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ENERGY CONSUMPTION AND HUMAN DEVELOPMENT IN SOUTH AFRICA: EMPIRICAL EVIDENCE FROM DISAGGREGATED DATA[1]

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ENERGY CONSUMPTION AND HUMAN DEVELOPMENT IN SOUTH AFRICA: EMPIRICAL EVIDENCE FROM DISAGGREGATED DATA

Mercy T. Musakwa [2] and Nicholas M. Odhiambo

Abstract

This study investigated the impact of energy consumption on human development in South Africa, using annual data from 1990 to 2019. The study used disaggregated data on energy measures namely: oil products consumption; electricity consumption; renewable energy consumption; natural gas; coal and lignite; and total energy consumption at an aggregate level. Human Development Index (HDI) was used as a measure of human development. By employing autoregressive distributed lag bounds test to cointegration and error correction model, the study found the impact of energy consumption on human development to be positive in the short run when renewable energy was used as a proxy, but insignificant in the long run. When oil products, natural gas and total energy were used as proxies for energy, a negative impact was confirmed in the short run, while an insignificant impact was confirmed in the long run. When electricity, coal and lignite were used as proxies for energy, an insignificant impact was confirmed, irrespective of the time frame considered. The results revealed that the positive impact of renewable energy on human development is not big enough to offset the negative impact of other energy sources. This suggests that South Africa has to continue to expand renewable energy if a positive impact of energy on human development is to be realised.

Key Words: human development; energy consumption; South Africa; human development index; autoregressive distributed lag.

JEL Classification: O13; O15; K32

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1. Introduction

The importance of energy in economic and human development has gained attention in recent years (Human Development Report, 2007/2008). It is undeniable that as an economy grows its gross domestic product, energy is needed, whether renewable or fossil energy. According to Human Development Report (2007/2008), modern energy is fundamental in driving economic growth, fulfilling social needs and human development. Energy has an impact on communication services, productivity, health, and education. Energy is an engine for economic development, making it a key component in the puzzle to achieve the Sustainable Development Goals (SDGs). There is growing consciousness of the negative impact of fossils on the environment, through greenhouse gas emissions and the pollution of the environment, which has negative effects on human development. The emissions pollute the environment and are also harmful to health. This has resulted in a gradual shift to renewable energy as a source of energy with less undesirable impacts on the environment and health. Despite the awareness of the negative consequences of fossil energy, most countries still rely on these fossils to advance economic growth. The importance of clean energy has been highlighted by the United Nations inclusion of Goal 7 – affordable and clean energy (United Nations 'UN', 2021). This implies an intentional shift of nations from economies based on fossil fuels, to clean sources of energy like solar, wind and water. South Africa is one of the signatories to the SDGs, thus putting a huge responsibility on the country to work together with other countries, to increase the use of clean energy at affordable prices.

Studies on the relationship between energy consumption and human development have gained traction in recent years. Some researchers have investigated the impact of energy on human development (see, for example, Acheampong, Erdiaw-Kwasie and Abunyewah, 2021; Sasmaz *et al*., 2020; Sarkodie and Adams, 2020; Orji *et al*., 2020) or causality between the two (see Sanchez-Loor and Zambrano-Monserrate, 2015; Niu *et al.*, 2013). These studies had varying results, but what has been consistent in the findings, is the positive impact that renewable energy has on human development. However, few studies have explored country-specific relationships between energy consumption and human development, including South Africa. Given the importance of identifying factors that are key in advancing human development, an investigation on the nature of the relationship is pertinent in South Africa. This study comes at a time when the country has experienced a shift from non-renewable energy sources to clean energy, like solar and water (Statistics South Africa 'Stats SA', 2020). This has resulted in the Department of Energy entering into agreements with 27 independent power producers (IPPs) to unlock R56 billion investment in renewable energy, among other initiatives (StatsSA, 2020). The main objectives of this study, therefore, are twofold: i) to investigate the impact of oil products, electricity, renewable energy, natural gas, coal and lignite and total energy consumption on human development; and ii) to establish which energy sources contribute the most to human development in South Africa.

This study departs from previous studies by examining the impact of energy consumption on human development, by using both aggregated (total energy consumption) and disaggregated energy measures (oil products, electricity, renewable energy, natural gas, coal, lignite and total energy consumption), and using the ARDL approach to examine the relationship. Given the advantages of the ARDL approach, such as robust in small samples, this study provides a rigorous analysis of the nature of the relationship in South Africa using annual data from 1990 to 2019.

The rest of the study is structured as follows: section 2 provides a literature review, while section 3 highlights estimation techniques. Section 4 discusses data analysis and findings of the study, and section 5 concludes the study.

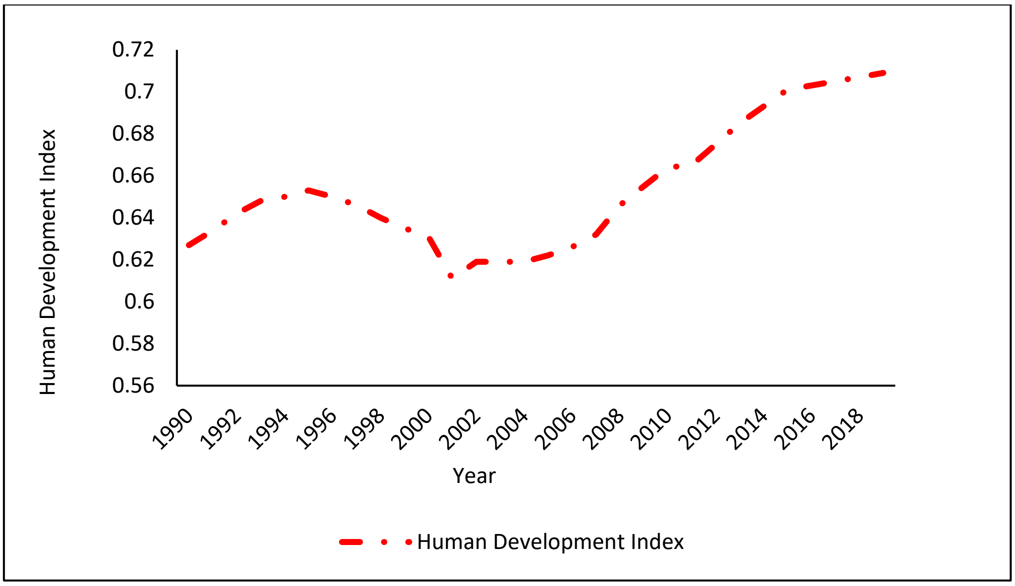
2. Literature Review

2.1 Energy Consumption and Human Development in South Africa

The Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) are programmes spearheaded by the United Nations Development Programme (UNDP), aimed at achieving economic development, and improving human development across developed and developing countries. Under the SDGs, the overarching objective of sustainable development is to be achieved through 17 SDGs that focus on different aspects of development. South Africa, as one of the signatories to these programmes, has an obligation to work towards the achievement of these goals, thereby improving well-being and advancing human development in the country. The National Development Programme 2030 largely encapsulates the SDGs.

The UNDP (2021a) provides a comprehensive list of indicators of human development, such as Human Development Indicators, expected years of schooling, gross national income per capita, inequality, trade and financial flows, poverty measured by poverty headcount, mobility, and communication – internet users. South Africa has made great progress in human development from a multi-faceted dimension. The National Development Programme 2030 is a national programme that expresses bold initiative by the government to provide a framework for the development of sustainable economic development, where human development takes a centre stage. The National Development Programme 2030 offers a long-term plan for South African economic development, characterised by low unemployment rates, elimination of poverty and inequality. This is envisaged to result in decent standards of living (Republic of South Africa, 2019).

