NATURAL RESOURCES, URBANISATION, ECONOMIC GROWTH AND THE ECOLOGICAL FOOTPRINT IN SOUTH AFRICA: THE MODERATING ROLE OF HUMAN CAPITAL

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Abstract: South Africa is the largest emitter of CO_2 and arguably the most developed and urbanised country in Africa. The country currently harbours an ecological deficit territory which could be the outcome of economic expansion, urban explosion, unsustainable resource exploration and a low level of human development. After all, environmental distortions are mainly the outcome of human activities. This study is a maiden attempt to examine the linkage between urbanisation, human capital, natural resources (NR) and the ecological footprint (EF) in South Africa. Unlike previous studies, this study employs positivist and relevant environmental indicators that accommodate built-up land, forest land, carbon footprint, ocean, grazing land and cropland. Findings from the long-run results suggest that urbanisation, economic growth and NR increase the EF, whereas human capital ensures environmental sustainability. The interaction between urbanisation and human capital mitigates environmental degradation by reducing the EF. The canonical cointegrating regression (CCR), dynamic ordinary least squares (DOLS) and the fully modified ordinary least squares (FMOLS) results further confirm the nature of the relationships and linkages existing with respect to NR, urbanisation, economic growth and the EF. A bidirectional causality exists between human capital, economic growth and the EF. Policies related to NR and urban sustainability, the limitations of the study, as well as possible directions for future research are discussed.

Keywords: urbanisation, natural resources, ecological footprint, human capital, South Africa

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Introduction

The dependence on non-renewable energy sources has been a major driver of economic growth in South Africa. Economic growth benefits the society via the provision of infrastructures, improvement in living standards and employment creation. However, it has its downsides, especially when an economy pays less attention to its natural environment while intensifying its desire for affluence (Uddin et al. 2019; Yasmeen et al. 2020). In Africa, South Africa is arguably the most developed. This development comes with employment generation, improved welfare, export expansion and a foreign direct investment (FDI) inflow. Now, keeping pace with this development comes at a cost to the environment. It has inflicted a trade-off between higher

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economic growth and lower environmental quality. Therefore, despite flourishing in terms of economic performances, the environmental attributes in South Africa have persistently deteriorated over time as the country now harbours an ecological deficit territory (Global Footprint Network (GFN), 2019). An ecological deficit territory is the one where the ecological footprint (EF) is higher than the biocapacity (Siriwat, Tiedt 2019; World Wildlife Fund, 2018). In South Africa, for instance, the biocapacity and EF were respectively 1.46 gha and 3.35 gha in 1990. The biocapacity dwindled to 1.26 gha, whereas the EF stood at 3.05 gha in 2000. In 2010, the EF soared to 3.60 gha, leading to a decline in the country's biocapacity to 1.08 gha. In 2017, the country's biocapacity declined to 1.03 gha, whereas its EF was 3.16 gha (GFN, 2019).

The EF is measured in global hectares (gha) of land. It measures the effects of anthropogenic activities on grazing land, crops land, ocean, forest products, carbon footprint and built-up land. Previous studies have used the EF to capture the influence of anthropogenic activities on the natural environment (Zameer et al. 2020; Destek, Sinha 2020; Zhang et al. 2020; Nathaniel 2020; Marti, Puertas 2020; Ulucak et al. 2020; Omoke et al. 2020; Baz et al. 2020; Yilanci, Pata 2020; Dogan et al. 2020; Altıntaş, Kassouri 2020; Zhang et al. 2020; Usman et al. 2020; Sharif et al. 2020). The link between natural resources (NR) extraction and the EF has been explored adequately well in the literature. According to Danish et al. (2019), economic growth is always accompanied by urbanisation and industrialisation. The latter encourages NR extraction, which could promote environmental degradation by reducing biocapacity. Activities such as mining, bush burning and deforestation have adverse effects on biodiversity as well as other components that support human existence (Balsalobre-Lorente et al. 2018). There is still no consensus on the impact of NR extraction on the EF. For instance, Zafar et al. (2019) and Ulucak et al. (2020) have discovered that NR extraction contributes to the well-being of the environment, whereas Hassan et al. (2019a, b) and Ahmed et al. (2020a, b) reported the opposite.

This study seeks to examine the NR–EF nexus in South Africa by considering the role of human capital and urbanisation. 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. Unlike Japan, Germany, the USA, Italy, France and other developed countries, South Africa generated 94.6% of its electricity from coal sources in 2005, 94.7% in 2006, 93.7% in 2013, and 92.7% in 2015. Although it reduced to 88.0% in 2017, South Africa had a coal power generation capacity of 39 GW as of 2018 (World Development Indicator (WDI), 2019). Coal is a non-renewable energy source that increases the emission of noxious gases capable of causing environmental deterioration. Recent studies have alluded to the adverse effects of coal consumption in South Africa (Joshua et al. 2020; Joshua, Bekun 2020; Magazzino et al. 2020; Udi et al. 2020). As a result of being the biggest economy in Sub-Saharan Africa (SSA), the urbanisation rate—as well as CO_2 emissions—have been on a stable rise in South Africa (Ndoricimpa 2017; Salahuddin et al. 2019). The urbanisation rate was 64.31%, 64.82%, 65.30%, 65.85%, 66.35% and 66.85% in 2014, 2015, 2016, 2017, 2018 and 2019 respectively (WDI, 2019). South Africa is currently the 14th highest emitter in the world (Salahuddin et al. 2019).

