The Impact of Urbanization on Energy Consumption In South Africa: An Empirical Investigation

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Abstract

The purpose of this paper is to examine the impact of urbanization on energy consumption in the case of South Africa. To empirically estimate this, the study employed the autoregressive distributed lag (ARDL) approach and annual time series data covering the period from 1983 to 2021. In this study, urbanization and energy consumption are measured through the total urban population as a share of the total population and total energy consumption per capita, respectively. The findings from the ARDL cointegration test confirm that an increase in urbanization leads to a short-run increase and a long-run decrease in energy consumption. The results further confirm that an increase in economic growth leads to a long-run and short-run increase in energy consumption. It was also found that financial development leads to a long-run increase in energy consumption, while its first lagged values lead to a short-run decline. Foreign direct investment was found to have no significant impact on energy consumption both in the long run and short run.

Keywords

urbanization, energy consumption, South Africa, ARDL, cointegration

Introduction

Over the last three decades, countries all over the world have witnessed a rapid increase in their levels of urbanization. The proportion of the world's population living in urban areas increased from 47% in 2000 to 57% in 2021(UNCTAD, 2022; World Bank, 2023). This is anticipated to increase in the next three decades to 68% as countries go through different phases of urban development. The case of South Africa is not different, as the country has also experienced a significant increase in the share of its population living in urban areas. Estimates from the World Bank (2023) show that South Africa's level of urbanization was at 68% in 2022, which suggests that more than half of the country's population lived in urban areas. This is expected to increase as the total population of the country is projected to increase by 19-24 million people in 2050, with most of the population living in urban areas (South African Cities Network, 2021). According to Totaforti (2021), urbanization is not harmful to a country's economy as it brings significant opportunities, such as a growing internal market, and can also boost productivity and economic innovation processes. Furthermore, it provides an opportunity for sustainability by creating social, environmental, and economic changes (Gu, 2019). The positive contribution of urbanization on economic growth is also backed by the existing empirical studies (see Song *et al*, 2018; Liang *et al*, 2022; Nguyen and Nguyen, 2016) among others. Although this is the case, urbanization remains a policy concern as it puts immense pressure on the demand for urban services (Gracia and Young, 2014). Studies such as (Totarforti, 2020; Shao *et al,*

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2022), among others, have looked at the impact of urbanization on housing demand and health spending, respectively. Both studies confirmed that urbanization leads to an increase in the demand for housing and health services, which suggests that urbanization does bring about a higher demand for certain urban services.

It is against this backdrop that this study examined the impact of the impact of urbanization on energy consumption in South Africa. The study is premised on the view that it is important for policymakers to understand the effect of urbanization on the demand for urban services and prepare for the projected increases going forward. Although studies have been conducted on the same topic in various countries, literature on this subject remains inadequate. To our knowledge, only one study has looked at the impact of urbanization on energy consumption in the case of South Africa, (see Fang *et al*, 2022). However, in this study, South Africa was grouped with other countries, which does not allow for a focus on country-specific issues.

The rest of the paper is organized as follows. Section 2 provides a brief overview of urbanization and energy consumption in South Africa. Section 3 presents a literature review. Section 4 presents the methodology employed in the study, and sections 5 and 6 present the results and conclusion of the study, respectively.

Urbanization and Energy Consumption in South Africa

South Africa is viewed as one of the most urbanized countries in Africa and has experienced a steady increase in urbanization levels over the years (Rogerson, *et al,* 2014). This began long before the country's transition to democracy in 1994. South Africa's share of the population living in urban areas was 47% in 1960 and this increased to 54% in 1994(World Bank, 2023). After democracy, the share of the country's population living in urban areas increased sharply to 68% in 2022. According to Cities Network (2021), this is projected to rise as the population of South Africa is expected to increase by 19 to 24 million people by 2050. According to (Rogerson, et al, 2014) urbanization in South Africa is accompanied by the industrialization process and increased work opportunities. These are often accompanied by the need to access infrastructure and use services such as energy for both commercial and residential purposes. Figure 1 shows the trends of urbanization and total primary energy consumption in South Africa.

