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Modelling the Impact of Energy Consumption, Natural Resources, and Urbanization on Ecological Footprint in South Africa: Assessing the Moderating Role of Human Capital

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ABSTRACT

Apart from being the most urbanized and largest emitter of CO_2 emissions in Africa, South Africa currently harbours an ecological deficit territory mainly due to its desire to attain more growth with less attention to its natural environment. Since environmental distortions are mainly an outcome of human activities, this study becomes the first to investigate the linkage between natural resource (NR), human capital, energy consumption, and ecological footprint (EF) in South Africa. Findings from the long-run results reveal that energy consumption, natural resource, economic growth, and urbanization add to the EF, while human capital curtails environmental deterioration. The interaction between human capital and urbanization helps in mitigating environmental degradation, which suggests a moderating effect of human capital in urban sustainability. The CCR, DOLS and FMOLS confirm the robustness of the findings. A feedback causality exists between natural resource and economic growth, and between economic growth and EF. Natural resources and urbanization also Granger cause EF. Lastly, policies relating to urban and natural resource sustainability and human capital development are discussed.

Keywords: Energy Consumption, Natural Resource, Human Capital, Urbanization, Ecological Footprint, South Africa
JEL Classifications: Q40, Q45, Q32

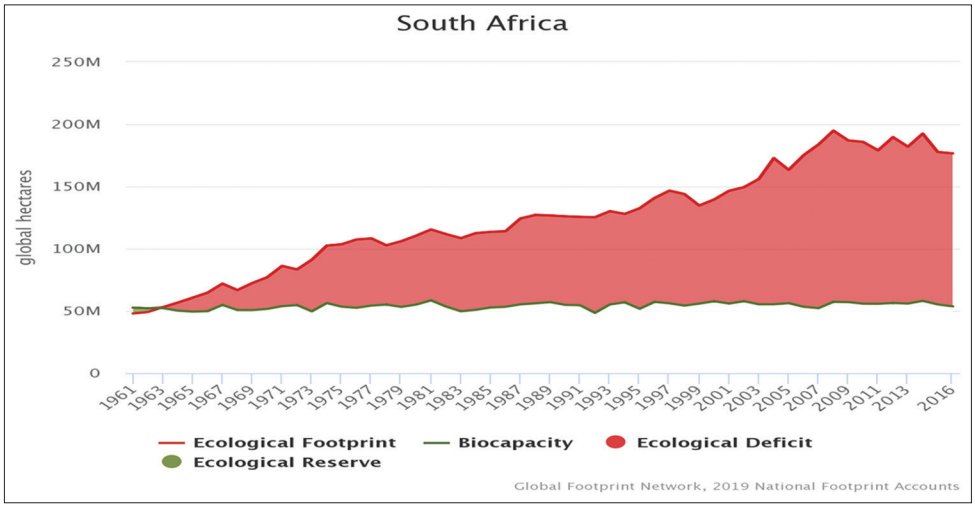
1. INTRODUCTION

The benefits of economic growth are hydra-headed. It can provide the needed infrastructures, reduce poverty, and improve people's living standard. On the flip side, it has its downsides, especially when an economy pays less attention to its natural environment while intensifying its desire for affluence (Meo et al., 2020a, 2020b; Ahmed et al., 2019a, 2019b; Nathaniel, 2019; Uddin et al., 2019; Omojolaibi and Nathaniel, 2020). In Africa, South Africa is arguably the most developed. This development comes with improved welfare, employment generation, FDI inflow, export expansion; however, keeping paste with this development, South Africa is now the largest emitter of CO_2 emissions in Africa, with an ecological deficit territory (Global Footprint Network, 2019).

A country is said to have an ecological deficit when its biocapacity is less than its EF (WWF, 2018; Nathaniel, 2021). In South Africa, for instance, the EF and biocapacity were 3.35gha and 1.46gha respectively in 1990. The EF was 3.05gha while the biocapacity was 1.26gha in 2000. Both increased to 3.60gha and 1.08gha respectively in 2010, and in 2016, the EF stands at 3.15gha, while the biocapacity dwindled to 0.95gha (GFN, 2019) Figure 1.

The EF is a measure of anthropogenic activities as it relates to the ocean, grazing land, carbon footprint, crops land, built-up land,

Figure 1: Ecological Footprint versus Biocapacity in South Africa



and forest products. It is measured in global hectares of land (gha). Recent studies have adopted the EF to measure anthropogenic activities on our natural environment (Solarin et al., 2021; Nathaniel, 2020; Zameer et al., 2020; Nathaniel et al., 2020a, 2020b; Danish et al., 2020; Destek and Sinha, 2020; Sharif et al., 2020; Usman et al., 2020; Jin et al., 2020; Altıntaş and Kassouri, 2020; Dogan et al., 2020; Yilanci and Pata 2020; Baz et al., 2020; Omoke et al., 2020). The link between NR and EF is heralded with lots of conflicts. For instance, economic growth which comes with industrialization and urbanization promotes NR extraction, and even its consumption, which in turn can prompt environmental deterioration by increasing the EF (Murshed et al., 2020; Danish et al., 2019).