The excessive exploration of NR could impact the EF (Zafar et al. 2019). Natural resources such as forest and croplands reduce human-caused emissions (Panayotou 1993; GFN 2018), whereas resources such as coal and oil decline environmental quality (Ahmadov, van der Borg 2019). The link between NR consumption/exploration and economic growth cannot be overemphasised. The early stage of development is associated with increased energy demand with little attention to environmental quality. As the economy expands further, the demand for renewables, energy-efficient commodities, a clean environment and NR preservation is desired. Thus, environmental quality improves. This is the intuition behind the Environmental Kuznets Curve (EKC) hypothesis (Nathaniel et al. 2021a).

To curb environmental degradation, sustainable management practice is required for resources to regenerate. Education and skilled human capital are needed for the sustainable consumption of NR. Education creates the required awareness to adopt environmental-friendly and energy-efficient technologies (Nathaniel et al. 2021b; Zafar et al. 2019). A skilled human capital contributes to a nation's economic growth and also sees the need to uphold environmental quality. For these reasons and more, this study considers human capital in the NR–EF nexus for South Africa.

The contributions of this study are as follows: (i) This is a seminal study to investigate the relationship between NR, human capital, economic growth, urbanisation and the EF in South Africa's context. Additionally, previous studies on South Africa have overlooked this important demographic variable—human capital in the growth-environment nexus. (ii) The introduction of the interaction term between urbanisation and human capital will help to identify some of the new dimensions of urban sustainability. This will expose the importance of human capital development in enhancing environmental quality as the country seeks to attain the Sustainable Development Goals by 2030. (iii) This study applies robust econometric techniques, including the Bayer and Hanck (BH) (2013) combined cointegration test and the autoregressive distributed lag (ARDL) bounds test approach. These econometric procedures accommodate time-series issues, account for structural breaks and produce reliable results (Ahmed et al. 2020a).

Literature review

The EKC is the theoretical basis for this research. The EKC was developed in a bid to explain how economic growth will continue to accelerate environmental deterioration at the early stages of economic expansion until it reaches a maximum point where the nexus between both becomes negative. The major intuition behind the EKC hypothesis is that environmental degradation declines with income after a threshold. It has been noted in recent studies that changes in the relationship between economic growth and environmental deterioration are not 'exogenous' processes, but could be influenced by some factors and economic policies (Copeland, Taylor 2004). As such, Dasgupta

Table 1. Studies on NR, human capital, energy consumption, and the EF.

Author(s)	Time period	Methodology	Variables considered	Country(ies)	Key finding(s)
Nathaniel (2021)	1990–2016	AMG	NRR, GDP, HC, EF	ASEAN bloc	NRR does not hurt environment in Thailand and Laos PDR. Bidirectional causality exists between HC and GDP, and between NRR and GDP.
Ulucak et al. (2020)	1995–2016	DOLS, FMOLS.	EF, GDP, NRR, URB, REN	BRICS	REN, URB, and NRR decrease EF. GDP enhances environmental degradation.
Ahmed et al. (2020a)	1970–2016	ARDL	NRR, HC, GDP, URB, EF	China	URB, NRR, and GDP drive EF in China.
Ahmed et al. (2020b)	1971–2014	CUP-FM, CUP-BC.	FDI, GDP, NRE, URB, HC, EF	G7 countries.	GDP, NRE, and URB increase EF, while HC and FDI reduce it.
Nathaniel (2020)	1971–2014	ARDL	GDP, NRE, URB, TRD, EF	Indonesia	NRE, GDP, and URB increase EF in Indonesia.
Baloch et al. (2019a)	1990–2016	Driscoll-Kraay panel regression	FDI, GDP, FDV, NRE, URB, EF	59 Belt and Road countries.	FDV, FDI, NRE and URB have negative influence on environment.
Hassan et al. (2019a)	1971–2014	ARDL	NRR, GDP, BIO, GDP^2 EF	Pakistan	Long-run causality exists between BIO and EF. NRR has positive impact on EF.
Hassan et al. (2019b)	1971–2014	ARDL	HC, GDP, BIO, EF	Pakistan	BIO increases EF. GDP declines EF by 0.60%. HC exerts negative effect on EF. GDP Granger causes EF.
Dogan et al. (2019)	1971–2013	ARDL	Fossil fuel energy, URB, Export, FDV, REN, EF	Mexico, Indonesia, Nigeria, and Turkey.	URB is chief cause of environmental degradation.
Nathaniel et al. (2020c)	1990–2016	AMG	REN, NRE, URB, EF, FDV, GDP	MENA	FDV, GDP, NRE, and URB increase EF in MENA. One-way causality flows from NRE and URB to EF.