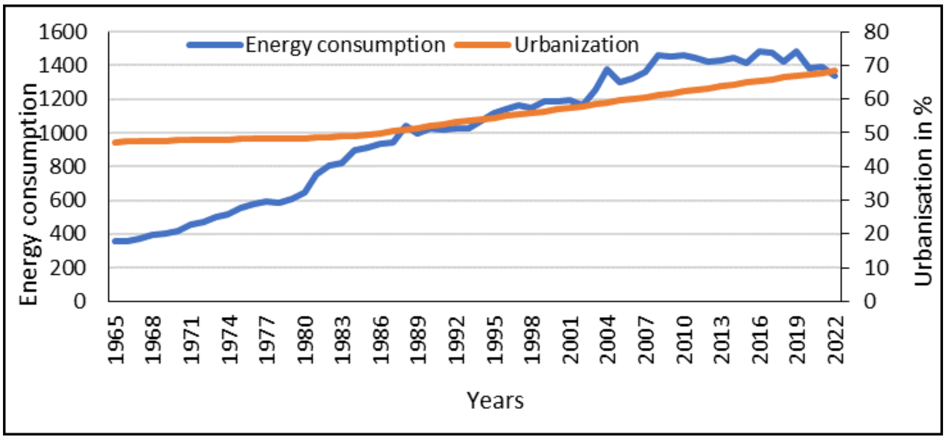

Figure 1: Urbanization and Energy Consumption in South Africa
Source: World Bank database, 2023

As shown in Figure 1, since 1983, urbanization and energy consumption have been generally moving together.

Literature Review

Urbanization forms a great part of a country's economic and social changes and as a result, it has attracted the attention of many researchers. A number of studies have looked at how urbanization impacts on the consumption of various types of energy. This includes studies such as Zhang and Lin (2012) who examined the impact of urbanization on energy consumption in various regions in China.

The study applied the STochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model to annual panel data covering the period from 1995 to 2010. The study used the population living in urban areas as a share of the total population and total energy consumption to measure urbanization and energy consumption respectively. The findings confirmed that urbanization generally has a positive significant impact on energy consumption in China. Furthermore, it was found that the effect of urbanization on energy consumption differs across different regions. Al-mulali *et al* (2012) examined the relationship between urbanization and energy consumption in the case of NEMA countries over a period from 1980 to 2009. The study employed the Pedroni cointegration test and panel Granger causality test and the results showed that urbanization positively impacts energy consumption. The results further confirmed a causal link between urbanization to energy consumption. Salim and Shafiei (2014) carried out a similar study for OECD countries using the STochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) for the period from 1980 to 2011. The findings confirmed that urbanization positively impacts on both renewable and non-renewable energy consumption. Lin and Li (2015) examined the impact of urbanization on energy consumption in 73 countries selected countries. The study applied the STIRPAT model on panel data covering the period from 1971 to 2010. The findings confirmed that urbanization leads to a decline in energy consumption in low-income countries, but it leads to an increase in energy consumption in middle and high-income countries. Sheng *et al* (2017) examined the impact of urbanization on energy consumption in 78 countries. The study applied the generalized method of moment estimation on panel data covering the period from 1995 to 2012. Urbanization is measured as the share of the population in urban areas over the total population. To measure energy consumption, the study employed two proxies, that is, the actual energy consumption per capita and the optimal energy consumption per capita. The study used the STIRPAT model on the results confirmed that urbanization has a positive impact on both proxies of energy consumption. Similar findings were reported by Shahbaz *et al* (2017) in the case of Parkistan. This was tested by applying the STIRPAT model and the ARDL bounds testing approach on a time series data covering the period from 1972Q1 to 2011Q4. Yang *et al* (2019) studied the impact of urbanization on energy consumption in various provinces in China using annual data covering the period from 1996 to 2014. The study used the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model. The study used various measures of energy consumption such as electricity consumption and total energy consumption and looked at both rural and urban areas. The findings confirmed that urbanization leads to an increase in energy consumption in both rural and urban areas. In 2020, a similar study was conducted by Wang for 136 countries in the world. The study employed the STIRPAT model on panel data covering the period from 1990 to 2015. The findings confirmed that the magnitude of the impact of urbanization on energy consumption differs in various regions of the world. The results confirmed that in Sub-saharan African countries, urbanization leads to a decline in energy consumption. This is because the rapid increase in urbanization is not accompanied by an increase in economic growth. It was also found that urbanization leads to an increase in energy consumption in developing Asian economies, Middle East and North Africa. The study also found that urbanization has no significant effect on energy consumption in developing European regions and central Asia. For India, a similar finding was confirmed in a study by Sahoo and Sethi (2020). The study applied the ARDL bound testing; Johansen & Juselius cointegration approach and Gregory & Hansen structural break cointegration technique on a time series data covering the period from 1980 to 2017. For Sub-Saharan African countries, Ali (2021) examined the impact of urbanization on energy consumption in 49 Sub-Saharan African countries. The study applied the unbalanced panel with data covering the period 1980–2014 and the results confirmed that urbanization has a positive impact on energy consumption. Using the fully modified ordinary least square (FMOLS), and the canonical cointegration regression (CCR), Warsame (2022) examined the impact of urbanization on energy consumption in Somalia for the period from 1990 to 2018. The findings confirmed that urbanization has a negative impact on energy consumption in Somalia. Fang *et al* (2022) carried out a similar study for Brazil, India, China, and South Africa using panel data covering the period from 1990 to 2015. The study employed the random effect estimation method and Feasible general least squares (FGLS). The findings confirmed that the study found that urbanization reduces the demand for renewable and non-renewable energy. Table 1 presents the summary of the reviewed literature.