Balsalobre-Lorente et al. (2018) argued that NR could shift a country's attention from non-renewable to renewables. As such, fossil fuel consumption may be minimized. Anthropogenic activities like deforestation, bush burning, mining, etc. destroy the biodiversity, soil, water, and air. All these arguments have opened the door to further investigation into the NR-EF nexus. Studies like (Danish et al., 2020; Zafar et al., 2019) reported that NR does not harm the environment, while Ahmed et al., 2020a; 2020b, Hassan et al., 2019) have confirmed that NR increases the EF.

This study is super useful for South Africa where economic advancement has intensified NR extraction, especially coal, due to large energy demand and the desire to earn foreign exchange. Coal accounted for about 72% of energy in South Africa in 2005. This was way above that of China, India, USA, South Korea, and Japan with 63.4%, 38.7%, 23.8%, 23.1%, and 21.1% respectively. South Africa generates 95% of its electricity from coal (Magazzino et al., 2020). Apart from being abundant and cheap, coal is a pollutant and non-renewable. It adds to emissions and truncates environmental sustainability. Unfortunately, coal, a natural resource, is a major source of energy in South Africa, its exploration and consumption have been found to environmentally harmful (Joshua and Bekun, 2020; Udi et al., 2020; Magazzino et al., 2020; Joshua et al., 2020). The urbanization rate in South Africa has been on a stable rise. It was 62.4% in 2012 and 65.3% in 2016 (WDI, 2019). South Africa is the biggest economy in sub-Saharan Africa (SSA) with the highest CO_2 emissions of 42.8%, and the 14th highest emitter in the world (Salahuddin et al., 2019; Ndoricimpa, 2017).

NR exacts an impact on the EF (Zafar et al., 2019). NR like the forest, developed lands, croplands, and grazing lands declines human-caused CO_2 emissions (GFN, 2018). However, NR like oil and coal reduce environmental quality (Ahmadov and van der Borg, 2019). NR is also closely linked with an economies income. As development starts, more energy (more NR) is consumed with little or no attention to the quality of the environment. As development persists, recognition is given to renewables as people increase their demand for NR preservation, clean environment, and energy-efficient commodities. Hence, an improvement in environmental quality. This explains the EKC hypothesis (Nathaniel et al., 2020c).

Economic growth engineer's industrialization which promotes NR extraction. As NR consumption increases through means like mining, deforestation, and agriculture, the environment could be adversely affected (Danish et al., 2019). NR extraction may improve income, but it reduces the biocapacity and increases the EF. Economic growth intensifies NR extraction which drives the EF (Panayotou, 1993; Ozturk and Al-Mulali, 2015). Sustainable management practice is sacrosanct for resource regeneration. The growth of an economy is key to urban population increase. On the other hand, urbanization increases energy and transportation demand, and industrialization which requires more energy (non-renewable) that increases the EF. As the income urban dwellers improve as a result of urbanization, renewables could form a large chunk of the energy mix, hence the EF decreases (Danish and Wang, 2019). Education and skilled human capital are needed for the sustainable use of NR. Human capital will contribute to societal readiness to adopt energy-efficient and environmental-friendly technologies (Zafar et al., 2019; Ozturk et al., 2016). Human capital has ecological benefit, and when human capital is skilled it can promote growth from different facets, and curtail urban anomaly (Ahmed, 2020b). This is the main reason why we included human capital in our study.

The study contributes in several strands to the existing literature. (i) it investigates the association between ecological footprint and natural resource in the presence of urbanization, human capital, energy consumption, and economic growth. This is the first study to explore the relationship between these variables in South Africa's context. (ii) we introduce the interaction term between urbanization and human capital in the model. This will help us identify some new dimensions of urban sustainability, and if human capital moderates the relationship between EF and urbanization. (iii) We test for the EKC for ecological footprint in South Africa, applied the Bayer and Hanck (BH) (2013) cointegration test, and causality test amidst the ARDL estimation technique. These econometric procedures are not only appropriate but produce reliable outputs.

2. LITERATURE REVIEW

We divide the literature into two subsections for easier understanding and to make it systematic in a way. The influence of urbanization, as well as, natural resource on the environment is still murky. The outcomes of various researches in this regard have been greeted with lots of discrepancies. Methodology, dataset, region considered, and estimation techniques are the main culprits for these irregularities.