The United Nations Development Programme 'UNDP' (2003) highlights 5 central challenges to sustainability as: income and wealth inequality, extreme poverty, provision of quality and affordable basic services, high sustainable growth rates and environmental sustainability. These challenges highlighted in the report are pillars to achieve human development. South Africa continues to face the challenges highlighted in 2003, as reported in the South Africa (2019) report. Even though the government has put programmes in place that help to ease some of the challenges, for example, on inequality, Broad-based Black Economic Empowerment (BBBEE), access to education, Employment Equity Act (EEA) and women empowerment remain a challenge (South Africa, 2019). These programmes are part of the government's efforts to make life better for South Africans. The progress that has been made, through different programmes put in place by the government, is evidenced by the advancement of human development as measured by the composite measure – Human Development Index that improved from 0.627 in 1990 to 0.709 in 2019 (UNDP, 2021b). Other metrics of human development, like life expectancy and household consumption expenditure, have shown a consistent improvement in recent years (World Bank, 2021). Figure 1 shows the trends in HDI in South Africa from 1990 to 2019.



Source: UNDP (2021b)

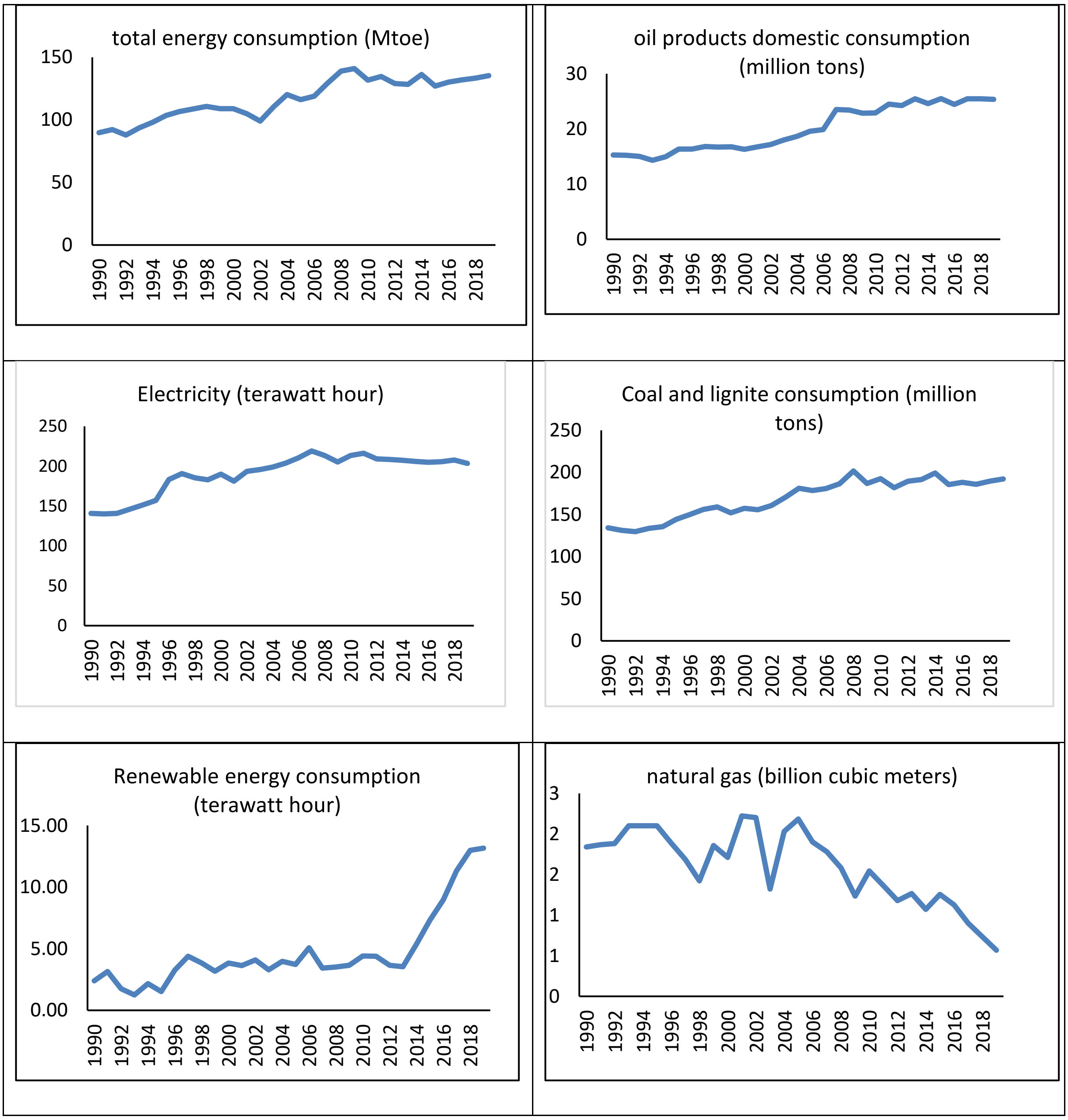
Figure 1: Trends in Human Development Index in South Africa 1990-2018

On the energy front, the 1998 White Paper on the Energy Policy provides a framework for the provision of energy in South Africa (Department of Minerals and Energy, 1998). The white paper was set to clarify the supply and consumption of energy. The main objectives of the energy sector are to, i) increase access to affordable energy services; ii) improve energy governance; iii) stimulate economic development; iv) manage energy-related environmental and health impacts; and v) secure supply through diversity (Department of Minerals and Energy, 1998).

The Integrated Resource Plan 2012-2030, promulgated in 2011, identified the energy generation technology that will meet demand by 2030. The plan incorporates the government's objectives of reduced greenhouse gas emissions, reduced water consumption, diversification of electricity generation and provision of affordable electricity (Republic of South Africa, 2019). South Africa continues to pursue a diverse energy mix to meet the current and future economic developments. A combination of 38GW from electricity generation using coal, 1,8

GW from nuclear, 2,7 GW from pumped storage energy, 1.7 GW from hydro, 3.8 GW from diesel and 3.7 GW from renewable energy (Republic of South Africa, 2019). The power generation output of each energy source clearly indicates South Africa's reliance on coal as a source of energy (Republic of South Africa, 2019). The energy sector alone contributes 80% towards total emission where 50% can be attributed to electricity generation and liquid fuel production (Republic of South Africa, 2019).

The quest for cleaner energy sources has seen the government exploring renewable energy, such as wind farms, while households and businesses have slowly migrated from the grid to renewable energy, like solar and wind power. This move can be explained, largely, by power outages and the wholesale and retail electricity tariff hikes. Coal and lignite consumption showed an upward trend from 1990, where 134 million tonnes were consumed compared to 192 million tonnes in 2019 (Enerdata, 2021a). The power plants took 60% of the total coal consumption in South Africa in 2019 (Enerdata, 2021b). This does not come as a surprise, given the reliance on coal for electricity production, according to the Integrated Resource Plan (2019). The same trend was also exhibited on oil consumption and natural gas consumption, with the transport sector registering the highest consumption of 69% of oil products, and industry recording 61% of natural gas consumption (Enerdata, 2021b). Electricity consumption steadily increased from 1990 where 141-terawatt hour was registered, compared to 204-terawatt hour in 2021, almost double the consumption from 1990 (Enerdata, 2021a). The industry, like in natural gas consumption, took the biggest share of 56% followed by residential consumption with 19% (Enerdata, 2021b). The data reflects a huge reliance of the South African industry on electricity as a source of power. The share of renewable energy (water, wind and solar) in total electricity production remains depressed between 1990 and 2021, with an average contribution of 0.2% throughout the study period. However, there has been a notable increase from 2015 to 2019, which coincides with the period when the government made concerted efforts to move to cleaner energy sources. Figure 2 reports the trends in energy consumption from 1990 to 2019 in South Africa.



