Energy Policy* 60:61–67

Akadiri SS, Bekun FV, Taheri E, Akadiri AC (2019) Carbon emissions, energy consumption and economic growth: a causality evidence. *International Journal of Energy Technology and Policy* 15(2-3): 320–336

Al-mulali U, Binti Che Sab CN (2012) The impact of energy consumption and CO2 emission on the economic growth and financial development in the Sub Saharan African countries. *Energy* 39(1):180–186

Al-Mulali U, Ozturk I, Solarin SA (2016a) Investigating the environmental Kuznets curve hypothesis in seven regions: the role of renewable energy. *Ecol Indic* 67:267–282

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

Asumadu-Sarkodie S, Owusu PA (2016a) Carbon dioxide emissions, GDP, energy use, and population growth: a multivariate and causality analysis for Ghana, 1971–2013. *Environ Sci Pollut Res* 23(13): 13508–13520

Asumadu-Sarkodie S, Owusu PA (2016b) The relationship between carbon dioxide and agriculture in Ghana: a comparison of VECM and ARDL model. *Environ Sci Pollut Res* 23(11):10968–10982

Balcilar M, Bekun FV, Uzuner G (2019) Revisiting the economic growth and electricity consumption nexus in Pakistan. *Environ Sci Pollut Res*, 1–13.



- Baloch MA, Zhang J, Iqbal K, Iqbal Z (2019) The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. *Environ Sci Pollut Res* 26(6):6199–6208
- Banerjee A, Dolado J, Mestre R (1998) Error-correction mechanism tests for cointegration in a single-equation framework. *J Time Ser Anal* 19(3):267–283
- Bayer C, Hanck C (2013) Combining non-cointegration tests. *J Time Ser Anal* 34(1):83–95
- Bekun FV, Agboola MO (2019) Electricity consumption and economic growth nexus: evidence from Maki cointegration. *Eng Econ* 30(1):14–23
- Bekun FV, Emir F, Sarkodie SA (2019a) Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. *Sci Total Environ* 655:759–765
- Bekun FV, Alola AA, Sarkodie SA (2019b) Toward a sustainable environment: Nexus between CO<sub>2</sub> emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. *Sci Total Environ* 657:1023–1029
- Bello MO, Solarin SA, Yen YY (2018) The impact of electricity consumption on CO<sub>2</sub> emission, carbon footprint, water footprint and ecological footprint: the role of hydropower in an emerging economy. *J Environ Manag* 219:218–230
- Boswijk HP (1995) Efficient inference on cointegration parameters in structural error correction models. *J Econ* 69(1):133–158
- Çetin M, Ecevit E (2015) Urbanization, energy consumption and CO<sub>2</sub> emissions in Sub-Saharan countries: a panel cointegration and causality analysis. *Journal of Economics and Development Studies* 3(2):66–76
- Charfeddine L (2017) The impact of energy consumption and economic development on Ecological Footprint and CO<sub>2</sub> emissions: evidence from a Markov Switching Equilibrium Correction Model. *Energy Econ* 65:355–374
- Charfeddine L, Al-Malk AY, Al Korbi K (2018) Is it possible to improve environmental quality without reducing economic growth: evidence from the Qatar economy. *Renew Sust Energ Rev* 82:25–39
- Cole MA, Neumayer E (2004) Examining the impact of demographic factors on air pollution. *Popul Environ* 26(1):5–21
- Department of Energy, South African Energy Synopsis (2010) [http://www.energy.gov.za/files/media/explained/2010/South\\_African\\_Energy\\_Synopsis\\_2010.pdf](http://www.energy.gov.za/files/media/explained/2010/South_African_Energy_Synopsis_2010.pdf)ckLR.
- Department of Minerals and Energy (2016) Digest of South African energy statistics. Republic of South Africa
- Destek MA, Sarkodie SA (2019) Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. *Sci Total Environ* 650:2483–2489
- Dickey DA, Fuller WA (1981) Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica: Journal of the Econometric Society*, 1057–1072.