2.1. Energy Consumption, Urbanization, Economic Growth and Ecological Footprint

Urbanization has received lots of attention as a potential determinant of EF of recent. Nathaniel (2020) investigated the impact of energy consumption, urbanization and economic growth on the EF in Indonesia from 1971 to 2014. The findings alluded to the fact that both variables add to the EF in Indonesia. Also, economic growth drives the EF. The author called for the use of renewables in Indonesia if the country desires to sustain its growth trajectory. Baloch et al. (2019) examined the effects of urbanization and economic growth on the EF in 59 countries from 1990 to 2016. Similar to Nathaniel (2020), both variables, coupled with energy use increase the EF. Hassan et al. (2019a) conducted a similar study for Pakistan; the results remained consistent with the other reviewed studies in terms of the deteriorating impact of economic growth and energy consumption on the environment. Still for the case of Pakistan, Hassan et al. (2019b) controlled for the influence of biocapacity and human capital in the growth-environment nexus. Economic growth was found not to be harmful as it reduced the EF by 0.60%. Dogan et al. (2019) were the first to conduct a study on the driving factors of EF in MINT countries. Urbanization appears to be the chief cause of environmental deterioration in MINT countries. In contrast to previous studies, Bello et al. (2018) reported an entire different finding. They discovered that, in Malaysia, urbanization does not deteriorate the environment. Nathaniel et al. (2020a) replicated the study of Dogan et al. (2019) for the MENA region adopting the AMG estimator without necessarily considering all the variables considered by the later. They reported the harmful impact of energy consumption, urbanization, and economic growth on the EF. These corroborate the findings of (Destek et al., 2018; Hassan et al., 2019a; Wang and Dong, 2019; He et al., 2019).

2.2. Natural Resources, Human Capital, and Ecological Footprint

There are studies on NR-EF nexus, but only a few studies have added human capital to the nexus. For instance, Ahmed et al. (2020a) tried to establish a link between human capital and EF for G7 countries. Their findings revealed the impact of human capital in mitigating degradation by reducing the EF. However, urbanization exacts an opposite influence on the EF. The findings were indeed revealing. Human capital is developed in G7 countries compared to other emerging economies. An improvement in human capital could just be the missing link to the attainment of environmental preservation. The studies of Ahmed et al. (2020a) is analogous to those of Ahmed et al. (2020b) who used the ARDL technique to examined the same relationship for China from 1970-2016. Danish et al. (2020) applied the DOLS and FMOLS techniques to investigate the impact of NR on EF in BRICS from 1992-2016. This study did not, however, account for human capital. Their findings confirmed that NR boosts environmental quality, unlike Ahmed et al. (2020a) that discovered the exact opposite for G7 countries. Zafar et al. (2019) used the ARDL technique to investigate the impact of human capital and NR on the EF in the US. They discovered that NR and human capital contribute to environmental wellness. Hassan et al. (2019a) explored the effect of NR and growth on the EF in Pakistan. Findings revealed that NR harms the environment in Pakistan. A feedback causality exists between NR and EF, and between biocapacity and EF. Ahmed and Wang (2019) examined the effect of human capital on the EF in India. Just like Zafar et al., (2019), human reduces the EF and human capital cause EF without feedback.

3. DATA AND METHOD

3.1. Data

This study relied on annual data spanning 1970-2016 for South Africa. The data on EF is mainly responsible for the time period s it ends in 2016. All the variables were converted into natural logarithm following the study of Ahmed et al. (2020b). The models to be estimated are stated below:

$$\Delta \ln(EF)_t = \psi_0 + \psi_e (EF)_{t-1} + \psi_g (GR)_{t-1} + \psi_n (GR^2) + \psi_h (HC)_{t-1} + \psi_u (EN)_{t-1} + \sum_{i=1}^{p} \beta_i \Delta (EF)_{t-i} + \sum_{j=0}^{q} \beta_j \Delta (GR)_{t-j} + \sum_{k=0}^{r} \beta_k \Delta (GR^2)_{t-k} + \sum_{l=0}^{s} \beta_l \Delta (HC)_{t-l} + \sum_{m=0}^{t} \beta_m \Delta (EN)_{t-m} + \mu_t \quad (1)$$

$$\Delta \ln(EF)_t = \psi_0 + \psi_e (EF)_{t-1} + \psi_g (GR)_{t-1} + \psi_n (NR) + \psi_h (HC)_{t-1} + \psi_u (UB)_{t-1} + \sum_{i=1}^{p} \beta_i \Delta (EF)_{t-i} + \sum_{j=0}^{q} \beta_j \Delta (GR)_{t-j} + \sum_{k=0}^{r} \beta_k \Delta (NR)_{t-k} + \sum_{l=0}^{s} \beta_l \Delta (HC)_{t-l} + \sum_{m=0}^{t} \beta_m \Delta (UB)_{t-m} + \sum_{n=0}^{u} \beta_n \Delta (IN)_{t-1} + \mu_t \quad (2)$$

$$\Delta \ln(EF)_t = \psi_0 + \psi_e (EF)_{t-1} + \psi_g (GR)_{t-1} + \psi_n (NR) + \psi_h (HC)_{t-1} + \psi_u (UB)_{t-1} + \sum_{i=1}^{p} \beta_i \Delta(EF)_{t-i} + \sum_{j=0}^{q} \beta_j \Delta(GR)_{t-j} + \sum_{k=0}^{r} \beta_k \Delta(NR)_{t-k} + \sum_{l=0}^{s} \beta_l \Delta(HC)_{t-l} + \sum_{m=0}^{t} \beta_m \Delta(UB)_{t-m} + \sum_{n=0}^{u} \beta_n \Delta(GR^2)_{t-1} + \psi_z (GR^2)_{t-1} + \mu_t \quad (3)$$