Table 1: Summary of the Reviewed Empirical Literature on the Impact of Urbanization on Energy Consumption

Author and date	**Country**	**Title**	**Econometric Techniques and Period**	**Indicators for urbanization and energy consumption**	**Results on the Impact of Urbanization on Energy Consumption**
Zhang and Lin (2012)	China	Panel estimation for urbanization, energy consumption, and CO2 emissions: A Regional Analysis in China.	Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) 1995 to 2010	Urbanization (URB) Total energy use Energy intensity (EI)	Urbanization leads to an increase in energy consumption
Al-mulali *et al* (2012)	MENA countries	Exploring the relationship between urbanization, energy consumption, and CO2 emission in MENA countries	Pedroni cointegration test 1980 to 2009	Total urban population Total primary energy consumption	Urbanization leads to an increase in energy consumption
Salim and Shafiei (2014)	OECD countries	Urbanization and renewable and non-renewable energy consumption in OECD countries: An empirical analysis	Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) 1980 to 2011	Total urban population as % of the total population Renewable and non-renewable energy consumption	Urbanization leads to an increase in renewable and non-renewable energy consumption
Lin and Li (2015)	73 Countries	Impacts of urbanization and industrialization on energy consumption/CO2 emissions: Does the level of development matter?	Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) and Dynamic panel threshold regression 1971–2010	Total urban population as % of the total population Sum of energy consumption	Urbanization leads to a decline in energy consumption in low-income countries. Urbanization leads to an increase in energy consumption in middle and high-income countries
Sheng *et al* (2017)	78 Selected countries	The impact of urbanization on energy consumption and efficiency	Generalized method of moments 1995 to 2012	Urbanization Actual energy consumption Optimum energy consumption	Urbanization leads to an increase in energy consumption
Yang *et al* (2019)	China	The impact of urbanization on China's residential energy consumption	Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) 1996-2014	Urbanization Residential energy consumption	Urbanization leads to an increase in energy consumption
Wang et al (2020)	136 countries	Does urbanization lead to less residential	Stochastic Impacts by Regression on	Urbanization	Urbanization leads to an increase in energy consumption