Author(s)	Time period	Methodology	Variables considered	Country(ies)	Key finding(s)
Nathaniel et al. (2020d)	1980–2016	Panel Quantile Regression	FDI, EF, NRE, URB, GDP, carbon footprint, CO_2 emissions	Coastal Mediterranean countries	NRE degrades environment. Effects of GDP and URB on environment were mixed for different indicators.
Ulucak et al. (2020)	1992–2016	FMOLS, DOLS.	NRR, URB, REN, GDP, GDP², EF	BRICS	EKC is validated in individual BRICS countries. NRR, URB, and REN reduce EF.
Destek, Sinha (2020)	1980–2014	MG. FMOLS-MG, DOLS-MG.	GDP, GDP², EF, REN, TRD, NRE	24 OECD countries.	EKC hypothesis does not hold. REN reduces EF.
Wang, Dong (2019)	1990–2014	AMG	REN, URB, GDP, GDP², EF, NRE	14 SSA countries.	Feedback causality runs among NRE, URB, GDP, and EF. NRE, GDP, and URB exert positive effects on EF.
Sharma et al. (2020)	1990–2015	Panel ARDL	REN, URB, POP, FOR, NRE, GDP, EF	Asia	URB, GDP, NRE, FOR, and POP drive EF. REN restores environmental quality.
Ansari et al. (2020)	1991–2017	PMG	EF, URB, Material footprint, GDP, GLO, NRE	37 Asian countries	URB and GLO increase EF. GDP and NRE also increase EF.
Sharif et al. (2020)	1965Q1–2017Q4	Quantile ARDL	NRE, EF, REN, GDP	Turkey	Feedback causality exists among listed variables; RE, GDP, NRE, and EF.
Altıntaş, Kassouri (2020)	1990–2014	CCEMG, IFE.	CO_2 emissions, EF, RE, GDP, NRE	Europe	RE is environmentally friendly. NRE exerts positive impact on EF.
Baz et al. (2020)	1971–2014	NARDL	GDP, NRE Capital, EF	Pakistan	EF Granger causes NRE. GDP does not cause EF.
Aziz et al. (2020)	1990–2018	QARDL	GDP, EF, FOR, RE	Pakistan	FOR and REN minimise EF. GDP increases EF thereby encouraging environmental degradation.

Note: ARDL – autoregressive distributed lag model; QARDL: BRICS – Brazil, Russia, India, China and South Africa; BIO – biocapacity; CUP-FM – continuously updated fully modified; CUP-BC – continuously updated bias-corrected; DOLS – dynamic ordinary least squares; EF – ecological footprint; EKC – Environmental Kuznets Curve; FDI – Foreign Direct Investment; FOR – forest; FMOLS – fully modified ordinary least squares; FDV – Financial Development; GLO – globalisation; HC – human capital; IFE – interactive fixed effects; MG – mean group; MENA – Middle East and North Africa; NR – natural resources; NRE – non-renewable energy; NARDL – non-linear ARDL; POP – population; REN – renewable energy; SSA – Sub-Saharan Africa; TRD – trade openness; TRD – trade; Quantile ARDL; URB – urbanisation.
Source: own compilation.

et al. (2002) posit that economic variables/policies are capable of influencing the shape of the EKC as well as the relationship between environmental degradation and economic growth. Hence, we included other variables such as urbanisation, human capital and NR as potential factors that can influence environmental degradation in South Africa. Table 1 presents a summary of recent studies on the EF determinants.

In summary, the influence of NR as well as urbanisation on the EF is still murky. There is no consensus as regards the impact of NR and urbanisation on environmental quality. The discrepancies in the existing studies could be attributed to the choice of the dataset, estimation technique(s), the region/country considered and the choice of variables/environmental indicator. Additionally, human capital is seldom considered as a potential determinant of the EF, and there is not any known study that has addressed this issue for the case of South Africa. Hence, the present study intends to fill this viable gap.

Data and method

Data

This study adopts annual time series data spanning 46 years, from 1970 to 2016 for South

Africa. The data span was selected considering the constraint on data availability. The following models, Eqs (1)–(3), are estimated in this study.

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

$$\ln(EF)_t = \psi_0 + \psi_e(EF)_{t-1} + \psi_g(GR)_{t-1} + \psi_n(NR) + \psi_h(HC)_{t-1} + \psi_u(UB)_{t-1} + \sum\beta_i n\,(EF)_{t-i} + \sum\beta_j n\,(GR)_{t-j} + \sum\beta_k n\,(NR)_{t-k} + \sum\beta_l n\,(HC)_{t-l} + \sum\beta_m n\,(UB)_{t-m} + \sum\beta_n n\,(IN)_{t-n} + \psi_i(IN)_{t-1} + \mu_t \quad (2)$$

$$\ln(EF)_t = \psi_0 + \psi_e(EF)_{t-1} + \psi_g(GR)_{t-1} + \psi_n(NR) + \psi_h(HC)_{t-1} + \psi_u(UB)_{t-1} + \sum_{i=1}^{p}\beta_i n\,(EF)_{t-i} + \sum_{j=0}^{q}\beta_j n\,(GR)_{t-j} + \sum_{k=0}^{r}\beta_k n\,(NR)_{t-k} + \sum_{l=0}^{s}\beta_l n\,(HC)_{t-l} + \sum_{m=0}^{t}\beta_m n\,(UB)_{t-m} + \sum_{l=0}^{u}\beta_n n\,(GR2)_{t-l} + \psi_z(GR2)_{t-1} + \mu_t \quad (3)$$

ψ_0 is the drift constant; p, q, r, s, t, u 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 n, where *GR*2, *IN*, *UB*, *HC*, *NR*, *GR* and *EF* represent the square of GDP, interaction term, urbanisation, human capital, NR, economic growth and the EF respectively. The main focus is on Model 1. Table 2 shows the sources and the measurements of the variables.