ψ_0 is the drift constant. u, t, s, r, q, and p are the lag lengths. The long-run multipliers are ψ_e, ψ_g, ψ_n, ψ_h, ψ_u, ψ_i, and ψ_z. The white noise and first difference operator are respectively μ_t and Δ. Where EF, GR, NR, HC, UB, IN, EN, and GR^2 represent ecological footprint, economic growth, natural resource, human capital, urbanization, interaction term, energy consumption, and the square of GDP respectively. The main focus is on Model 1. We controlled for the interaction term and the square of GDP in Model 2 and 3 respectively. Table 1 for the measurements and sources of the variables.

3.2. Methodology

3.2.1. Unit root

Unlike most previous studies that adopted the conventional unit root tests like the Dickey and Fuller (1981) and Phillips and Perron (1988), we applied three tests that do not only improved on the weaknesses of the aforementioned tests, but also account for breaks. One of these tests is the Zivot and Andrews (ZA) (1992). The ZA test suggested the three models are shown in Eq. 4, 5 and 6.

$$\Delta x_t = a + a x_{t-1} + bt + cDU_t + \sum_{j=1}^{K} d_j \Delta x_{t-j} + \mu_t \quad (4)$$

$$\Delta x_t = b + b x_{t-1} + ct + bDT_t + \sum_{j=1}^{K} d_j \Delta x_{t-j} + \mu_t \quad (5)$$

$$\Delta x_t = c + c x_{t-1} + ct + dDU_t + dDT_t + \sum_{j=1}^{K} d_j \Delta x_{t-j} + \mu_t \quad (6)$$

DT_t and DU_t are the trend shift and the dummy variable respectively. Where $DU_t = \{^{1 \ldots if\ t>TB}_{0 \ldots if\ t<TB}$ and $DU_t = \{^{t-TB \ldots if\ t>TB}_{0 \ldots if\ t<TB}$.

Table 1: Measurement and source of data

S/N	Indicator name	Measurement	Source
1	Urbanization	Urban population (% of total population)	WDI (2019)
2	Energy consumption	Kilogram of oil equivalent per capita	✓
3	Natural resource	Total natural resource rent (% of GDP)	✓
4	GDP Per Capita	In constant 2010 USD	✓
5	Interaction term	(Human capital x Urbanization)	✓
6	GDP Per Capita^2	In constant 2010 USD	✓
7	Ecological footprint	Global hectares per capita	GFN (2019)
8	Human capital	Human capital index	Penn world table

Sources: Author's compilation. Note: GFN represents Global Footprint Network

3.2.2. Cointegration tests

In addition to the bounds test, the BH was applied. The benefits of the BH test are numerous. Cointegration tests (like Johansen and Juselius, 1990; Banerjee et al., 1998; Boswijk, 1995; Johansen 1991; Engle and Granger, 1987) have their weaknesses. For instance, inconsistency in one-step, in relation to the Engle and Granger (1987) test, which is a two-step test, could be transferred to the next step. For the Johansen and Juselius (1990) and Johansen (1991) tests to be efficient, the sample must be large, and all variables must be I(1). The BH test adopts a combined approach. Hence, overcoming the weakness of the previous test (Ahmed et al., 2019a).

The Fisher form of the BH test is given as:

$$EG\text{–}JOH = -2[ln(\rho_{EG}) + (\rho_{JOH})] \quad (7)$$

$$EG\text{–}JOH\text{–}BO\text{–}BDM = -2[ln((\rho_{EG}) + (\rho_{JOH}) + (\rho_{BO}) + (\rho_{BDM})] \quad (8)$$

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

3.2.3. ARDL technique

The ARDL technique of Pesaran et al. (2001) was preferred because it is not biased to small sample size (Keho, 2019). It can simultaneously correct for endogeneity and serial correlation inasmuch as the lag length is efficiently modified. Variables with different optimum lag lengths and integration are accommodated, except for I(2) variables (Wang et al., 2019). The Toda and Yamamoto (TY) (1995) was used to check for the direction of causality among the variables. Apart from being the modified version of the Wald test, it is way superior and provides robust estimates than the conventional Granger causality test, irrespective of variables order of integration.

4. RESULTS AND DISCUSSION

From Table 2, GR^2 has the highest average. Also, NR remains the most volatile of the variables. All the variables are positively skewed except EF. The variables are platykurtic; indicating less or few extreme outliers. The normality of the variables is confirmed based on their probability values, but for HC.