- Emir F, Bekun FV (2018) Energy intensity, carbon emissions, renewable energy, and economic growth nexus: new insights from Romania. *Energy & Environment* 30(3):427–443
- Engle RF, Granger CW (1987) Co-integration and error correction: representation, estimation, and testing. *Econometrica: Journal of the Econometric Society*, 251–276.
- Farhani S, Chaibi A, Rault C (2014) CO<sub>2</sub> emissions, output, energy consumption, and trade in Tunisia. *Econ Model* 38:426–434
- Feng S (2017) The driving factor analysis of China's CO<sub>2</sub> emissions based on the STIRPAT model. *Open J Soc Sci* 5(05):49
- Global Footprint Network (2017) National footprint accounts, ecological footprint. Retrieved from <http://data.footprintnetwork.org>.
- Gungor H, 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
- Hassan ST, Xia E, Khan NH, Shah SMA (2019) Economic growth, natural resources, and ecological footprints: evidence from Pakistan. *Environ Sci Pollut Res* 26(3):2929–2938
- Hossain MKN (2011) “Present condition and outlook of energy resource industry in Bangladesh”, IEEJ, May 2011, available at: <http://eneken.ieej.or.jp/data/3838.pdf> (Accessed 13 Jan 2019).
- IPCC (2007) In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) *Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC*. Cambridge University Press, Cambridge, p 996
- Jóhannesson SE, Davíðsdóttir B, Heinonen JT (2018) Standard ecological footprint method for small, highly specialized economies. *Ecol Econ* 146:370–380
- Johansen S (1991) Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica* 59(6):1551–1580
- Jorgenson A (2016) Environment, development, and ecologically unequal exchange. *Sustainability* 8(3):227
- Kaltenegger O, Löschel A, Pothen F (2017) The effect of globalisation on energy footprints: disentangling the links of global value chains. *Energy Econ* 68:148–168
- Kasman A, Duman YS (2015) CO<sub>2</sub> emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. *Econ Model* 44:97–103
- Katircioğlu S, 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
- Katircioğlu S, Katircioğlu S, Kilinc CC (2018) Investigating the role of urban development in the conventional environmental Kuznets curve: evidence from the globe. *Environ Sci Pollut Res* 25(15):15029–15035
- Khobai H (2017) The relationship between energy consumption, economic growth and carbon dioxide emission.
- Khobai HB, 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
- Khobai H, Le Roux P (2018) Does renewable energy consumption drive economic growth: evidence from Granger-causality technique. *Int J Energy Econ Policy* 8(2):205–212
- Kohler M (2013) CO<sub>2</sub> emissions, energy consumption, income and foreign trade: a South African perspective. *Energy Policy* 63:1042–1050
- Li K, Lin B (2015) Impacts of urbanization and industrialization on energy consumption/CO<sub>2</sub> emissions: does the level of development matter? *Renew Sust Energ Rev* 52:1107–1122
- Liddle B, 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
- Lin D, Wackernagel M, Galli A, Kelly R (2015) Ecological footprint: informative and evolving—a response to van den Bergh and Grazi (2014). *Ecol Indic* 58:464–468
- Liu X, Bae J (2018) Urbanization and industrialization impact of CO<sub>2</sub> emissions in China. *J Clean Prod* 172:178–186
- Maleka EM, Mashimbye L, Goyns PH (2010) South African energy synopsis 2010. Department of Energy, South Africa
- Martinez-Zarzoso IA, Maruotti A (2011) The impact of urbanization on CO<sub>2</sub> emissions: evidence from developing countries. *Ecol Econ* 70(7):1344–1353
- Menyah K, Wolde-Rufael Y (2010) Energy consumption, pollutant emissions and economic growth in South Africa. *Energy Econ* 32(6):1374–1382
- Nathaniel SP (2019) Modelling urbanization, trade flow, economic growth and energy consumption with regards to the environment in Nigeria. *GeoJournal*, 1–15.