Methodology

Unit root

Previous studies failed to consider the possibility of structural breaks in the series. To overturn the inefficiencies that could emanate from such a decision, this study applies the Zivot and Andrews (ZA) (1992) test to account for structural breaks to attain robust estimates. The models of the ZA test are shown in Eqs (4)–(6).

$$x_t = \varphi + ax_{t-1} + bt + cDU_t + \sum_{j=1}^{K} d_j n\, x_{t-j} + \mu_t \quad (4)$$

$$x_t = \Gamma + bx_{t-1} + ct + bDT_t + \sum_{j=1}^{K} d_j n\, x_{t-j} + \mu_t \quad (5)$$

$$x_t = \mathcal{C} + cx_{t-1} + ct + dDU_t + dDT_t + \sum_{j=1}^{K} d_j n\, x_{t-j} + \mu_t \quad (6)$$

$\mathcal{C}$, Γ and φ are the constant terms. DT_t is the trend shift, whereas DU_t represents the dummy variable, where $DU_t = \begin{cases} t - TB \ldots \text{if } t > TB \\ 0 \ldots \text{if } t < TB \end{cases}$ and $DT_t = \begin{cases} 1 \ldots \text{if } t > TB \\ 0 \ldots \text{if } t < TB \end{cases}$.

Cointegration tests

The BH cointegration test is applied to ascertain the possibility of a long-run relationship among the variables. The traditional cointegration tests, including those of Johansen and Juselius (1990), Engle and Granger (1987), Boswijk (1995), Banerjee et al. (1998) and Johansen (1991) have their weaknesses. For instance, the Johansen (1991) and Johansen and Juselius (1990) tests can only be efficient when the sample size is

Table 2. Measurement and source of data.

S/N	Indicator name	Measurement	Source
1	Urbanisation	Urban population (% of total population)	WDI (2019)
2	Natural resources	Total natural resource rent (% of GDP)	✓
3	GDP per capita	In constant 2010 USD	✓
4	Interaction term	(Human capital × Urbanisation)	✓
5	GDP per capita^2	In constant 2010 USD	✓
6	Ecological footprint	Global hectares per capita	GFN (2019)
7	Human capital	Human capital index	Penn World Table

GFN – global footprint network; WDI – World Development Indicator.
Source: own compilation.

large and all variables are integrated at I(1). The BH test adopts a combined approach that yields robust outputs. The Fisher form of the BH test is shown in Eqs (7) and (8).

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

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

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

ARDL technique

The ARDL technique is not biased to a small sample size (Keho 2019). It can simultaneously correct for serial correlation and endogeneity. The technique also accommodates I(0), I(1) or a combination of I(0) and I(1) variables (Wang et al. 2019). Since the ARDL technique does not provide information on the direction of causality, the Toda and Yamamoto (TY) (1995) test was selected to investigate the direction of causality. The TY test is a modified version of the Wald test. The outputs from the TY test are robust compared to the conventional Granger causality test (Amiri, Ventelou 2012).

Results and discussion

This section presents the plots of the series.

Figure 1 reveals that the EF, human capital and urbanisation have been on the increase in South Africa. Additionally, economic growth and NR have been fluctuating over time.

From Table 3, it can be perceived that NR is the most volatile of the variables. The EF is negatively skewed and all the variables are platykurtic. The probability value of 0.030 suggests that the series of human capital is not normally distributed. Unit root tests are needed to select the appropriate estimation technique. The Ng Perron (2001) and DF-GLS (Dickey-Fuller Generalized Least Squares) tests (Table 4) confirmed a mixed order of integration, whereas the ZA test (Table 5) affirmed stationarity at I(1). Structural breaks exist in the series of the EF, economic growth, NR, human capital and urbanisation. These breaks are due to the economic and political reforms in the country.

The cointegration results in Tables 6 and 7 confirmed long-run interactions among the variables. From Table 6, the F-statistics from the three models is greater than the critical values at 5% levels. This further affirmed the existence of cointegration. The BH test requires the values of both $EG - JOH - BO - BDM$ and $EG - JOH$ to be greater than the 5% critical values for cointegration to exist. Since that is the case in Table 7, we cannot deny the existence of cointegration.

Table 8 shows consistent long-run results as regards the impact of each of the explanatory variables on the EF. From the findings, urbanisation, NR and economic growth increase environmental degradation, whereas human capital decreases the EF. The South African economy is energy-dependent (Magazzino et al. 2020). The country consumes more non-renewable energy sources, especially coal. Non-renewable energy sources are finite and high in emissions. Their impacts on the environment could be far-reaching. This outcome corroborates the findings of Liu et al. (2020) for G7 countries and Ulucak et al. (2020) for Brazil, Russia, India, China and South Africa (BRICS).

The impact of NR on the environment depends on the nature of the resource and how it

Table 3. Descriptive statistics.