Source: Enerdata (2021a)

Figure 2: Energy Consumption Distribution in South Africa from 1990 to 2019

Figure 2 reports a general trend of an increase in energy consumption across all disaggregated measures of energy, except natural gas that generally exhibits a downward trend from 1990

(Enerdata, 2021a). However, the decrease in natural gas consumption did not offset the gains in other energy sources, such as electricity, coal and lignite, and oil products, which resulted in an increase in total energy consumption in South Africa during the period under study. One important trend to note is the surge in renewable energy consumption from 2014, where consumption jumped by 1.81-terawatt hour from 3.55 to 5.36 (Enerdata, 2021a). This trend was maintained up to 2019, showing a general appreciation of clean energy sources in South Africa.

2.2 A Review of Related Literature

Human development, according to United Nations Development Programme (UNDP) (2021a), emphasises the richness of human life by, giving people freedom and opportunities so that they live lives that they value; improving the lives people lead as opposed to assuming economic growth will provide opportunities for people to better their lives; and ability of people to choose. This definition points to the multiplicity of aspects that make people live lives that they value and improve themselves. Among such aspects, is access to basic services like education and health, (Shuaibu, 2016) and institutional quality (Binder and Georgiadis, 2011). According to Binder and Georgiadis (2011), institutional quality is important to human development in developing countries compared to developed countries. The UNDP (1990) identified three key aspects that are important for human development. These are long and healthy life, acquired knowledge and access to resources needed for a decent life. These essential aspects of human development were deemed important, to create accessibility to other opportunities that advance human development. The measure of human development is complex and there is no single measure that can sufficiently capture all aspects. Different studies have used several indicators, such as GDP, life expectancy, literacy, government expenditure on health or education, and infant mortality rate. The 17 SDGs cover all important aspects of sustainable human development (United Nations 'UN', 2021). The SDGs cover economic, social and environmental aspects that help to improve the quality of life and provide valuable livelihoods. This study uses the Human Development Index which is an index that consists of measures on health, education and standards of living (GDP).

South Africa has a variety of energy sources that range from petroleum (fossil fuels), natural gas, electricity, coal, renewable energy and nuclear power. Although there are a variety of energy sources, South Africa still relies largely on coal as the source of energy, especially in electricity generation. In most recent times, the call for cleaner energy sources, such as solar and water, has increased due to global warming. The Sustainable Development Goals, Goal number 7 (affordable and clean energy) also encourages clean energy and the increasing use of renewable energy for sustainable development and reduction in carbon emissions, which is a culprit in global warming.

A large body of literature on the impact of energy on human development is biased towards disaggregated measures of energy, such as electricity and renewable energy. Although the role of energy in economic development has received attention, studies are split between those that explored the impact of energy on human development (Acheampong, Erdiaw-Kwasie and Abunyewah, 2021; Sasmaz *et al*., 2020; Yunashev *et al.*, 2020; Ray *et al*., 2016; Ouedraogo, 2013) or the impact of human development on energy consumption, for example, Sarkodie and Adams (2020), and those that investigated the causality between the two (Sanchez-Loor and Zambrano-Monserrate, 2015; Niu *et al.*, 2013). This study reviews other studies that have investigated the impact of energy on human development, those that have investigated the impact of human development on energy, and those that have analysed the causality between the two.

Acheampong, Erdiaw-Kwasie and Abunyewah (2021) investigated the impact of access to energy on human development in 79 energy-poor countries from sub-Saharan Africa, South Asia, and Caribbean-Latin America. Using data from 1990 to 2018 and Lewbel two-stage least squares approach, the study found that clean energy and electricity have a positive impact on human development in the aggregated sample. Furthermore, the study found that clean energy and electricity improved human development in the Caribbean, Latin America, and sub-Saharan Africa, but worsened human development in South Asia.

Sasmaz *et al*., (2020) investigated the relationship between renewable energy and human development in 28 Organisation for Economic Cooperation and Development (OECD). Using data from 1990 to 2017 and employing the Westerlund and Edgerton panel cointegration test, and Dumitrescu and Hurlin causality test, renewable energy was found to affect human development positively. In the same study, a bidirectional causality was found between renewable energy and human development. In a separate study, Sarkodie and Adams (2020) investigated the nexus between electricity, human development income level, income inequality and political system environment in Sub-Saharan Africa, using data from 1990 to 2017. Using a non-parametric regression analysis, human development was found to have a positive impact on access to electricity consumption.

Yunashev *et al.*, (2020) investigated the impact of quality and volume of energy consumption on human development, using sample countries. Using three-stage least squares, and HDI as a proxy for human development, energy consumption and renewable energy as proxies for energy consumption, the study found the share of clean energy consumption to have a positive impact on human development. Orji *et al*. (2020) investigated the impact of information and communication, technology and power supply on human capital development in Nigeria and found the same results as Yunashev *et al*. (2020) and Sasmaz *et al*. (2020). Shobande (2019) investigated the effects of energy on socioeconomic predators for 23 African countries using data from 1999 to 2014. The study used human development index (HDI) and inequality-adjusted Human Development index to investigate the relationship. Using the Gary Becker hypothesis and the Michael Grossman demand for healthcare model, the study found a positive relationship between energy consumption and human development proxied by the HDI and inequality adjusted HDI.

Ray *et al*. (2016) investigated the impact of energy on Human Development Index using bio-mass energy. Using long term field studies, in rural areas of different geographical locations, the study found output and emission intensity to have a direct input on HDI through health, education and income generation. A switch from raw bio-mass energy sources to solar energy was found to provide positive development to the villagers.

Ouedraogo (2013) investigated the relationship between human development and energy consumption in 15 developing countries, using data from 1988 to 2008. The study used total energy consumption and electricity as measures of energy. Using panel cointegration and panel-based error correction models, the study found a neutral effect on energy consumption and electricity on HDI. However, in the long term, a 1% increase in energy consumption led to a reduction in HDI by 0.8% and a 1% increase in per capita electricity consumption led to an increase in HDI by 0.11%. Pirlogea (2012), using panel data, investigated the relationship between renewable energy and human development in 28 OECD countries, using data from 1990 to 2008. Using regression analysis, the study found a positive relationship between high levels of energy and human development.

Kanagawa and Nakata (2008), using a bottom-up equilibrium model, found access to electricity among the rural areas to improve socioeconomic conditions. In the same study, electricity was found to have a positive correlation with HDI in 120 developing countries. Martinez and Ebenhack (2008) also investigated the correlation between Human Development Index and energy consumption in 120 nations. A strong relation was observed for most of the world. The study found huge gains in human development are possible in poor countries with small incremental access to energy, in contrast to moderate and energy-advantaged nations that consume modern energy.