Unit root tests are needed to guide the aid the direction of the analysis and techniques to be applied in this study. The unit root results are presented in Tables 3 and 4. Here the DF-GLS, Ng and Perrron (2001), and the Zivot and Andrews (ZA) (1992) was applied. The first two tests are in harmony. They confirmed a mixed

Table 2: Descriptive statistic

	EF	GR	GR2	NR	HC	UB	IN	EN
Mean	1.07	8.77	14.5	1.65	0.72	3.99	0.54	3.85
Max.	3.93	8.93	15	2.67	1.01	4.17	0.8	5.33
Mini.	1.1	8.61	14	0.65	0.58	3.86	0.42	1.76
Std. D	0.24	0.09	0.3	0.46	0.13	0.1	0.11	0.26
Skewness	–0.11	0.26	0.28	0.06	0.86	0.31	0.83	0.45
Kurtosis	2.19	2.12	2.12	2.7	2.38	1.66	2.35	2.07
Prob.	0.5	0.35	0.34	0.9	0.03	0.12	0.24	0.12

Source: Authors' Computations

Table 3: Results of the DF-GLS and NG-Perron unit root tests

Variables	DF-GLS		NG-PERRON			
	At level	Difference	At Level		Difference	
	T-Statistic.	T-Statistic	T-Statistic	MSB 5%	T-Statistic	MSB 5%
EF	0.091	–6.811***	0.829	0.233	0.148**	0.233
GR	–0.846	–4.228***	0.346	0.233	0.162**	0.233
HC	–0.318***	–0.208	0.244**	0.233	0.559	0.233
NR	–2.426	–8.647***	0.234	0.233	0.154***	0.233
UB	–1.702***	–0.797	0.143**	0.233	0.519	0.233
IN	–0.528***	–0.474	0.228**	0.233	0.551	0.233
GR2	–0.92	–4.152***	0.338	0.233	0.164***	0.233
EN	0.196	–6.987***	0.767	0.233	0.169***	0.233

Source: Authors computation. Note: *** and ** represent 1% and 5% significance level respectively. –1.61 (10%), –1.94 (5%), and –2.61 (1%) are the DF-GLS critical values

Table 4: ZA unit root results

Variables	ZA unit root test			
	Level		Difference	
	t-value	Break year	t-value	Break year
EF	–4.191	2003	–8.473***	2008
GR	–3.116	2004	–5.155**	1994
NR	–3.659	1987	–9.614**	1981
HC	–1.726	2001	–5.336***	2001
UB	–4.991	1986	–7.031***	1985
IN	–3.581	2001	–3.989***	2001
GR2	–3.024	1985	–5.206**	1994
EN	–3.564	1995	–6.864***	2009

Source: Authors computation. ***and **represent 0.01% and 0.05% significance levels respectively

level of integration, but the later (ZA) affirmed stationarity at I(1). Structural breaks exist in the series of EF, GR, NR, HC, and UB in the year 2003, 2004, 1994, 1987, 2001, etc. These breaks are due to economic and political reforms in the country.

For robustness, two cointegration tests were applied for the three models (Tables 5 and 6). The outcome of the tests is in the affirmative. They both confirmed that a long-run relationship is evident in the models.

Since the F-stat from the three models is greater than the critical values at 5% levels, we can't deny the existence of a long-run relationship in Table 5. The BH test requires the values of both EG-JOH and EG-JOH-BO-BDM to be greater than the 5% critical values. Since that is the case in Table 6, then cointegration exists.

Table 7 reports the ARDL results for the three models. The long-run results are the same in terms of the impact of each of the variables on the EF. Growth, NR, energy consumption, and urbanization add to environmental degradation, while human capital promotes environmental quality. South Africa, like other BRICS countries, have witnessed a fairly stable growth over the years and is arguably the most developed in the continent. However, one important factor that has contributed to the country's growth is energy consumption (Nathaniel et al., 2019; Joshua and Bekun 2020; Magazzino et al., 2020). Unfortunately, the country consumes more of non-renewable energy sources. These energy sources are pollutants and their impact on the environment could be far-reaching. This is consistent with the findings of Danish et al. (2020) for BRICS; Ahmed et al. (2020a) and Liu et al. (2020) for G7 countries.

Table 5: ARDL bounds test

Long-run results			
Model 1	**Lower bound**	**Upper bound**	**Significance level**
Fc (lngr, lngr2, lnen, lnhc). F= 8.1562	2.20	3.09	10%
	2.56	3.49	5%
	3.29	4.37	1%
Model 2			
Fc (lngr, lnnr, lnhc, lnub, lnin). F=7.6069	1.81	2.93	10%
	2.14	3.34	5%
	2.82	4.21	1%
Model 3			
Fc (lngr, lnnr, lnhc, lnub, lngr2). F=8.2785	2.26	3.35	10%
	2.62	4.79	5%
	3.41	4.68	1%

Source: Authors' computations

NR can either promote or deteriorate the environment depending on the resource and how it is being explored. In South Africa, coal is one of the most explored resources. Coal is finite, it is non-renewable and hence pollutes the environment. Studies have confirmed coal consumption to be particularly harmful in South Africa (Udi et al. 2020; Joshua et al., 2020). This finding complements the studies of Hassan et al. (2019) for Pakistan, Ahmed et al. (2020b) for China, and Ahmed et al. (2020a) for G7; but contradict those of Kongbuamai et al. (2020) for ASEAN, Balsalobre-Lorente et al. (2018) for the EU; Zafar et al. (2019) for the United States, Al-Mulali et al. (2015) for Vietnam, and Danish et al. (2020) for BRICS.