	EF	GR	GR	NR	HC	UB	IN
Mean	1.070	8.772	14.51	1.657	0.727	3.991	0.549
Max.	3.930	8.933	15.05	2.678	1.016	4.179	0.801
Min.	1.100	8.615	14.00	0.650	0.584	3.867	0.426
Std. D	0.245	0.093	0.309	0.460	0.131	0.104	0.114
Skewness	−0.117	0.265	0.281	0.062	0.862	0.311	0.836
Kurtosis	2.198	2.126	2.128	2.707	2.384	1.669	2.350
Prob.	0.505	0.359	0.348	0.905	0.037	0.120	0.042

EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation; GR – economic growth; IN – interaction between HC and UB.
Source: author's computation.

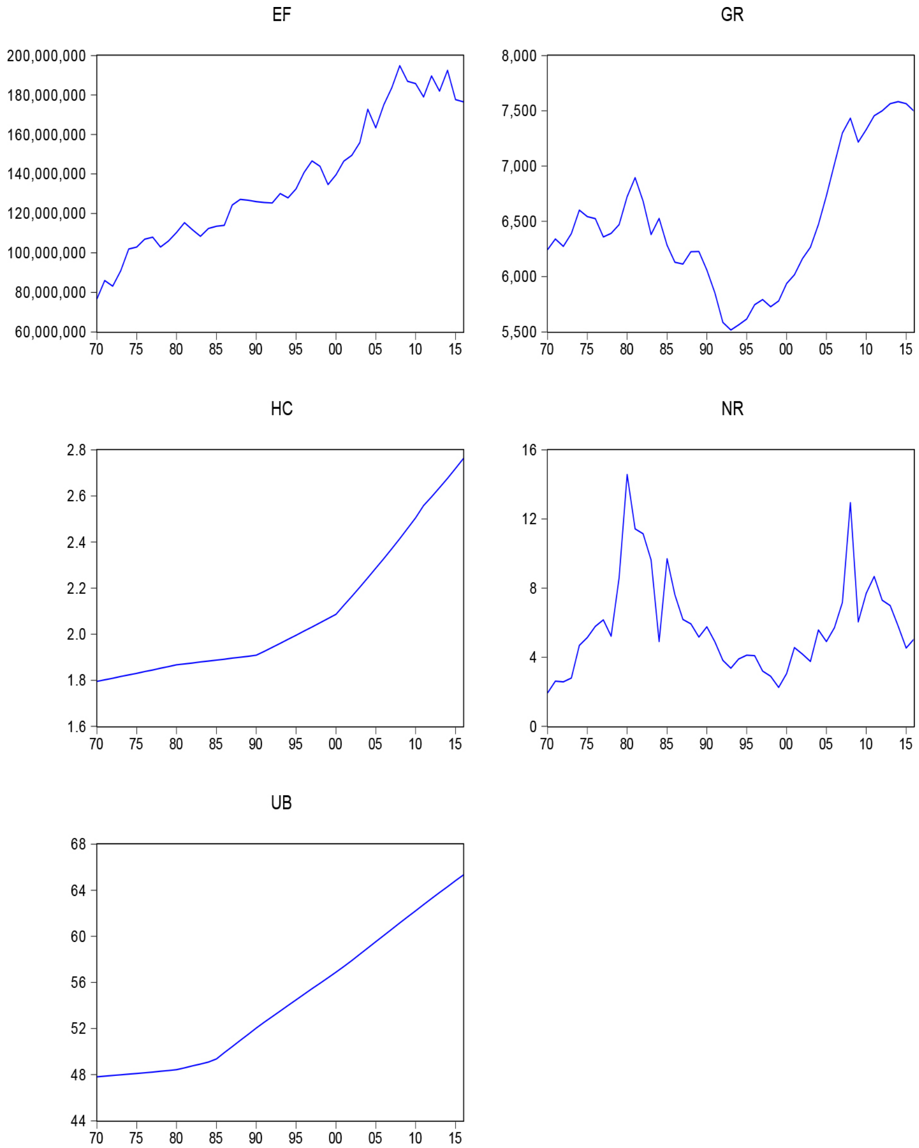

Fig. 1. Plots of the series. EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation.
Source: own compilation.

Table 4. 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
GR^2	−0.920	−4.152***	0.338	0.233	0.164***	0.233

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.
EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation.
Source: author’s computation.

is being explored. In South Africa, coal is one of the most explored resources. Studies—including those of Joshua et al. (2020) and Udi et al. (2020)—have confirmed coal consumption to be particularly harmful in South Africa. However, Kongbuamai et al. (2020), Zafar et al. (2019) and Al-Mulali et al. (2015) discovered NR to be a driver of environmental sustainability in ASEAN, the United States and Vietnam respectively. This finding supports the fact that the consumption and exploration of NR have not been sustainable in South Africa. South Africa generates 95% of its electricity from coal—a non-renewable energy source that pollutes the environment. From the results also, urbanisation contributes to environmental degradation by increasing the EF. This outcome complements the findings of Nathaniel et al. (2019), Salahuddin et al. (2019) and Sarkodie and Adams (2018) for South Africa, and the findings of Al-Mulali et al. (2015), Fan and Zhou (2019) and Fan et al. (2019) for Vietnam. The finding is intuitive because urbanisation drives economic growth and other activities that encourage energy consumption.

Table 5. 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
GR^2	−3.024	1985	−5.206**	1994

Note: *** represents 0.01% significance level.
EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation.
Source: author's computation.

Table 6. Bounds test results.