		energy consumption? A comparative study of 136 countries	Population, Affluence, and Technology (STIRPAT) 1990 to 2015	Residential energy consumption	
Sahoo and Sethi (2020)	India	Impact of industrialization, urbanization, and financial development on energy consumption: Empirical evidence from India	The autoregressive distributed lag (ARDL) bound testing; Johansen and Juselius cointegration approach.	Urbanization Total primary energy consumption	Urbanization leads to an increase in energy consumption
Ali (2021)	49 Sub-Saharan African countries	Urbanization and energy consumption in Sub-Saharan Africa	unbalanced panel 1980–2014	Urbanization Total energy consumption Electricity consumption	Urbanization leads to an increase in energy consumption
Warsame (2022)	Somalia	The Impact of Urbanization on Energy Demand: An Empirical Evidence from Somalia	Modified ordinary least square (FMOLS) 1990 to 2018	Urbanization Energy consumption per capita	Urbanization leads to a decline in energy consumption
Fang *et al* (2022)	Brazil, India, China, and South Africa	Does urbanization induce renewable energy consumption in emerging economies? The role of education in energy switching policies	Feasible general least squares (FGLS) and Panel random-effects estimations. 1990 to 2015	Urban population Oil consumption, coal consumption, natural gas consumption, solar energy consumption, Geo-thermal, Biomass energy consumption and Other renewable energy consumption	urbanization induces energy use in emerging economies

Estimation techniques and empirical analysis

Model specification and data

The general model used to examine the impact of urbanization on energy consumption can be expressed as follows:

ENG = f (URBAN, YPC, FD, FDI)……………………………………………….(1)

Where: ENG is energy consumption, Urban is urbanization, YPC is economic growth and FD is financial development.

The autoregressive distributed lag (ARDL) approach

To empirically examine the impact of urbanization on energy consumption, the study uses the autoregressive distributed lag (ARDL) approach developed by Pesaran *et al.* (2001). This method is preferred over other econometric cointegration methods because it has the following advantages:

- It can be applied regardless of whether the regressors are integrated of order zero [I (0)], order one [I (1)], or fractionally integrated, as long as they are not integrated of order two [I (2)] or higher.

- It does not require that all the series be integrated of the same order. (Pesaran *et al.,* 2001).
- The technique can be applied to small or finite sample sizes and to variables with different optimal lags.
- Finally, the ARDL approach simultaneously estimates the long-run and short-run coefficients, therefore making possible inferences on the long-run estimates (Arize,2017).

The ARDL model can be specified as follows:

$$\Delta ENG_t = \varphi_0 + \sum_{i=1}^{n} \varphi_{1i}\,\Delta ENG_{t-i} + \sum_{i=0}^{n} \varphi_{2i}\,\Delta URBAN_{t-i} + \sum_{i=0}^{n} \varphi_{3i}\,\Delta YPC_{t-i} + \sum_{i=0}^{n} \varphi_{4i}\,\Delta FD_{t-i} + \sum_{i=0}^{n} \varphi_{5i}\,\Delta FDI_{t-i} + \varphi_6 ENG_{t-1} + \varphi_7 URBAN_{t-1} + \varphi_8 YPC_{t-1} + \varphi_9 FD_{t-1} + \varphi_{10} FDI_{t-1} + \mu_{1t} \quad \dots (2)$$

Where: φ_0 is the *constant*, $\varphi_1 - \varphi_5$ is the short run coefficient, $\varphi_6 - \varphi_{10}$ is the long run coefficient, Δ is the difference operator, *n* is the lag lengths; and μ_{1t} is the white-noise error term.
All variables remain as defined in Equation 1.
The corresponding ECM model associated with ARDL model presented in Equation 1 can be expressed as follows:

$$\Delta ENG_t = \varphi_0 + \sum_{i=1}^{n} \varphi_{1i}\,\Delta ENG_{t-i} + \sum_{i=0}^{n} \varphi_{2i}\,\Delta URBAN_{t-i} + \sum_{i=0}^{n} \varphi_{3i}\,\Delta YPC_{t-i} + \sum_{i=0}^{n} \varphi_{4i}\,\Delta FD_{t-i} + \sum_{i=0}^{n} \varphi_{5i}\,\Delta FDI_{t-i} + \omega_1 ECM + \mu_{2t} \quad \dots (3)$$

