Examining the determinants of electricity demand by South African households per income level

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Abstract

For the period 1975 – 2016, this paper examines the determinants of the residential demand for electricity in South Africa including disposable income, electricity prices, food prices as well as the impact of the 2007/08 load-shedding wave and the 2008 electricity price restructuring. Given the high income inequality levels in South Africa, this relationship was investigated at aggregated and disaggregated income levels. Based on an Autoregressive Distributed Lag (ARDL) model, the empirical results indicate long-run cointegration between residential electricity consumption, gross national disposable income, electricity prices and food prices. Disposable income elasticities have a positive sign for the aggregate and all income groups, indicating that as income increases, South African households consume more electricity (normal good). As expected, price elasticities are negative and significant – for both the aggregated and disaggregated models – indicating that electricity prices do influence electricity demand for all South African households. The paper also examines the complementarity or substitutability of food and electricity. At both the aggregated and disaggregated income levels, the results showed that food and electricity are substitute goods for all South African households. However, as expected, the magnitude of this relationship is marginally different for each income group.

JEL Codes: C13, C22, Q41

Keywords: Residential Sector, price elasticity, income elasticity, ARDL, South Africa

1 Introduction

The South African residential sector has been increasing its electricity consumption overtime, especially since the early 2000s (Eskom, 2015; Bohlmann & Inglesi-Lotz, 2018; DoE, 2019) – as can be seen in Figure 1, with the exception

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of 2014/15, where South Africa experienced its second wave of load-shedding[1] and consumers were forced to reduce their electricity consumption[2]. The increases in electricity consumption in the South African residential sector can be mainly attributed to the government's commitment to achieve universal electricity access by 2025, which has led to a household electrification rate of almost 90 percent in South Africa (IEA, 2016; DoE, 2017; StatsSA, 2013, Bohlmann & Inglesi-Lotz, 2018). This commitment to universal access to electricity started in the early 1990s and was emphasised later on in 2002 when the Integrated National Electrification Programme (INEP) – the main electrification programme in South Africa – was introduced (Bohlmann & Inglesi-Lotz, 2018). Increases in residential electricity consumption have been re-enforced with the introduction of the Free Basic Electricity Programme (FBE) in 2003, which provides 50 kWh of free electricity per month to low-income households to help them cover their basic energy needs (DME, 2003; Bohlmann & Inglesi-Lotz, 2018).

This paper focuses on examining the residential demand for electricity in South Africa for the period 1975-2016 using an autoregressive distributed lag (ARDL) model. The main objective is to evaluate residential demand for electricity in South Africa as a function of gross national disposable income, electricity prices, food prices and a dummy variable accounting for the possible structural break caused by load-shedding and the electricity price re-structuring that happened in the country in 2008. Given the high income inequality levels in South Africa, this relationship is investigated for all South African households in aggregate as well as for low-, middle- and high-income households separately. The importance of evaluating the determinants of electricity consumption at disaggregated income levels is of upmost importance in the South African case; the above mentioned income inequality in the country leads to South African households being affected differently – by for example changes in prices – according to the income bracket they fall on.

Additionally, since electricity and food are two of the main items that South African households consume within their budget, we aim at identifying whether electricity and food are substitute or complement goods. Overall, we present the potentially different impact of main electricity and economic indicators to the South African households depending on their income bracket (quantile).

The main motivation to including food prices in our analysis arose from the fact that over time, on average, South African households' consumption expenditure by main expenditure group and income has been dominated by expenditure on *Housing, water, electricity, gas and other fuels; Transport; Food and non-alcoholic beverages; and Miscellaneous goods and services* (which include medical aid contributions and insurance) (StatsSA, 2008a; 2008b; 2012; 2017). Therefore, electricity and food are part of the basic basket of goods and services consumed by South African households. Given the rising electricity and food prices in South Africa, which affect the affordability of these basic goods and services, it is important to understand the relationship between the consump-

[1] Load-shedding or load reduction is the South African term for electricity rationing.
[2] A supply-side shock due to lack of electricity supply

tion of these items which could be either complementary or substitute goods. Additionally, given the water, food and energy nexus, the complex relationship between these domains necessitates an integrated approach to ensuring, amongst others, food security and energy production worldwide (United Nations, 2020). Therefore, this paper provides insight into the food-energy linkages within the overall nexus. This is also in accordance with the extensive literature on the water, food and energy nexus as highlighted in Smajgl, et al. (2016), Schlör et al. (2018), Zhang et al. (2018) & Pahl-Wostl (2019) amongst others.