This finding is evidence that the consumption and exploration of NR have not been sustainable in South Africa. The country has exacted enormous pressure on its NR to meet its energy demands. South Africa generates 95% of its electricity from coal. Some researchers are of the opinion that NR abundance should reduce a country's reliance on energy import, with a gradual shift to less-polluting sources which will abate environmental degradation. But, the case is, however, different for South Africa where coal is a major energy source. Just like economic growth and energy consumption, urbanization also exacts a negative impact on the environment. This confirms the earlier findings of Sarkodie and Adams (2018), Salahuddin et al. (2019), and Nathaniel et al. (2019) for South Africa. This finding is intuitive and appealing because urbanization triggers economic growth and other social

Table 6: BH test results

Estimated models	EG-JOH	EG-JOH-BO-BDM	Cointegration
lnEF=f(lnGR,lnGR2,lnEN,lnHC)	13.453**	33.231**	Yes
lnEF=f f(lnGR,lnNR,lnHC,lnUB,lnIN)	21.361**	44.537**	Yes
lnEF=f(lnGR,lnNR,lnHC,lnUB,lnGR2)	15.101**	36.342**	Yes
5% Critical value (For Model 1)	10.576	20.143	
5% Critical value (For Model 2 and 3)	10.419	19.888	

Source: Authors' computations. Note: ** Represents 0.05% significance levels

Table 7: ARDL results

Variables	Model 1	Model 2	Model 3
Long-run results			
GR (log)	0.454** (2.478)	0.675*** (4.322)	0.431*** (3.021)
GR2 (log)	–0.034*** (–5.678)	-	–0.442** (2.546)
HC (log)	–1.324** (–2.726)	–2.227** (–2.177)	–1.435*** (–3.291)
EN (log)	0.066*** (2.773)	-	-
NR (log)	-	0.097*** (3.356)	0.060*** (2.976)
IN (log)	-	–0.991*** (–3.355)	-
UB (log)	-	2.998*** (6.830)	2.799*** (4.967)
Short-run results	Model 1	Model 2	Model 3
Dlog(EF(–1))	–0.956*** (–6.535)	–0.622*** (–5.789)	–0.957*** (–6.534)
Dlog(GR)	0.434** (2.380)	0.622*** (3.034)	14.46 (0.957)
Dlog(HC)	–1.694 (–0.815)	–0.231** (–2.154)	–0.945 (–0.453)
Dlog(HC(-1))	1.699 (0.635)	-1.386 (-1.260)	1.667 (0.623)
Dlog(EN)	0.032** (2.156)	-	-
Dlog(EN(-2)	0.022 (1.520)	-	-
Dlog(NR)	-	0.060** (2.683)	0.027* (1.737)
Dlog(NR(-2)	-	0.342 (1.056)	0.022*** (6.485)
Dlog(UB)	-	1.866*** (5.912)	11.50*** (3.705)
CointEq(-1)*	–0.956*** (–7.574)	–0.622*** (–7.209)	–0.757*** (–7.651)
Diagnostic tests			
R-squared	0.743	0.583	0.751
χ^2 Jarque-Bera	0.611	0.914	0.515
χ^2 LM test	0.872	0.244	0.788
χ^2 Ramsey	0.172	0.466	0.286
χ^2 Breusch-Pagan-Godfrey	0.322	0.510	0.168

Source: Authors' computations. Note: ***, ** and * represent statistical significance at the 1%, 5%, and10% levels of significance respectively. t-statistics are in parentheses

Table 8: Robustness check

Variables	FMOLS	DOLS	CCR
GR (log)	0.620** (2.243)	0.378** (2.413)	0.320*** (5.367)
HC (log)	–2.065*** (–3.939)	–1.916*** (–10.96)	–1.787*** (–16.29)
EN (log)	0.094*** (3.008)	0.139*** (4.620)	0.096*** (5.799)
GR^2 (log)	–0.946*** (–3.454)	–0.141*** (–11.48)	–0.276*** (–29.66)

Source: Authors' computations. Note: *** and ** represent statistical significance at the 1% and 5% levels respectively. t-statistics are in parentheses

activities that promote energy consumption. Urbanization in South Africa is linked to industrialization that is characterized by massive energy use which stimulates environmental deterioration. This is, however, not the only way urbanization contributes to environmental degradation in South Africa, it could also contribute through enormous waste generation, and increasing demand for water, food, transportation, and other resources.