Where: ECM_{t-1} is the lagged error-correction term, ω_1 *is the coefficient* of the lagged error-correction term (ECM_{t-1}). and μ_{2t} white-noise error term.
The study employed annual time-series data that spanned from 1983 to 2021. This chosen period was informed by the availability of reliable data on the key variables used in this study. The primary source of data used in this study was the World Bank Development Indicators database (World Bank, 2023). Table 2 gives a summary of the description of variables used in the study as well as their measurements and a priori expectations.

Table 2: Data Sources and Measurement of Variables

Variables	Description	Measurement	Expectation	Source
ENG	Energy consumption	Total energy consumption per capita	-	WDI
URBAN	Urbanization	Total urban population (% of total population)	Positive	WDI
YPC	GDP per capita	GDP / Population	Positive	WDI
FD	Financial development	Domestic credit to the private sector (% of GDP)	Positive	WDI
FDI	Foreign direct investment	FDI (% of GDP)	Positive	WDI

Source: Author's Compilation.

Empirical Analysis

Stationary Tests

Although the ARDL approach does not require all variables to be integrated of order one [I(1)], the technique cannot be applied if any of the variables included in the model is integrated of order two [i.e., I(2)] or higher. Consequently, it is important to ensure that no variable is I(2). For this purpose, the study used the Dickey-Fuller Generalised Least Square (DF-GLS), Phillips-Perron (PP) test, and Unit Root with Break test. The results of these tests are reported in Tables 3 and 4.

Table 3: Stationarity Test for all Variables - DF-GLS and Phillips-Perron (PP)

	Dickey-Fuller Generalised Least Square (DF-GLS)			
Variable	Level		First Difference	
	Without Trend	With Trend	Without Trend	With Trend
ENG	-1.5157	-2.1611	-3.5035***	-6.1155***
URBAN	-1.6374	-4.1409**	-2.8346***	-
YPC	-0.7652	-1.6448	-3.8301***	-4.3627***
FDI	-2.9546***	-3.8314***	-	-
FD	-0.9768	-0.8043	-5.0245***	-5.4815***
	Phillips-Perron (PP)			
	Level		First Difference	
	Without Trend	With Trend	Without Trend	With Trend
ENG	-2.4652	-4.7969***	-7.5202***	-
URBAN	0.2765	-3.5747**	-4.3845***	-
YPC	-0.7935	-1.8689	-4.4255***	-5.7603***
FDI	-1.1875	-3.8595**	-6.5788***	-
FD	0.2640	-0.3854	-4.9695***	-5.3910***

Notes: ** and *** denote stationarity at the 5% and 1% significance levels, respectively.

Table 4: Stationarity Test for all Variables - Unit Root with Break Test

	Unit Root with Break Test			
	Level		First Difference	
	Statistic	Break Year	Statistic	Break Year
ENG	-2.3088	2017	-9.0606***	2004
URBAN	-5.3219**	1989	-	-
YPC	-2.9200	2003	-5.7811***	1992
FDI	-2.3555	2000	-7.7884***	2020
FD	-2.4841	2003	-6.0584***	2006

NB: ** and *** denote stationarity at the 5% and 1% significance levels, respectively.

The results of stationarity reported in Tables 3 and 4 show that the dependent variable (energy consumption) is integrated of order one [i.e., I(1)], while the remaining variables are fractionally integrated of order one [I(1)] and order zero [I(0)]. These results have been confirmed by the Dickey-Fuller Generalised Least Square (DF-GLS), Phillips-Perron (PP), and Unit Root with Break Test. The results of the DF-GLS test show that all variables are I(1), except the FDI, which was found to be I(0).