Although several studies found a positive relationship between energy and human development, Wang, Danish and Wang (2018) analysed the relationship between renewable energy, economic growth and human development using data from 1990 to 2014, for Pakistan. Employing two-stage squares (2SLS) analysis, the findings of the study indicated that renewable energy does not lead to improvement in human development.

On the causality between energy and human development, Sanchez-Loor and Zambrano-Monserrate (2015) investigated the relationship between electricity consumption, direct foreign capital investment, gross domestic product, remittances and human development in Mexico, Ecuador and Colombia, using data from 1980 to 2012. In the study, they found a bidirectional causality between human development and electricity production in Colombia. In a similar vein, Niu *et al.* (2013) investigated the causality between human development and electricity consumption using panel data from 1990 to 2009, for 50 countries sub-divided into four categories according to income level. Using human development indicators, per-capita GDP, consumption expenditure, life expectancy, urbanisation rate and adult literacy, they found a bidirectional causality existed between electricity consumption and five indicators. The higher the income of a country, the greater the electricity consumption, and the higher the human development level was.

The literature review clearly shows varied results depending on the country under study and the energy measure used. Although there is a drive to move towards the use of clean energy, the impact of energy measures in the clean energy category was not consistent across all studies. Some studies found a positive impact of electricity and renewable energy on human development, while others found an insignificant or negative relationship between the two. However, studies that found electricity and renewable energy to have a positive impact on human development outnumbered those that found a negative or neutral effect. This suggests a positive impact of electricity and renewable energy on human development, though this must be taken with caution as results vary with the study country. Although causality does not mean impact, all causality studies reviewed found a bidirectional causality between electricity and human development, suggesting the two are closely related.

3. Estimation Techniques and Empirical Results

3.1 Estimation Techniques

This study employs the autoregressive distributed lag approach developed by Pesaran and Shin (1999) and later expanded by Pesaran *et al.* (2001), to investigate the impact of energy consumption on human development. The ARDL approach was selected because of several advantages such as, robust in small samples; the approach provides results in short and long run time frameworks; unlike other methods that require a system of equations, the ARDL uses a single equation; and the variables in the ARDL model do not need to be integrated in the same order. These advantages have influenced the selection of this method to investigate the relationship obtaining in South Africa, between human development and energy consumption.

Definition of Variables

Variables of interest in this study are energy measure at aggregate level measured by total energy consumption (TEC) and disaggregated energy measures captured by natural gas consumption (NGC); oil products consumption (OPC); natural gas consumption (NGC); electricity consumption (ELC); coal and lignite consumption (CIC); and renewable energy consumption (REC). The measure of human development used in this study is Human Development Index (HDI). Other control variables that were included to fully specify the model are trade openness (TOP), education (EDU), inflation (INFL) and real gross domestic product (GDP). Definitions of the variables are given in Table 1.

Table 1: Variable Definition

Variable	**Definition**
Oil products consumption (OPC)	Oil products measured in million tonnes.
Electricity consumption (ELC)	Electricity consumption measured in terawatt hour.
Renewable energy consumption (REC)	Wind and solar generated electricity measured in terawatt hour.
Natural gas consumption (NGC)	Natural gas measured in billion cubic metres.
Coal and lignite consumption (CIC)	Coal and lignite measured in million tonnes.
Total energy consumption (TEC)	Total energy consumption measured in million tonnes of oil equivalent.
Education (EDU)	Gross primary school enrolment.
Inflation (INFL)	Consumer price index.
Real gross domestic product (GDP)	GDP measured at constant 2010 prices.
Trade openness (TOP)	Exports plus imports divided by GDP.

Source: Enerdata (2021) and United Nations Development Programme (2021b)

Model Specification

The general model specification for the study is given in Equation 1.

$$\mathrm{HDI} = \alpha_0 + \alpha_1 \mathrm{EM} + \alpha_2 \mathrm{EDU} + \alpha_3 \mathrm{GDP} + \alpha_4 \mathrm{INFL} + \alpha_5 \mathrm{TOP} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where human development is measured by Human Development Index (HDI) and EM is energy consumption captured by:

OPC – oil products consumption;

ELC – electricity consumption;

REC – renewable energy consumption;

NGC – natural gas consumption;

CIC – coal and lignite consumption;

TEC – total energy consumption;

Each of the energy measures enters the equation one at a time;

TOP – trade openness;

EDU – education;

INF – inflation;

GDP – real gross domestic product;

α_0 – is a constant; $\alpha_1 - \alpha_5$ are coefficients; and ε_t is the error term.

The Autoregressive Distributed Lag (ARDL) bounds specification of Equation 1 is given in Equation 2

$$\Delta \mathrm{HDI} = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, \Delta \mathrm{HDI}_{t-i} + \sum_{i=0}^{q} \alpha_{2i} \Delta\, \mathrm{EM}_{t-i} + \sum_{i=0}^{q} \alpha_{3i}\, \Delta \mathrm{EDU}_{t-i} + \sum_{i=0}^{q} \alpha_{4i}\, \Delta \mathrm{GDP}_{t-i}$$

$$+ \sum_{i=0}^{q} \alpha_{5i}\, \Delta \mathrm{INFL}_{t-i} + \sum_{i=0}^{q} \alpha_{6i}\, \Delta \mathrm{TOP}_{t-i} + \pi_1 \mathrm{HDI}_{t-1} + \pi_2 \mathrm{EM}_{t-1} + \pi_3 \mathrm{EDU}_{t-1}$$

$$+ \pi_4 \mathrm{GDP}_{t-1} + \pi_5 \mathrm{INFL}_{t-1} + \pi_6 \mathrm{TOP}_{t-1} + \mu_{1t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where all the variables are as described in Equation 1; $\alpha_1 - \alpha_6$ are shortrun coefficients; $\pi_1 - \pi_6$ are short-run and long-run coefficients respectively; and μ_1 is an error term.

ECM-based Model Specification

A cointegration test is conducted to establish if the variables in the model have a long-run relationship. If a long-run relationship is established, the estimation will be done in two steps. The first step is the estimation of the long-run equation and obtaining the residuals. These residuals are included in the short-run estimation of the equation; thus, an ECM is estimated. However, if no long-run relationship is established, only the short-run equation is estimated. The general error correction model for the ARDL model specified is given in Equation 3.

$$\Delta HDI = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, \Delta HDI_{t-i} + \sum_{i=0}^{q} \alpha_{2i} \Delta\, EM_{t-i} + \sum_{i=0}^{q} \alpha_{3i}\, \Delta EDU_{t-i} + \sum_{i=0}^{q} \alpha_{4i}\, \Delta GDP_{t-i}$$

$$+ \sum_{i=0}^{q} \alpha_{5i}\, \Delta INFL_{t-i} + \sum_{i=0}^{n} \alpha_{6i}\, \Delta TOP_{t-i} + \theta_n ECM + \mu_{2t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where ECM is the error correction, θ_n is an error correction coefficient and μ_2 is the error term.

Data Sources

All energy data, namely: total energy consumption, natural gas consumption, oil products consumption, electricity consumption, coal and lignite consumption, and renewable energy consumption were extracted from Enerdata, while HDI was extracted from the United Nations Development Programme. Other remaining variables, trade openness, education, inflation, and real gross domestic product were retrieved from the World Development Indicators database.

3.2 Empirical Results

Stationarity Test

A stationarity test was conducted on all the variables to ascertain whether the variables are integrated of order one [I(1)] or order zero [I(0)], which is acceptable with the ARDL-bounds test. Augmented Dickey-Fuller (ADF), Dickey-Fuller Generalised Least Squares (DF-GLS) and Phillip Perron (PP) unit root tests were used. Table 2 reports the results of the unit root test.