Human capital reduces the EF. This reason is justified as human capital has played a key role in South Africa's drive for economic prosperity. An educated human capital will crave for a better environment, which will propel an efficient use and conservation of NR, energy-saving, and the adoption of environmental friendly technology at the collective and individual level. Human capital is also key for financial development, and could serve as a pathway through which NR can trigger growth (Zallé, 2019). This outcome is in consonance with those of (Zafar et al., 2019; Ahmed and Wang, 2019).

Interestingly, the interaction term exhibits a significant and negative coefficient inferring the moderating role of human capital in mitigating environmental deterioration in South Africa. Urbanization increases the EF, but its interaction with human capital reduces it. This provides a great insight that human capital is germane for urban sustainability. We further observed the existence of the EKC for ecological footprint in South Africa evident from the positive/negative coefficient of GDP/GDP^2 in Table 7, Model 3. This is a confirmation that pollution reduces as growth persists in South Africa. The short-run outcomes are consistent with those of the long-run but for the inconsistent impact of human capital on the EF. The short-run evidence affirmed that human capital is

Table 9: Toda-Yamamoto test results

Null Hypotheses	MWALD Stat.	Probability	Causality
GR→EF	7.233	0.026	Yes
HC→EF	5.330	0.069	Yes
NR→EF	4.398	0.110	No
EN→EF	7.194	0.027	Yes
EF→GR	6.473	0.039	Yes
HC→GR	17.02	0.002	Yes
NR→GR	5.725	0.057	Yes
EN→GR	7.875	0.019	Yes
EF→HC	0.601	0.740	No
GR→HC	0.678	0.712	No
NR→HC	1.007	0.604	No
UB→HC	1.623	0.444	No
EF→NR	0.146	0.079	Yes
GR→NR	0.466	0.000	Yes
HC→NR	1.364	0.046	Yes
UB→NR	9.809	0.481	No
EF→UB	0.146	0.929	No
GR→UB	0.466	0.791	No
HC→UB	1.364	0.505	No
EN→UB	9.809	0.007	Yes

Source: Authors' computations

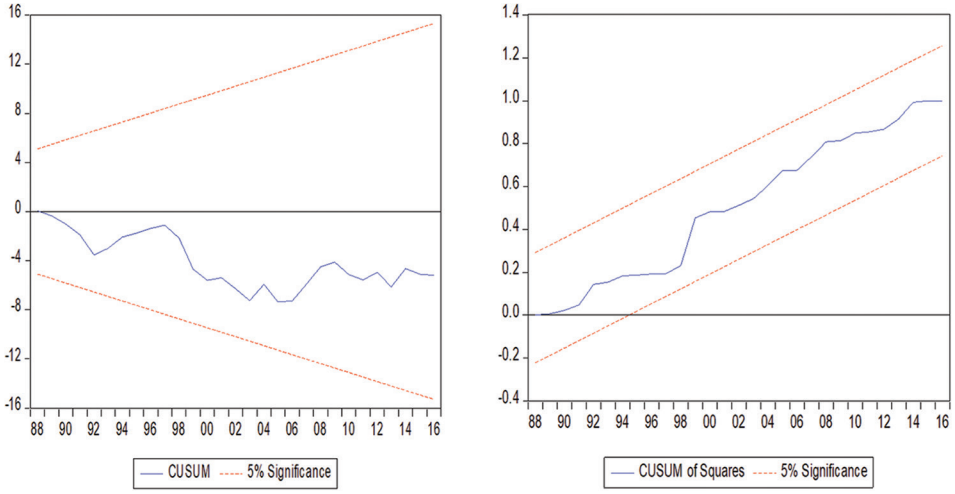
not potent enough to reduce the EF in Model 1 and 3. This calls for human capital development for a better environment in South Africa.

Table 8 confirmed the robustness of our findings in Table 7. The three results (FMOLS, DOLS, and CCR) are in harmony with all the long-run findings; therefore similar discussion/interpretation applies.

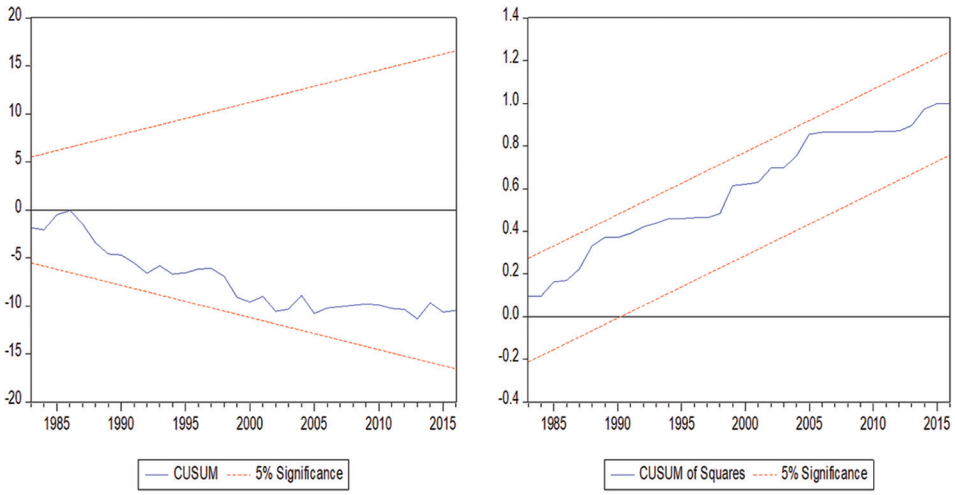
The causality test in Table 9 showed different directions of causality. A feedback causality between NR and GR, and GR and EF revealed that Natural resource plays an important role in South Africa's growth trajectory and also contributes to pollution. As such, there is a need to ensure its efficient exploration and consumption. A unidirectional causality from EN to EF, EN to UB, and from EN to GR re-emphasizes urban sustainability, sustainable exploration, and the need for clean energy consumption in South Africa.