ARDL Bounds Testing Approach

Since the results of the unit root test show that no variable is integrated of order two or higher, we can proceed and test for cointegration using the bounds test. The results of the bounds test results for cointegration are reported in Table 5.

Table 5: Bounds Test

Null hypothesis: No levels relationship
Number of cointegrating variables: 4
Trend type: Rest. constant (Case 2)

Sample size: 40		
Test Statistic		Value
F-statistic		6.170614

Asymptotic Critical Values

	10%		5%		1%	
Sample Size	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
35	2.460	3.460	2.947	4.088	4.093	5.532
40	2.427	3.395	2.893	4.000	3.967	5.455
Asymptotic	2.200	3.090	2.560	3.490	3.290	4.370

* I(0) and I(1) are respectively the stationary and non-stationary bounds.

The results reported in Table 5 show that the calculated F-statistic is 6.1706, which is higher than the bound critical values at the 1% level of significance. This confirms that there is a long-run relationship between energy consumption and its dependent variables, namely urbanisation, economic growth, foreign direct investment, and financial development. The long-run and short-run results are presented in Table 6.

Table 6: Short-run and Long-run Results

Regressors	Coefficient	T-ratio
Panel A – Long run Results		
C	147.4542***	11.99887
URBAN	-2.068960***	-5.347263
YPC	0.007831***	4.409027
DCPS	0.190958**	2.510493
FDI	-1.663242	-1.342343
Panel B – Short-Run Results		
DENG (-1)	-0.657417***	-4.410656
DURBAN	11.72633***	5.625593
DYPC	0.012596***	4.507078
DDCPS)	0.046716	0.949077
D(DCPS)(-1)	-0.215352***	-3.884380
D(FDI)	-0.320078	-1.491832
ECM (-1)	-0.657417***	-6.588405

R-squared	0.630741	Akaike info criterion	4.749291
Adjusted R-squared	0.576438	Schwarz criterion	5.002623
S.E. of regression	2.427754	Hannan-Quinn criter.	4.840888
F-statistic	11.61524	Akaike info criterion	4.749291
Prob(F-statistic)	0.000001		

Note: ** and *** indicate significance of variables at 5% and 1% level of significance

Short-run and Long-run Results

The short-run results reported in Table 6 show that an increase in urbanization leads to an increase in per capita energy consumption. This is consistent with our a priori expectation and is supported by the coefficient of urbanization in the energy consumption equation, which has been found to be positive and statistically significant. However, contrary to our expectation, an increase in urbanization has been found to lead to a decrease in per capita energy consumption in the long run. These results can be confirmed by the coefficient of urbanization in the energy consumption per capita equation, which has been found to be negative and statistically significant. These findings are, however, consistent with some other previous findings such as those by Lariviere and Lafrance (1999), who found, inter alia, that high-density cities in China use less electricity per capita than low-density ones. Previous studies have also argued that an increase in urbanization could reduce residential energy consumption through the efficient use of public infrastructure such as public transport and other energy-intensive utilities (see, for example, Chen *et al.*, 2008; Liddle, 2004). Other studies have also shown that the impact of urbanization on energy consumption is not homogenous across countries but rather varies from country to country depending on the country's stage of development (see Poumanyvong and Kaneko, 2010).

In terms of the control variables, the results show that economic growth leads to an increase in energy consumption both in the long-run and short-run. This is in line with the expected findings and is confirmed by the coefficient of this variable which is significant and positive. The positive impact of economic growth on energy consumption is also supported by the findings of previous empirical studies, such as Sahoo and Sethi (2020) in the case of India and Shahbaz and Lean (2012) in the case of Tunisia, among others. Financial development was found to have a positive and significant impact on energy consumption in the long run, while its lagged values have a negative impact in the short run. The positive impact of financial development on energy consumption is supported by previous studies, such as Sadorsky (2011) in the case of Central and Eastern European frontier economies and Mukhtarov (2020) in the case of Kazakhstan, among others. Although the negative impact of financial development on energy consumption contradicts the a priori expectation, it is supported by previous studies, such as Chiu and Lee (2020) in the case of 79 countries and Gómez and Rodríguez (2019) in the case of the North American Free Trade Agreement (NAFTA) countries, among others. Foreign direct investment was found to have no significant impact on energy consumption.