Table 2: Unit Root Test Results

Augmented Dickey-Fuller (ADF)					Dickey-Fuller Generalised Least Square (DF-GLS)				Phillip and Perron (PP) Root Test			
Variable	Stationarity of all Variables in Levels		Stationarity of all variables in First Difference		Stationarity of all Variables in Levels		Stationarity of all variables in First Difference		Stationarity of all Variables in Levels		Stationarity of all variables in First Difference	
	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend
HDI	0.7793	0.1854	2.9394*	-3.3883*	-0.8534	-1.7636	-2.9172**	-3.4119**	-0.1476	-0.3133	-2.9120*	-3.3093*
OPC	-0.4546	-2.4476	-6.3697***	-6.2416***	-0.0149	-2.3089	-6.2436***	-6.4588***	-0.3526	-2.4476	-6.3979***	-6.2899**
ELC	-2.1265	-1.0960	-4.6770***	-6.2416**	-0.9510	-1.269	-4.6255***	-5.3148***	-2.2600	-0.8621	-4.6790***	-8.3493***
OPC	-0.4546	-2.4475	-6.3697***	-6.2416**	-0.0149	-2.3089	-6.2436**	-6.4588***	-0.3526	-2.4476	-6.3979***	-6.2899***
NGC	-1.2746	-3.1460	-5.4975***	-5.7985***	-1.2032	-1.0770	-5.5852***	-6.0415***	-0.6574	-3.0283	-8.4273***	-7.2056***
CIC	-1.5438	-1.9356	-7.0121***	-7.1189***	-0.6372	-1.0769	-6.7274***	-7.3290**	-1.2296	-1.8629	-7.1249***	-7.5762***
TEC	-1.3621	-2.1716	-5.1949***	-5.1407***	-0.6737	-2.2750	-5.2756***	-5.3414***	-1.3229	-2.2360	-5.2168***	-5.1670***
GDP	1.7405	-2.0933	-3.0483**	-3.1712*	-0.3384	-2.0933	-2.6198**	-3.1713**	-1.4120	-2.8924	-2.9189*	-5.2211***

TOP	-1.3022	-2.6680	-5.6460***	-5.6068***	-1.1555	-2.8236	-5.3633***	-6.0812***	-1.0074	-2.4973	-8.8905***	-8.2326***
EDU	-1.5000	-2.7278	-3.6113**	-3.5776*	-1.5495	-2.7527	-3.6292***	-3.7539**	-1.7558	-2.2102	-3.6258**	-3.5955**
INFL	-2.4063	-1.4408	-4.6082***	-5.3993***	-1.8294	-2.3659	-1.9745*	-5.5017***	-2.3795	-3.2184	-8.4067***	-9.4600***

The stationarity test results reported in Table 2 confirm stationarity of variables in levels or first difference. To proceed with the analysis, a cointegration test is done to determine if there is a long-run relationship between the variables in the models. The results for the cointegration test are presented in Table 3.

Table 3: Cointegration Test Results

Dependent Variable	Function		F-Statistic		Cointegration Status	
HDI	F (HDI|OPC, GDP, TOP, EDU, CPI)		8.1380^{***}		Cointegrated	
	F (HDI|ELC, GDP, TOP, EDU, CPI)		5.4106^{***}		Cointegrated	
	F (HDI|REC, GDP, TOP, EDU, CPI)		6.5756^{***}		Cointegrated	
	F (HDI|NGC, GDP, TOP, EDU, CPI)		8.2933^{***}		Cointegrated	
	F (HDI|CIC, GDP, TOP, EDU, CPI)		5.1711^{***}		Cointegrated	
	F (HDI|TEC, GDP, TOP, EDU, CPI)		8.4748^{***}		Cointegrated	
Asymptotic Critical Values (unrestricted intercept and no trend)						
Critical Values	1%		5%		10%	
	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
	3.41	4.68	2.62	3.79	2.26	3.35

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

The calculated F-statistic is compared to the critical values also reported in Table 3. If the calculated F-statistic is greater than the upper bound at 10%, 5% or 1%, then cointegration is confirmed in the function. If the calculated F-statistic is lower than the lower bound or falls between the upper bound and the lower bound, no long-run relationship can be concluded. Cointegration results presented in Table 3 show the presence of cointegration in all the functions.

Coefficient Estimation

From the cointegration testing, all functions in the model were found to be cointegrated. To proceed with the analysis, an error correction model is estimated. The selection of the lags of each variable in each function was done, using either the Akaike Information Criteria (AIC) or the Schwarz Bayesian Information Criteria (SIC), depending on the criterion that gives the most parsimonious model. The long-run and the short-run results are presented in Tables 4 and 5, respectively.

Table 4: Long-run Results

Variables	Model 1 (Oil Products Consumption – OPC) ARDL (3,3,3,3,3,3)		Model 2 (Electricity consumption - ELC) ARDL (1,1,1,1,1,1)		Model 3 (Renewable energy consumption - REC) ARDL (2,3,3,3,3,3)		Model 4 (Natural gas energy consumption - NGC) ARDL (3,1,1,1,1,1,1)		Model 5 (Coal and lignite consumption - CIC) ARDL (1,1,1,1,1,1)		Model 6 (Total energy - TEC) ARDL (1,2,2,2,2,2)	
Regressors	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
C	-1.6727***	-10.8493	-0.1929***	6.8710	0.194***	5.968	-0.4508	-4.5617	0.1189***	6.2076	0.0028*	2.1641
OPC/ELC/REC/NGC/CIC/TEC	0.0123	0.4743	0.0001	0.5532	-0.0020	-1.4697	-0.4914	-1.2204	-0.0017	-2.8494	-0.0002	-0.2120
EDU	0.0559*	3.0111	0.0007	1.1676	0.0025	1.7816	0.0662	1.4184	0.0050***	3.8268	0.0037	1.5377
GDP	0.0512	0.1429	-0.0121***	-3.4600	0.0065*	2.6980	0.1107**	2.1842	0.0097***	-7.3110	0.0085***	3.9363
INFL	0.0101	0.6207	-0.0023***	-3.1501	-0.0002	-0.0576	0.1387	1.5520	-0.0024	-1.5121	0.0054	1.2041
TOP	0.0122	0.4277	0.0011***	3.0065	-0.0005	-0.2981	-0.0376**	-2.3408	-0.0009	-1.0539	0.0000	0.0573