As argued by Narayan and Smyth (2005) and Blignaut et al. (2015), reliable estimates of price and income elasticity of demand (like the ones calculated in this paper) are necessary when formulating and evaluating policies, especially those regarding household behaviour and the environment - particularly in the electricity sector. Thus, this study aims to estimate the long-run elasticities of residential demand for electricity in South Africa to understand and quantify the determinants of residential demand for electricity so in future we can accurately measure households' response to various energy related policy proposals such as the carbon tax and demand side management policies that aim at reducing electricity consumption in the residential sector. In estimating these parameters, we will follow the methodological approach used by Narayan and Smyth (2005) and Ziramba (2008) in which the authors used the bounds testing approach to cointegration analysis in evaluating residential electricity demand for the case of Australia and South Africa respectively.

Thus, the main contribution of this study is three-fold: i) the South African literature has dealt with electricity demand in aggregate (Pouris, 1987; Ziramba, 2008), or per economic sector (Inglesi-Lotz and Blignaut, 2011) or at a micro-level (Ye et al., 2018). However, when it comes to the residential sector, economic and energy policies are implemented in a more aggregate level. Hence, this paper offers a proposed framework by separating the households into low-, middle- and high- income brackets; ii) the data on these income quantiles are not easily available for a longer time period; this study aims at amalgamating all information available on this in one dataset; and iii) taking into consideration, the socioeconomic conditions of South African households and the food-energy nexus in the literature, this study includes food prices as an extra determinant on the households' decision to consume electricity.

Additionally, this paper contributes to the literature by updating the different elasticities previously estimated by Ziramba (2008) using a longer time period, 1975-2016 and by adding different determinants of electricity consumption such as a dummy representing the load-shedding and the electricity price re-structuring that happened in South Africa in 2008.

The remainder of this paper is structured as follows: Section 2 provides a brief background on electricity consumption in the South African residential sector; it also provides information on the South African household's basic basket of goods and services consumption expenditure. Section 3 provides a review of the empirical studies on the residential demand for electricity. Section 4 presents the methodology and data. The empirical results are provided in section 5. Section 6 summarises the main findings and concludes the paper.

2 Background

This section provides some insights into electricity consumption in the residential sector in South Africa. It describes some of the factors – such as the price restructuring that arose from the energy crisis in 2008 – that might have affected electricity consumption over time. This section is important as it provides the background and motivation behind some of the key variables used as determinants of electricity demand in the residential sector in this study.

2.1 Electricity Consumption in the South African Residential Sector

The increasing trend in electricity consumption in the residential sector can be attributed to the efforts by the South African Department of Energy through the Integrated National Electrification Programme (INEP), which had contributed to the improvements in access to electricity in the country coupled with historically low electricity prices – up to 2007 (World Bank, 2017b; Bohlmann & Inglesi-Lotz, 2018).

Between 1994 and 2016 access to electricity in South Africa increased from 56 percent to over 86 percent, with almost 16 million households electrified by 2017 (DoE, 2017; World Bank, 2017a; 2017b). As part of the INEP's mandates, South Africa is committed to achieve universal access to electricity by 2025. Therefore, electricity consumption in the residential sector is expected to continue growing.

During October 2007 and February 2008, Eskom faced challenges in provisioning enough electricity for the country. Increasing electricity demand coupled with diminished reserve margins led to major electricity supply interruptions and the implementation of load-shedding to manage the energy shortage in South Africa (Eskom, 2008). It has been argued that the 2007/08 electricity crisis was a consequence of electricity demand estimations being lower than what they actually were which led to Eskom not making provisions for expanding its generation capacity on time; lack of electricity generation and; a reduction in the quality of coal received which necessitated the burning of higher volumes of coal for the same output of electricity (Eskom, 2008). The damages to the South African economy as a consequence of the electricity crisis were estimated at over R50 billion Rands (Mail & Guardian, 2008).

South Africa's electricity prices have been known for being amongst the lowest electricity prices in the world (Eskom, 2008). These prices do not reflect the true cost of producing, transporting and distributing electricity (Eskom, 2008). Therefore, after the 2007/2008 electricity crisis, the South African National Economic Development and Labour Council (NEDLAC) supported Eskom's application for a tariff increase for the 2008/2009 financial year, in order to set an electricity price that was cost reflective whilst also ensuring that the poor were protected and that they still have access to affordable electricity. NERSA – the regulator of electricity prices in South Africa – approved the price increases in June 2008 by increasing the average price of electricity by 27.5% for the 2008/2009 financial year (Eskom, 2008).

It has been argued, that prior to 2008, due to South Africa's historically low electricity prices, South African consumers did not have an incentive to consume electricity efficiently, which has been shown in increasing electricity consumption levels (Blignaut et al., 2015). However, since the 2007/2008 crisis, electricity prices in South Africa have increased at around 25 percent per annum, which is said to have influenced consumer behaviour (refer to Figure 3 for a depiction of electricity prices in the South African residential sector). This study aims at investigating whether post-2008, electricity prices have indeed influenced electricity consumption in the residential sector in South Africa.