The error correction of the estimated model is significant and negative, confirming the speed of adjustment of the estimated variables towards equilibrium. Figures 2 and 3 present the of CUSUM and CUSUMSQ tests.

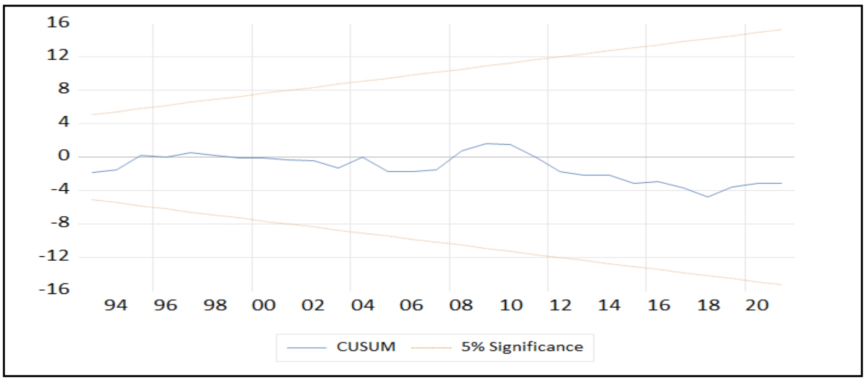

Figure 2: CUSUM Plot
Source: Author's computation

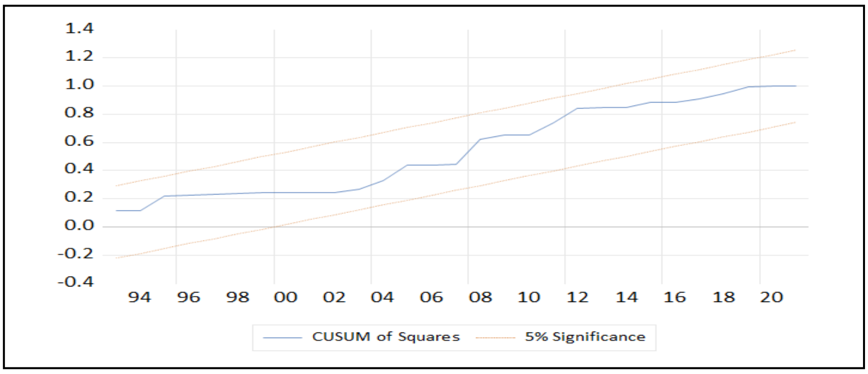

Figure 3: CUSUMSQ of Squares Plot
Source: Author's computation

The CUSUM and CUSUMSQ results confirm that the estimated model is stable.

Conclusion

This study examined the impact of urbanization on energy consumption in South Africa using annual time series data for the period from 1983 to 2021. This was examined using the autoregressive distributed lag (ARDL) approach. The findings confirmed that urbanization leads to a short-run increase and a long-run decrease in per capita energy consumption. It was also found that economic growth leads to a long-run and short-run increase in energy consumption. Financial development was found to have a positive long-run impact on energy consumption, while its first-lagged values have a negative impact in the short run. foreign direct investment is found to have no long-run and short-run effect on energy consumption. The positive impact of urbanization on energy consumption indicates the need for policymakers to invest in other sources of energy in order to meet the energy demand that comes with urbanization. Furthermore, the findings suggest the need for the South African government to move towards adopting more energy-efficient technologies. Energy demand can also be managed by ensuring that new commercial and residential structures are energy efficient. The study has examined the impact of urbanization on energy consumption by using the total energy consumption as a proxy and did not make a distinction between renewable energy and non-renewable energy. Therefore, further studies on this subject can examine the impact of urbanization on different types of energy to get a better understanding of which energy demand is driven more by urbanization.

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