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

Table 5: Short-run Results

Variables	Model 1 (Oil Products Consumption – OPC) ARDL (3,3,3,3,3,3)		Model 2 (Electricity consumption - ELC) ARDL (1,1,1,1,1,1)		Model 3 (Renewable energy consumption – REC) ARDL (2,3,3,3,3,3)		Model 4 (Natural gas energy consumption -NGC) ARDL (3,1,1,1,1,1)		Model 5 (Coal and lignite consumption - CIC) ARDL (1,1,1,1,1,1)		Model 6 (Total energy - TEC) ARDL (1,2,2,2,2,2)	
Regressors	**Coefficient**	**T-ratio**	**Coefficient**	**T-ratio**	**Coefficient**	**T-Ratio**	**Coefficient**	**T-ratio**	**Coefficient**	**T-ratio**	**Coefficient**	**T-ratio**
dHDI1	-0.8765***	-7.5163	-	-	-0.2504	-1.5451	-0.1217	-0.6093	-	-	-	-
dHDI2	-0.5598***	-8.3090	-	-	-	-	-0.0181	-0.2027	-	-	-	-
dOPC/ELC/REC/NGC/CIC /TEC	-0.0140	-2.9190*	0.0001	0.5873	0.0001	0.1688	-0.0940***	-3.1873	-0.0003	-1.4500	-0.0003*	-2.1032

dOPC1	-0.0603**	-5.3276	-	-	0.0001**	2.9194	-	-	-	-	0.0019	1.5188
dOPC2	-0.03666**	-3.9593	-	-	-0.0000	-0.0283	-	-	-	-	-	-
dEDU	0.0206***	6.6671	0.0007	1.1676	0.0000	0.0366	0.0167***	3.4462	-0.0018**	2.5728	-0.0000	-0.1198
dEDU1	-0.0011	-0.3153	-	-	0.0013	2.6092	-	-	-	-	0.0018***	4.9443
dEDU2	0.0267***	6.2271	-	-	0.0011	1.4931	-	-	-	-	-	-
dGDP	-0.0477**	-3.7566	-0.0121***	-3.4600	-0.0065*	-2.6205	0.0152	0.7527	-0.0088**	-2.6891	-0.0004	-0.2739
DGDP1	-0.1662***	-9.5138	-	-	-0.0240***	-6.2961	-	-	-	-	-0.0119***	-4.7431
dDGDP2	-0.2278***	-7.1052	-	-	-0.0111	-2.0661	-	-	-	-	-	-
dINFL	-0.0240**	-4.9150	-0.0023***	-3.1501	-0.0023**	-3.2658	0.0224***	4.1818	-0.0014*	-1.8403	-0.0071	-1.4965
dINFL1	-0.0666***	-7.9000	-	-	-0.0034***	-5.3207	-	-	-	-	-0.0018***	-3.5427
dINFL2	-0.0397***	-8.8981	-	-	-0.0014*	-2.2945	-	-	-	-	-	-
dTOP	0.0190***	9.3328	0.0011***	3.0065	0.0016***	4.5478	-0.0028	-1.1594	0.0004	0.9849	0.0009***	4.2946
dTOP1	0.0285***	10.9957	-	-	0.0028***	6.2709	-	-	-	-	0.0012**	4.2095
dTOP2	0.0241***	8.7043	-	-	0.0014**	2.8629	-	-	-	-	-0.2770***	-8.9151
ECM(-1)	-0.8085***	-9.8558	-0.5768	-6.9514	-0.7531	-6.1544	-0.2128***	-4.70753	-0.5977***	-6.3366		
	R^2 – 0.988 R-bar squared – 0.963 S.E of Regression – 0.013		R^2 – 0.706 R-bar squared – 0.626 S.E of Regression – 0.006		R^2 – 0.951 R-bar squared – 0.859 S.E of Regression – 0.002		R^2 – 0.736 R-bar squared – 0.619 S.E of Regression – 0.042		R^2 – 0.671 R-bar squared – 0.582 S.E of Regression – 0.006		R^2 – 0.882 R-bar squared – 0.800 S.E of Regression – 0.003	

	AIC – -5.648 SBC – -4.736 DW – 2.078	AIC – -7.190 SBC – -6.60 DW – 1.757	AIC – -8.856 SBC – -7.992 DW – 2.436	AIC – -3.234 SBC – -2.803 DW – 2.146	AIC – -7.078 SBC – -6.749 DW – 1.868	AIC – -8.466 SBC – -7.895 DW – 2.259

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

The long-run and short-run results presented in Tables 4 and 5 confirm that renewable energy has a positive impact on human development, only in the short run in South Africa. This is a confirmation of the advantages of renewable energy as a clean source of energy associated with reduced pollution. These findings are consistent with findings by Olimpia *et al*. (2021) in a study on Central and Eastern European countries, Sasmaz *et al*., (2020) and Pirlogea (2012) in separate studies on OECD countries, and Acheampong *et al*. (2021) in a study on 79 energy-poor countries. An insignificant impact of renewable energy on human development in the long run is not unique to South Africa alone, Wang, Danish and Wang (2018) in a study on Pakistan found the same results. The findings of the study also reveal that oil products, though insignificant in the long run, have a negative impact on human development in the short run. This does not come as a surprise as the oil products are part of fossil fuels, which have the potential to pollute the air and affect human welfare negatively. Further, natural gas was found to be insignificant in the long run and has a negative impact on human development in the short run. Although natural gas is a source of energy, accessibility, acceptability, and affordability is still a challenge in South Africa. According to Enerdata (2021b), 61% of total gas consumption is taken by industries, suggesting low domestic uptake of gas as an alternative to common energy sources, like electricity.

Total energy consumption was found to be insignificant in the long run but has a negative impact on human development in the short run. This finding reflects the negative weight that all disaggregated energy measures have on human development, except for renewable energy. This finding implies that, despite the positive impact of renewable energy in the short run, this effect is offset by the negative impact of oil products and natural gas consumption. Electricity consumption, and coal and lignite consumption were found to be insignificant, irrespective of the time frame considered. These results are not unique to South Africa. Ouedraogo (2013) found electricity to have a neutral effect on human development from a study on 15 developing countries.

Other results from Function 1, where oil products consumption is used as a measure of energy, presented in Tables 4 and 5, show that: i) education (EDU) has a positive impact on human development in the short run and in the long run; ii) GDP has an insignificant impact on human development in the long run and a negative impact in the short run; iii) inflation is insignificant in the long run and has a negative impact in the short run; and iv) trade openness has a positive impact on human development, regardless of the time frame considered.

Other results presented in Tables 4 and 5 for Function 2, where electricity is a measure of energy, show that: i) education has an insignificant impact on human development both in the long run and the short run; ii) GDP has a negative impact on human development in the long run and the short run. This result could be explained by high income inequality where a large part of the GDP is owned by a few, whilst the majority have a small share; iii) inflation has a negative impact on human development in the long run and the short run; and iv) trade openness has a positive impact on human development, according to the findings of this study. This could be explained by the ability of South Africans to consume a wide variety of goods from domestic production and imports.

Results presented in Tables 4 and 5 for Function 3, where renewable energy is used as a proxy for energy reveal that: i) education is insignificant in the long run and in the short run; ii) GDP has a positive impact on human development in the long run and a negative impact in the short run; iii) inflation is insignificant in both the long and the short run; and iv) trade openness has a positive impact on human development in the short run and an insignificant impact in the long run. These findings could be explained by a negative impact of an increase in competition from foreign markets on the domestic market, which may result in the closure of domestic firms and loss of jobs, if they fail to survive the competition.

The results presented in Tables 4 and 5 for Function 4, where natural gas is used as a measure of energy reveal that: i) education has a positive impact on human development only in the short run, while an insignificant impact was registered in the long run; ii) GDP has a positive impact on human development in the long run, but not in the short run; iii) inflation has a positive impact on human development only in the short run and is insignificant in the long run. This could be explained by the need for a certain level of price increase to keep producers incentivised, but not for a prolonged period, because of the undesired negative effects of inflation; and iv) trade openness has a positive impact on human development in the long run but not in the short run.

The results presented in Tables 4 and 5 for Function 5, where coal and lignite are used as measures of energy show that: i) education has a positive impact on human development only in the short run, while in the long run an insignificant impact was confirmed; ii) GDP has a positive impact on human development in the long run, and a negative impact in the short run; iii) inflation has an insignificant impact on human development in the long run and a negative impact in the short run; and iv) trade openness is insignificant in both the long run and the short run.