Models	Lower bound	Upper bound	Significance level
Model 1			
Fc (lngr, lnnr, lnhc, lnub). F = 8.3425	2.25 2.86 3.69	3.59 3.76 4.46	10% 5% 1%
Model 2			
Fc (lngr, lnnr, lnhc, lnub, lnin). F = 7.6069	1.81 2.14 2.82	2.93 3.34 4.21	10% 5% 1%
Model 3			
Fc (lngr, lnnr, lnhc, lnub, $lngr^2$). F = 8.5647	2.29 2.71 3.46	3.38 4.56 4.76	10% 5% 1%

Source: author's computation.

Table 7. BH test results.

Estimated models	EG − JOH	EG − JOH − BO − BDM	Cointegration
*ln*EF = f(*ln*GR,*ln*NR,*ln*HC,*ln*UB)	14.651	38.854	Yes
*ln*EF = f(*ln*GR,*ln*NR,*ln*HC,*ln*UB,*ln*IN)	21.361	44.537	Yes
*ln*EF = f(*ln*GR,*ln*NR,*ln*HC,*ln*UB,*ln*GR^2)	15.101	36.342	Yes
5% critical value (for Model 1)	10.576	20.143	
5% critical value (for Models 2 and 3)	10.419	19.888	

Note: ** represents 0.05% significance level.
EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation.
Source: author's computation.

Unlike urbanisation and economic growth, the coefficient of human capital is negative, which suggests that human capital enhances environmental quality by reducing the EF. Over the years, human capital has played a vital role in the country's drive for economic prosperity/development. An educated human capital demands clear energy, contributes meaningfully to the financial system and ensures the sustainable use of NR for a stable growth path (Zallé 2019; Ibrahim, Sare 2018; Ogundari, Awokuse 2018).

Interestingly, the coefficient of the interaction term is negative and significant suggesting the moderating role of human capital in mitigating

Table 8. ARDL results.

Long-run results			
Variables	Model 1	Model 2	Model 3
Constant	4.162**	4.432**	2.465
	(2.478)	(3.441)	(1.047)
GR (log)	0.032**	0.546***	0.129***
	(2.675)	(4.567)	(3.657)
HC (log)	−0.044**	−0.146**	−0.198***
	(−2.987)	(−2.286)	(−3.892)
NR (log)	0.275***	0.297***	0.140***
	(2.979)	(3.486)	(3.287)
UB (log)	0.450***	0.228***	0.052***
	(7.657)	(6.836)	(6.679)
IN (log)	–	−0.231***	–
	–	(−4.675)	–
GR^2 (log)	–	–	−0.056***
	–	–	(−7.546)
Short-run results			
Variables	Model 1	Model 2	Model 3
EF(-1) (log)	−0.298***	−0.672***	−0.098***
	(−4.564)	(−6.978)	(−7.619)
Dlog(HC)	−1.324	−0.174**	−1.534
	(−0.246)	(−2.167)	(−0.678)
Dlog(HC(-1))	1.349	−0.437	1.872
	(0.392)	(−1.443)	(0.954)
Dlog(NR)	0.032***	0.060***	0.007*
	(5.923)	(5.823)	(1.878)
Dlog(NR(-2)	0.062	–	0.567
	(1.409)	–	(1.765)
Dlog(UB)	0.629***	0.672***	0.050***
	(6.867)	(7.562)	(6.985)
Dlog(GR)	0.045***	0.045***	1.546
	(4.670)	(3.967)	(0.845)
CointEq(-1)*	−0.986***	−0.876***	−0.156***
	(−8.719)	(−7.491)	(−6.821)
Diagnostic tests			
R-squared	0.767	0.627	0.843
χ^2 Jarque-Bera	0.867	0.965	0.825
χ^2 LM test	0.629	0.564	0.725
χ^2 Ramsey	0.185	0.487	0.627
χ^2 Breusch-Pagan-Godfrey	0.489	0.646	0.342

Note: ***, ** and * represent statistical significance at the 1%, 5% and 10% levels of significance respectively; t-statistics are in parentheses.
ARDL – autoregressive distributed lag; EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation.
Source: author's computation.

Table 9. Robustness check.

Variables	FMOLS	DOLS	CCR
GR (log)	0.056**	0.202**	0.326***
	(2.276)	(2.581)	(4.768)
HC (log)	−0.064***	−1.667***	−0.621***
	(−5.835)	(−9.673)	(−8.289)
NR (log)	0.024***	0.241***	1.046***
	(3.768)	(4.573)	(9.231)
UB (log)	0.348***	0.271***	0.2286***
	(3.987)	(9.482)	(7.271)

Note: *** and ** represent statistical significance at the 1% and 5% levels respectively; t-statistics are in parentheses.
CCR – canonical regression; DOLS – dynamic ordinary least squares; FMOLS – fully modified ordinary least squares; HC – human capital; NR – natural resources; UB – urbanisation.
Source: author's computation.

Table 10. Toda-Yamamoto test results.