- Nathaniel SP, Iheonu CO (2019) Carbon dioxide abatement in Africa: the role of renewable and non-renewable energy consumption. *Sci Total Environ* 679:337–345
- Odhiambo NM (2011) Economic growth and carbon emissions in South Africa: An Empirical investigation. *International Business & Economics Research Journal (IBER)* 10(7):75–84
- Okafor HO (2012) Testing the relationship between energy consumption and economic growth: evidence for Nigeria and South Africa. *Journal of Economics and Sustainable Development* 3(11):111–124
- Okunola AM, Nathaniel SP, Festus VB (2018) Revisiting population growth and food production nexus in Nigeria: an ARDL approach to cointegration. *Agricultural and Resource Economics: International Scientific E-Journal* 4(4):41–51
- Onafowora OA, Owoye O (2014) Bounds testing approach to analysis of the environment Kuznets curve hypothesis. *Energy Econ* 44:47–62
- Osabuohien ES, Efobi UR, Gitau CMU (2014) Beyond the environmental Kuznets Curve in Africa: evidence from panel cointegration. *J Environ Policy Plan* 16(4):517–538
- Pen Y, Shi C (2010) Determinants of carbon emissions growth in China: a structural decomposition analysis. *Energy Procedia* Vol 5
- Perman R, Stern D (2003) Evidence from panel unit root and cointegration tests that the environmental Kuznets curve does not exist. *Aust J Agric Resour Econ* 47:325–347
- Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. *J Appl Econ* 16(3):289–326
- Phillips PC, Perron P (1988) Testing for a unit root in time series regression. *Biometrika* 75(2):335–346
- Poumanyong P, Kaneko S (2010) Does urbanization lead to less energy use and lower CO<sub>2</sub> emissions? A cross-country analysis. *Ecol Econ* 70(2):434–444
- Puzon KAM (2012) Carbon emissions and economic development in East Asia: a macroeconomic inquiry. *Chulalongkorn Journal of Economics* 24:1–10
- Rana R, Sharma M (2018) Dynamic causality testing for EKC hypothesis, pollution haven hypothesis and international trade in India. *The Journal of International Trade & Economic Development*, 1–17.
- Rehman A, Rauf A, Ahmad M, Chandio AA, Deyuan Z (2019) The effect of carbon dioxide emission and the consumption of electrical energy, fossil fuel energy, and renewable energy, on economic performance: evidence from Pakistan. *Environ Sci Pollut Res*, 1–14.
- Ross L, Arrow K, Cialdini R, Diamond-Smith N, Diamond J, Dunne J et al (2016) The climate change challenge and barriers to the exercise of foresight intelligence. *BioScience* 66(5):363–370
- Sadorsky P (2013) Do urbanization and industrialization affect energy intensity in developing countries? *Energy Econ* 37(C):52–59
- Samu R, Bekun FV, Fahrioglu M (2019) Electricity consumption and economic growth nexus in Zimbabwe revisited: fresh evidence from Maki cointegration. *International Journal of Green Energy* 16(7): 540–550
- Shafiei S, Salim RA (2014) Non-renewable and renewable energy consumption and CO<sub>2</sub> emissions in OECD countries: a comparative analysis. *Energy Policy* 66(C):547–556
- Shahbaz M, Lean HH (2012) Does financial development increase energy consumption? The role of industrialization and urbanization in Tunisia. *Energy Policy* 40(1):473–479
- Shahbaz M, Sinha A (2019) Environmental Kuznets curve for CO<sub>2</sub> emissions: a literature survey. *J Econ Stud* 46(1):106–168
- Shahbaz M, Lean HH, Shabbir MS (2012) Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. *Renew Sust Energy Rev* 16(5):2947–2953
- Shahbaz M, Mutascu M, Azim P (2013a) Environmental Kuznets curve in Romania and the role of energy consumption. *Renew Sust Energy Rev* 18:165–173
- Shahbaz M, Kumar Tiwari A, Nasir M (2013b) The effects of financial development, economic growth, coal consumption and trade openness on CO<sub>2</sub> emissions in South Africa. *Energy Policy* 61:1452–1459
- Shahbaz M, Salah G, Ur I, Imran K (2014a) Industrialization, electricity consumption and CO<sub>2</sub> emissions in Bangladesh. *Renew Sust Energy Rev* 31:575–586
- Shahbaz M, Khraief N, Uddin GS, Ozturk I (2014b) Environmental Kuznets curve in an open economy: a bounds testing and causality analysis for Tunisia. *Renew Sust Energy Rev* 34:325–336
- Shahbaz M, Solarin SA, Sbia R, Bibi S (2015) Does energy intensity contribute to CO<sub>2</sub> emissions? A trivariate analysis in selected African countries. *Ecol Indic* 50:215–224
- Sinha A, Shahbaz M, Balsalobre D (2017) Exploring the relationship between energy usage segregation and environmental degradation in N-11 countries. *J Clean Prod* 168:1217–1229
- Solarin SA, Tiwari A, Bello MO (2019) A multi-country convergence analysis of ecological footprint and its components. *Sustain Cities Soc*, 101422.
- Stern D (2014) *The environmental Kuznets curve: a primer*. Centre for Climate Economics & Policy, Crawford School of Public Policy, The Australian National University.
- Tian X, Chang M, Shi F, Tanikawa H (2014) How does industrial structure change impact carbon dioxide emissions? A comparative analysis focusing on nine provincial regions in China. *Environ Sci Pol* 37:243–254
- Ulucak R, Lin D (2017) Persistence of policy shocks to ecological footprint of the USA. *Ecol Indic* 80:337–343
- USAID (2016) Greenhouse Gas Emissions in South Africa. Available from: [http://www.users/cqwanzcho/downloads/ghg%20emissions%20fact%20sheet%20south%20africa%20-%207-516%20usaidsacomm\\_rev08-26-16\\_clean%20\(1\)](http://www.users/cqwanzcho/downloads/ghg%20emissions%20fact%20sheet%20south%20africa%20-%207-516%20usaidsacomm_rev08-26-16_clean%20(1)). Last Accessed 20 Feb 2017.
- Wang J, Dong K (2019) What drives environmental degradation? Evidence from 14 Sub-Saharan African countries. *Sci Total Environ* 656:165–173
- WDI (2017) <http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators>.
- Winkler H (2007) Long term mitigation scenarios: technical report. Department of Environment Affairs and Tourism, South Africa.
- World Bank (2017) World Development Indicators. Retrieved from <http://data.worldbank.org/data-catalog/world-development-indicators>
- Yang Y, Fan M (2019) Analysis of the spatial-temporal differences and fairness of the regional energy ecological footprint of the Silk Road Economic Belt (China Section). *J Clean Prod* 215:1246–1261
- York R, Rosa EA, Dietz T (2003) STIRPAT, IPAT and IMPACT: analytic tools for unpacking the driving forces of environmental impacts. *Ecol Econ* 46(3):351–365
- Zhang L, Dzakpasu M, Chen R, Wang XC (2017) Validity and utility of ecological footprint accounting: a state-of-the-art review. *Sustain Cities Soc* 32:411–416
- Zivot E, Andrews DWK (1992) Further evidence on the Great Crash, the oil price shock, and the unit root hypothesis. *J Bus Econ Stat* 10(3): 251–270

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.