The results presented in Tables 4 and 5 for Function 6, where total energy is used as a measure of energy reveal that: i) education has a positive impact on human development only in the short run, while an insignificant impact was registered in the long run; ii) GDP has a positive impact on human development in the long run and an insignificant impact in the short run; iii) inflation has a negative impact on human development in the short run and an insignificant impact in the long run; iv) trade openness has a positive impact on human development in the short run and an insignificant impact in the long run.

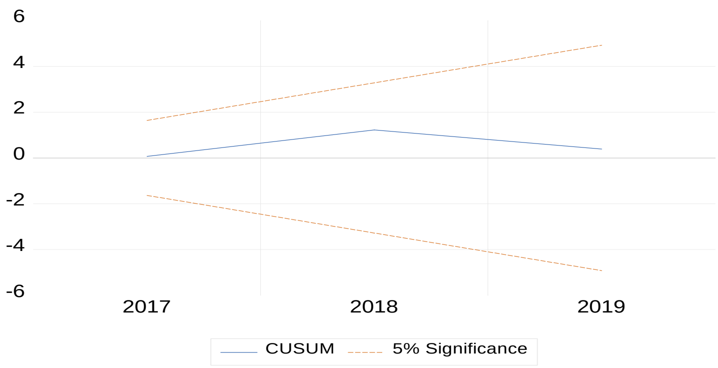
Overall, energy consumption in South Africa has a negative impact on human development. This is evidenced by three out of six proxies of energy consumption namely, total energy consumption, oil products consumption and natural gas consumption that had a significant negative impact on human development in the short run. The long run impact of energy consumption cannot be confirmed in South Africa. All energy measures used in the study were insignificant in the long run. The positive impact that renewable energy has on human development is insignificant to offset the negative impact from oil products and natural gas consumption. The South African government has a huge task of expanding renewable energy consumption and possibly reducing reliance on oil products and natural gas, to realise a positive impact of energy on human development. Diagnostic results are presented in Table 6.

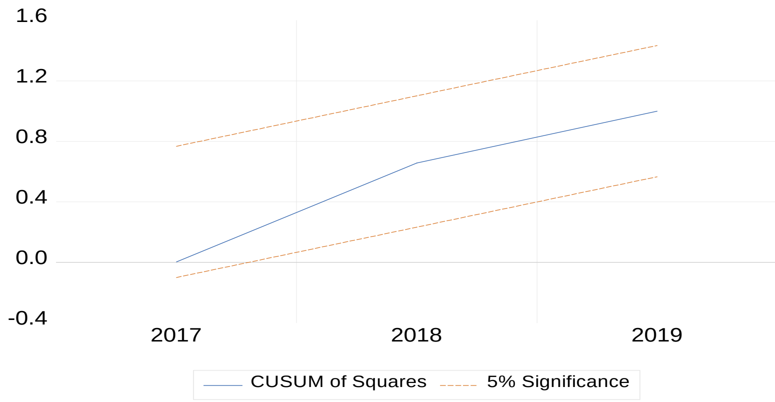
Table 6: Diagnostic Results

LM Test Statistic	Functions					
	Function 1 (HDI & OPC)	Function 2 (HDI & ELC)	Function 3 (HDI & REC)	Function 4 (HDI & NGC)	Function 5 (HDI & CIC)	Function 6 (HDI & TEC)
Serial Correlation (CHSQ 1)	0.723 [0.639]	0.181 [0.836]	1.721 [0.281]	1.417 [0.284]	0.574 [0.575]	0.308 [0.742]
Functional Form (CHSQ 1)	0.510 [0.549]	0.815 [0.427]	1.239 [0.304]	1.233 [0.241]	1.233 [0.241]	8.866 [0.008]
Normality (CHSQ 2)	1.135 [0.567]	1.721 [0.281]	0.479 [0.787]	1.762 [0.414]	1.417 [0.811]	0.294 [0.863]
Heteroscedasticity (CHSQ 1)	0.874 [0.648]	1.141 [0.391]	3.131 [0.138]	1.050 [0.466]	1.802 [0.133]	1.048 [0.481]

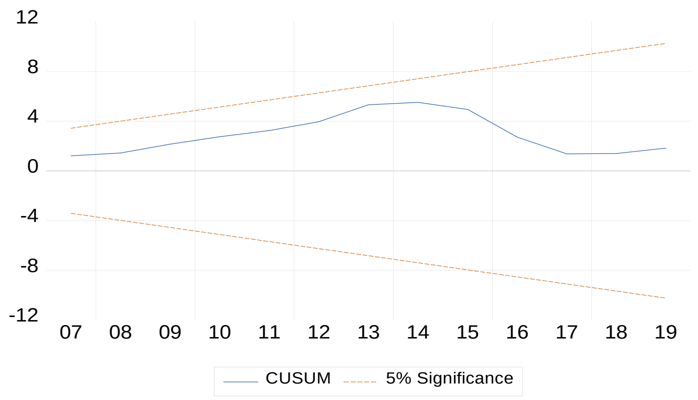
Diagnostic results reported in Table 6 show that Functions 1, 2, 3, 4 and 5 passed serial correlation, functional form, normality test and heteroscedasticity, while Function 6 passed all the other tests, except functional form. Further investigation on the cumulative sum recursive squares (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) revealed that all models are stable at 5% significance level. The results of the CUSUM and the CUSUMQ are presented in Figure 3.