Null Hypotheses	MWALD Stat.	Probability	Causality
GR→EF	6.015	0.021	Yes
HC→EF	5.892	0.044	Yes
NR→EF	4.042	0.120	No
UB→EF	8.763	0.007	Yes
EF→GR	7.382	0.035	Yes
HC→GR	9.702	0.031	Yes
NR→GR	5.819	0.042	Yes
UB→GR	8.281	0.018	Yes
EF→HC	1.745	0.650	No
GR→HC	0.619	0.723	No
NR→HC	1.891	0.634	No
UB→HC	2.817	0.380	No
EF→NR	0.483	0.066	Yes
GR→NR	0.581	0.001	Yes
HC→NR	1.291	0.035	Yes
UB→NR	9.382	0.491	No
EF→UB	0.173	0.849	No
GR→UB	0.481	0.341	No
HC→UB	1.461	0.635	No
NR→UB	9.903	0.045	Yes

Note: All the variables are logged.
EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation.
Source: author's computation.

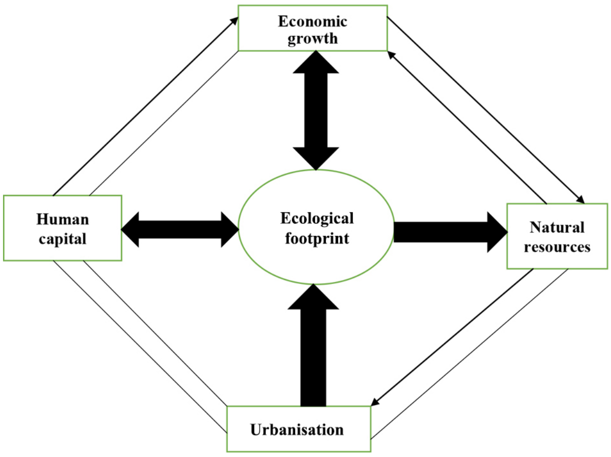

Fig. 2. Causality relationship schema.
EF – ecological footprint; HC – human capital; NR – natural resources; UB – urbanisation.

environmental degradation in South Africa. Although urbanisation increases the EF, its interaction with human capital reduces it. The intuition from the finding is that human capital is sacrosanct for urban sustainability. The validity of the EKC is confirmed evident from the positive/negative coefficient of GDP/GDP² in Table 7, Model 3. The short-run results are consistent with those of the long run. However, the impact of human capital on the EF is not consistent in the short run. The short-run evidence affirmed that human capital has an insignificant impact on the EF. As such, there is a need for human capital development to curb environmental degradation.

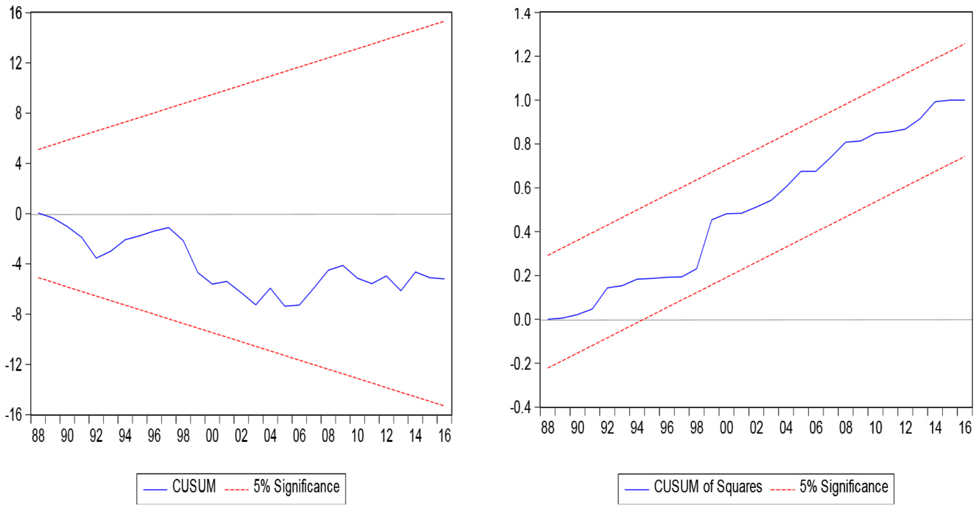

Fig. 3. Cusum and Cusumsq plots for Model 1.
Source: own compilation.

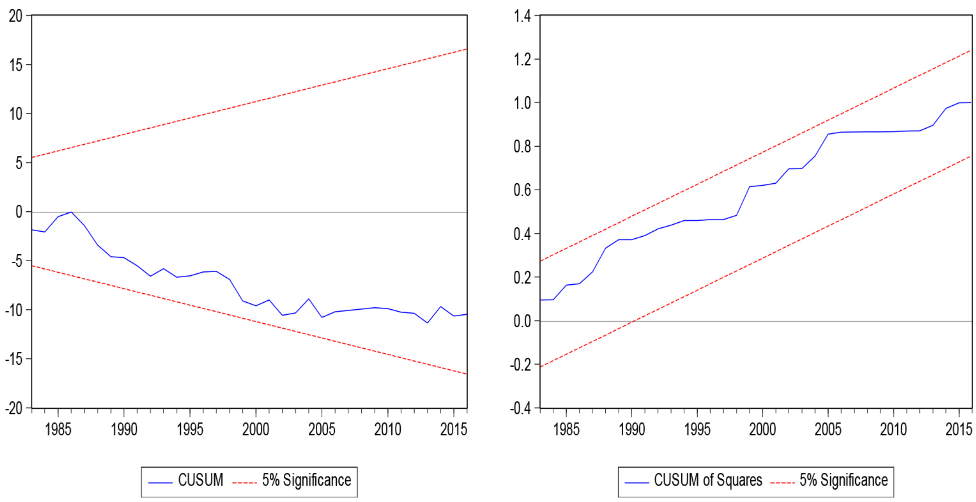

Fig. 4. Cusum and Cusumsq plots for Model 2.
Source: own compilation.