2.2 South African household's basic basket of goods and services consumption expenditure – average household expenditure

A key contribution of this study is the analysis of the determinants of electricity consumption in the residential sector not only at an aggregated income level, but given the income inequality levels in South Africa, at a disaggregated income level – low-, middle- and high- income. Therefore, it is imperative to understand the income disparity in South Africa and how households at different income levels spend their income – with the focus being on electricity and food.

Income is an important determinant of expenditure patterns. Typically, low-income earners have expenditure patterns that are very different from those of high-income earners. Therefore, in this section, we differentiate and compare income and expenditure patterns amongst income groups.

In this study, food prices have been added as part of the determinants of electricity consumption in the South African residential sector. This is to determine whether South African households consider electricity and food as complementary or substitute goods, and whether this relationship is different amongst different income groups. Therefore, it is important to understand whether or not South African households' pattern of expenditure on basic goods includes electricity and food – and if these items represent a significant share of their total consumption expenditure.

Calculating the average consumption of food and electricity is not relevant for policy making. However, calculating consumption at different income levels and highlighting the vast differences in consumption patterns between low-income and high-income households is of upmost importance. For example, food and electricity for low-income households might be considered subsistence goods whereas for high-income households is different. Low-income households are energy poor (spend more than 10 percent of their income on electricity), which is not the case for high-income households. Thus, this study evaluated in detail the top five goods consumed by all households in South Africa at both the aggregate and disaggregate income levels over time.

In South Africa, there are two key publications that focus on reporting income and expenditure patterns of South African households: 1) the '*Income and Expenditure of Households*' (Statistics South Africa, 2008; 2012) and; 2) '*Liv-*

ing Conditions of Households in South Africa' (Statistics South Africa, 2011; 2017a). These sources provide us with comparable data points for 2005/2006, 2008/2009, 2010/2011 and 2014/2015, therefore, from these publications, we can draw conclusions about the latest income and expenditure patterns of South African households and determine what their basic basket of goods is. Additionally, the '*Poverty Trends in South Africa: An Examination of Absolute Poverty Between 2006 and 2015*' publication by Statistics South Africa (2017b), provides some insight into the poverty profile of individuals and households at national and provincial levels.

In terms of income inequality, data showed that during the 2005-2015 period, on average, households in the bottom decile earned only 0.48 percent of total income per household in South Africa. However, households on the top decile earned 51.67 percent of total income earned in South Africa[3]. When grouping the different income deciles by low-income (deciles 1-4), middle-income (deciles 5-8) and high-income (9-10), it can be seen that low-income households, on average, earned only 5.85 percent of total income earned in South Africa – compared to high-income households who earned 70.03 of total income on average (refer to Table A.1 in the appendix for detail on income per households per decile as well as the share of total income earned in South Africa per households per decile[4]).

For the period 2014/2015, it was reported that South African households spent approximately R103293, with the main component of the expenditure – as per previous years – being *Housing, water, electricity, gas and other fuels* representing 32.6 percent of total expenditure. *Transport* represented the second largest expenditure item in this period (16.3 percent), followed by *Miscellaneous goods and services* at 14.7 percent).On average, the main expenditure items for the average South African household is *Housing, water, electricity, gas and other fuels*. However, as it will be described below, this picture looks very different when looking at households at disaggregated levels of income.

2.2.1 Disaggregated Household Expenditure – focusing on 2014/2015 data

Focusing on *Food and non-alcoholic beverages* and *Housing, water, electricity, gas and other fuels* – which contain food and electricity, two key variables in this study; low income households (decile 1) consumed 2.5 percent of total consumption of *Food and non-alcoholic beverages*, compared to high-income households (decile 10) which consumed 21.2 percent of total consumption of *Food and non-alcoholic beverages* (StatsSA, 2017a) – refer to Table 1.

With regards to *Housing, water, electricity, gas and other fuels*, low-income households (decile 1) consumed 0.9 percent of total consumption of *Housing, water, electricity, gas and other fuels*, compared to high-income households (decile

[3] Decile 1 (lowest) refers to the 10% of the population with the lowest income and decile 10 (upper) refers to the 10% of the population with the highest income

[4] Detailed income data was only available for Statistics South Africa 2008; 2012& 2017a

10), which consumed 51.3 percent of total consumption on *Housing, water, electricity, gas and other fuels* (StatsSA, 2017a) – refer to Table 1.

As shown in Table 2, when evaluating the composition of household consumption expenditure by low-income households (decile 1), it can be seen that over 60 percent of their total expenditure goes to *Food and non-alcoholic beverages* (31.1 percent) and *Housing, water, electricity, gas and other fuels* (29 percent). The third largest expenditure group for low -income households is, *Transport*, contributing 11.8 percent to total low-income household consumption expenditure (StatsSA, 2017a) (Refer to Table 2).