The CUSUM and CUSUMsq plots for each of the models confirmed that the models are stable and can be used for forecast.

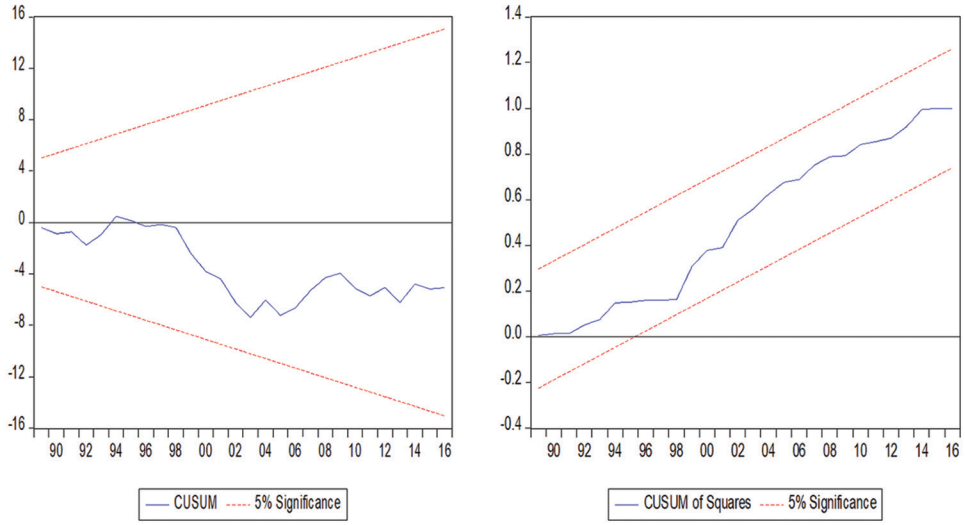
Cusum and Cusumsq Plots for Model 1



Cusum and Cusumsq Plots for Model 2



Cusum and Cusumsq Plots for Model 3



5. CONCLUSION

This study investigated the linkage between natural resource, energy consumption, urbanization, human capital, and EF in South Africa. DF-GLS and Ng-Perron tests alluded to a mixed level of integration, while the BH test affirmed that cointegration abounds in the series. The ARDL, complemented with the FMOLS, DOLS, and CCR results confirmed that economic growth, energy consumption, natural resource, and urbanization increase the EF, while human capital reduces it in the long-run. Results further suggest that the EKC for EF exists for South Africa, and the interaction of urbanization and human capital can ensure urban sustainability in the country. A feedback causality exists between natural resource and economic growth, and between economic growth and EF. Natural resources and urbanization also Granger causes EF. These results have policy implications and calls for reasonable policy directions.

Since natural resource drives growth, and coal consumption is a major natural resource used for electricity generation and other activities, and natural resource increases the EF; the need arises for policymakers to adjust the country's energy portfolio and make a paradigm shift to clean energy sources. This might not be an easy sail considering the country's financial wellbeing. However, creating awareness, providing the household with palliatives (subsidies, tax and interest rate holidays, etc.), encouraging firms to embark on cleaner production while taxing the dirtier ones could be a good step in the right direction. The country also needs to gradually shift attention to other natural resources that are less of a pollutant and ensure its sustainable exploration, without altering the growth process. These will ease the difficulties associated with attaining SDG 7 (Affordable and Clean Energy).

Development issues like inequality, lack of amenities, and low income are the major cause of urban explosion. The concentration of infrastructures in cities like Johannesburg, Pretoria, Durban, and Cape Town, and a dearth of such infrastructures in Ntabankulu, Nkangala, and uMgungundlovu will only encourage urbanization as people will prefer to live in cities where they can easily make earns meet with fewer efforts. The need for smart cities cannot be overemphasized. Smart cities enhance the performance of urban services like transportation and energy to attain sustainability and innovation. All these will put the country in the pathway of achieving the SDG 11 (Sustainable Cities and Communities). Most importantly, human capital needs to be developed in South Africa for sustainable communities, cities and energy. Once human capital is developed, the demand for renewables will increase, and the sustainability of the environment will be a priority.

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