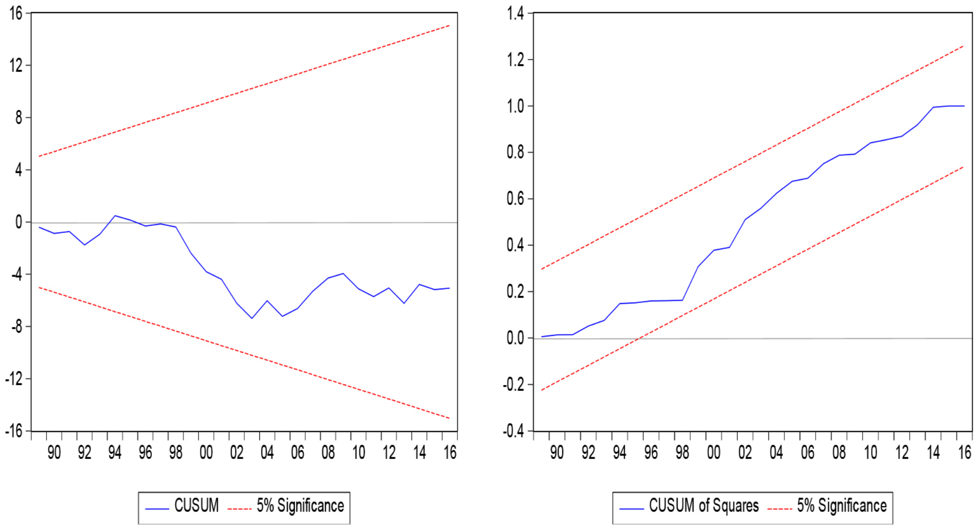

Fig. 5. Cusum and Cusumsq plots for Model 3.
Source: own compilation.

The fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS) and canonical cointegrating regression (CCR) results in Table 9 confirmed the robustness of our findings in Table 8. Therefore, a similar discussion/interpretation applies.

In Table 10, a bidirectional causality exists between economic growth and NR, economic growth and the EF, and between human capital and the EF. This reveals that NR play an important role in South Africa's growth trajectory and also contributes to pollution. The causality relationship schema is presented in Figure 2.

The Cusum and Cusumsq plots for each of the models (Figs 3–5) confirmed that the models are stable and can be used for forecast.

Conclusion

This study examined the relationship between human capital, urbanisation, economic growth, NR and the EF in South Africa. The NG-Perron and DF-GLS unit root tests affirmed a mixture of I(0) and I(1) for the variables, whereas the BH test affirmed a long-run relationship among the variables in the estimated models. The ARDL, FMOLS, DOLS and CCR results showed that urbanisation, NR and economic growth increase the EF, whereas human capital promotes environmental sustainability in the long run. The results validated the EKC for the EF in South Africa. A bidirectional causality exists between economic growth, NR and the EF. Also, urbanisation and NR drive the EF in South Africa.

These findings emphasise the need for policymakers in South Africa to adjust the country's energy portfolio and encourage the consumption of renewables (such as solar, wind, hydropower and geothermal power). These energy sources are clean and low in emissions. They are environmentally friendly and sustainable (Nathaniel, Bekun 2020; Ali et al. 2020). The transition to clean energy sources might not be an easy sail considering South Africa's financial strength, but creating awareness, providing the household with palliatives (subsidies, interest rate holidays, tax, etc.) and encouraging firms to embark on cleaner production while taxing the dirtier ones could be a good step in the right direction. Moreover, there is a need to concentrate on NR that are less of a pollutant and ensure their sustainable exploration, without altering the country's growth process.

Development issues, such as lack of amenities, inequality and low income, are the main causes of the urban explosion. The concentration of infrastructures in cities like Cape Town, Durban, Pretoria and Johannesburg and a dearth of such infrastructures in, e.g., uMgungundlovu, Nkangala and Ntabankulu will only encourage urbanisation, as people will prefer cities to rural areas. The need for smart cities cannot be overemphasised. Smart cities promote the efficiency of urban services, such as energy and transport, to achieve innovation and sustainability. Most importantly, human capital needs to be developed in South Africa for sustainable cities, energy and resources. Once human capital is developed, the consumption of clean energy sources will increase and the preservation of biodiversity will be a priority.

This study has some limitations. For instance, some determinants of the EF were not considered in the estimated models. This is a pointer for future researchers in this field. Additionally, future studies may want to explore the moderating role of income inequality and governance on the EF and other sustainability indicators by applying robust estimation technique(s). The sample could also be extended to include more emerging economies for a more reliable policy formation. There are more global perspectives to this study, and it is highly relevant to international readers and policymakers outside South Africa. Countries are expected to comply with the Kyoto Protocol and the Paris Agreement of 2015 by consuming renewables and reducing the demand for fossil fuels, since these energy sources are harmful to the environment. The mitigation of pollution could be achieved by engaging in cleaner production and consumption. Additionally, investing aggressively in the green energy sectors will encourage the development of cleaner production technologies.

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