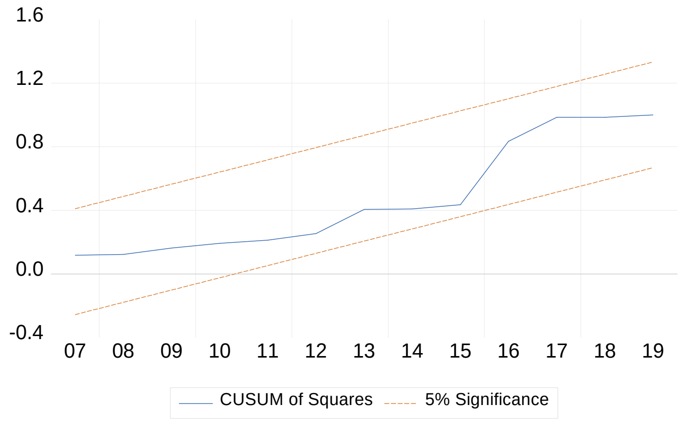
Panel 1: HDI and OPC



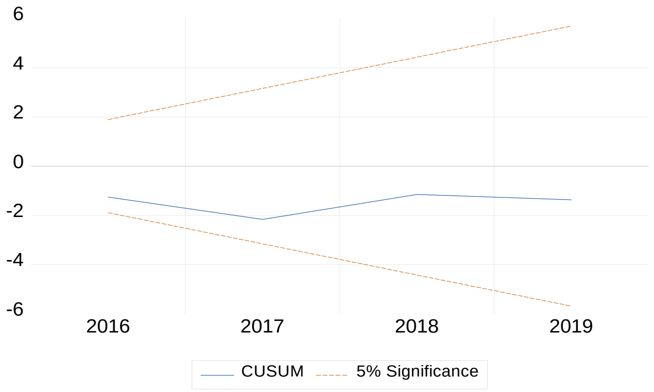


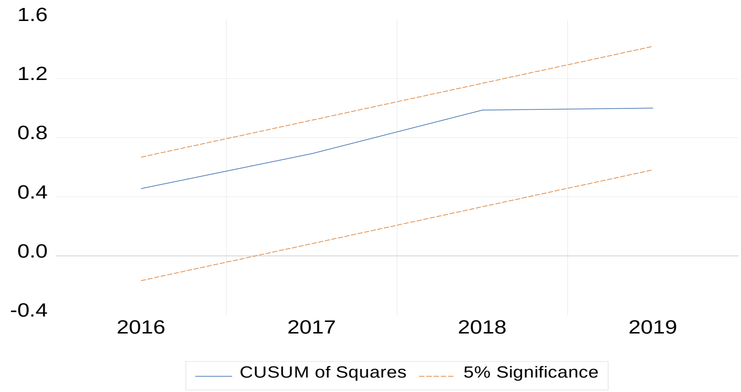
Panel 2: HDI and ELC



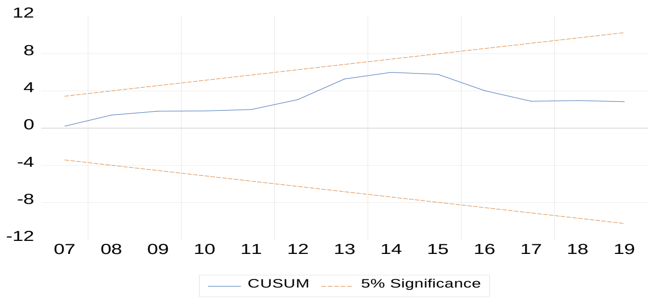


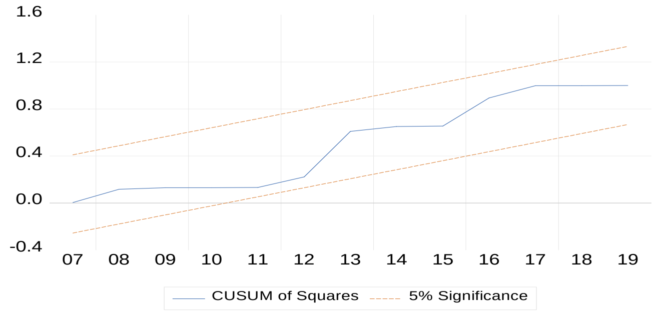
Panel 3: HDI and REC



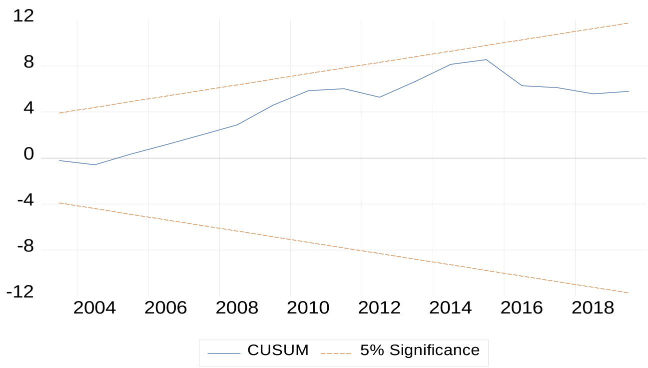


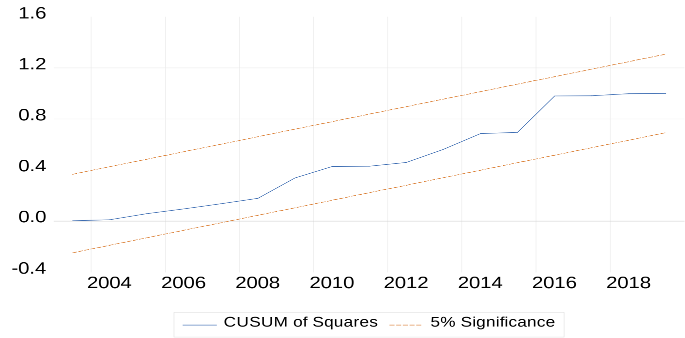
Panel 4: HDI and NGC



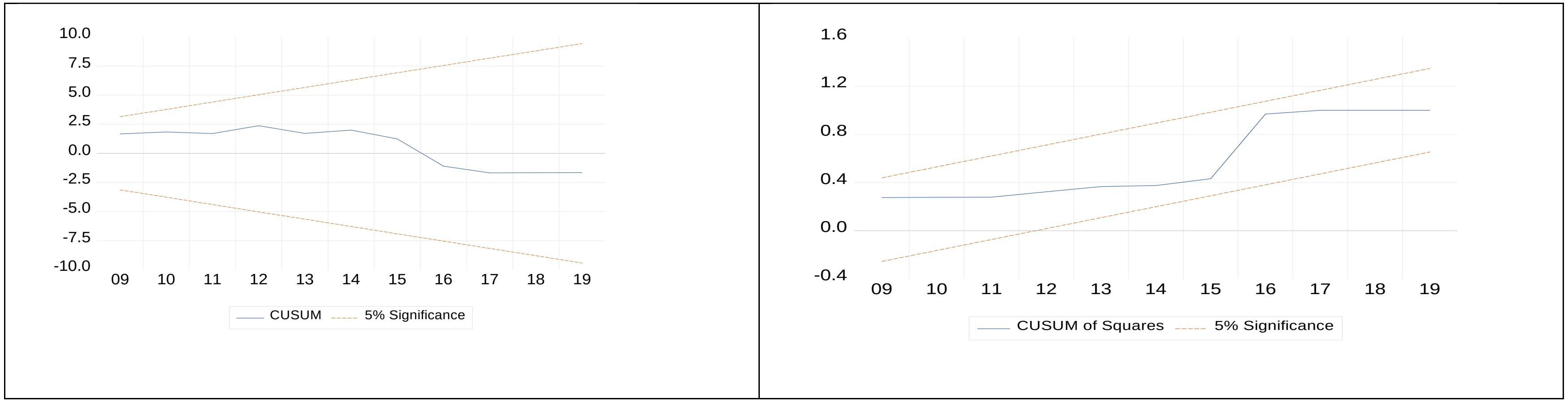


Panel 5: HDI and CIC





Panel 6: HDI and TEC



Source: Diagnostic Analysis

Figure 3: CUSUM and CUSUMQ Results

4. Conclusion and Policy Recommendations

In this study, the impact of energy consumption on human development is investigated for South Africa, using annual data from 1990 to 2019. The study uses aggregate data (total energy consumption) and disaggregated data with energy measures namely, oil products, electricity, renewable energy, natural gas, and coal and lignite as proxies of energy. Employing the autoregressive distributed lag (ARDL) approach, the study found renewable energy to have a positive impact on human development, but only in the short run. Oil products and natural gas were found to have a negative impact on human development in the short, while insignificant in the long run. The total energy consumption was found to have a negative impact on human development in the short run. Electricity, coal and lignite were found to be insignificant, irrespective of the time considered. The impact of energy consumption on human development in the long run could not be confirmed in this study, as evidenced by all energy measures, which have been found to be statistically insignificant in the long run. Thus, the positive impact of renewable energy is not strong enough to offset the negative impacts from oil products and natural gas. Based on the findings of this study, it is recommended that South Africa has to continue to expand renewable energy if a positive impact of energy on human development is to be realised. These findings also confirm the need for South Africa to continue with the policies that promote partnership between the public and the private sector to increase renewable energy production and consumption. This move will consequently result in positive human development, at least in the short run.

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