3 Literature review

Empirical studies on the determinants of electricity consumption worldwide – including developed and developing countries – have been well documented. The modelling approach, data used and methodology applied varies in the literature. This is influenced by the particularities of the country's electricity industry and the availability of data. Overall, time-series, cross sectional and panel data techniques have been applied in analysing demand for electricity (Madlener et al., 2011). This section reviews some key studies on the subject whilst highlighting the difference amongst these studies and the contribution that this paper attempts.

contains a selection and summary of the literature on electricity consumption most relevant to this study.

3.1 Modelling Electricity Demand

According to Narayan, Smyth and Prasad (2007:4488), based on household production theory – and unconstrained by data limitations – a model of residential demand for electricity should be represented as a function of *"...own price, price of a substitute source of energy, real income, price of household appliances and other factors that may influence household preferences such as temperature"*. The literature suggests that an ultimate model of residential electricity demand should explain electricity demand as a function of own price, price of a substitute of energy such as gas, real income, and other variables such as population and temperature that might explain household consumption of electricity/energy (Madlener et al., 2011; Narayan & Smyth, 2005; Narayan, Smyth & Prasad, 2007). However, due to data constraints some studies have explained residential electricity consumption as a function of one explanatory variable only: temperature by Al-Zayer and Al-Ibrahim (1996), real income by Dincer and Dost (1997). A common approach is to study electricity demand as a function of real income and price of electricity (Arisoy & Ozturk, 2014; Rai, Reedman & Graham, 2014; Campbell, 2018; Loi, & Ng, 2018; Doojav & Kalirajan, 2019). Other studies have included own price, price of a substitute and real income as the determinants for electricity consumption (Ramcharram, 1988; Al-Faris, 2002; Narayan and Smyth, 2005). There are studies such as Majumdar and

Parikh (1996) and Nasr et al. (2000) who did not include any price variables as part of the determinants for electricity demand. Majumdar and Parikh (1996) modelled the demand for energy in India as a function population growth and oil prices. Nasr et al. (2000) modelled electricity demand in Lebanon as a function of imports and temperature. Selected studies – such as Donatos and Mergos (1991) and Okajima and Okajima (2013) – have included prices variables as well as other related variables including temperature and income as determinants of electricity demand. Donatos and Mergos (1991) modelled residential demand for electricity in Greece as a function of price of electricity, price of LPG (as a substitute source of energy), population, temperature, sales of electrical appliances, price of diesels and the number of consumers. Kwakwa (2017), modelled electricity consumption in Egypt as a function of price, income, urbanisation, financial development, carbon emission, trade and education.

A recent study by Zhu et al. (2018), highlighted that the elasticity of demand for electricity in the residential sector has been widely studied in the literature. The authors highlighted that price, income and environmental factors have all been recognised as key determinants of electricity consumption in the residential sector. The authors also noticed that the most popular methods used in the literature to study residential electricity demand were Ordinary least squares (OLS), Error components model (ECM), Instrumental variables (IV) and Maximum likelihood (ML), with other methods – which the authors did not specify – being used less frequently,

3.2 South African studies

In South Africa – with the exception of Anderson (2004), Ziramba (2008; 2009) and Ye et at. (2018) which studied the determinants of electricity consumption in the residential sector – many studies have focused on studying electricity consumption at the aggregate level (Pouris, 1987; Inglesi, 2010; Inglesi-Lotz, 2011), and at sectoral level (Inglesi-Lotz & Blignaut, 2011; Blignaut et al., 2015), but not focusing on the residential sector.

3.2.1 Aggregate electricity/energy studies

In South Africa, some of the key studies that have focused on studying aggregate electricity demand include Pouris (1987), Amusa et al. (2009), Inglesi (2010) and Inglesi-Lotz (2011).

Pouris (1987), used an unconstrained distributed lag model to estimate the effects of price on the demand for electricity in South Africa over the period 1950-83 to estimate the long-run own-price of electricity demand and the long-run income elasticity. The author concluded that the long-run own-price elasticity of electricity in South Africa is -0.90 and the income elasticity in the long-run is0.71. Results indicate that prices could be consider as an effective policy instrument to promote reductions in electricity consumption in South Africa (Pouris, 1987).

Amusa et al. (2009) applied the ARDL cointegration methodology to study the factors influencing aggregate electricity consumption in South Africa for the period 1960-2007. The authors added real income and price of electricity as the determinant of electricity consumption. Results showed that in-line with the literature, in the long-run, income is the main determinant of electricity demand whilst prices were found to be insignificant. The long-run income elasticity was reported to be 1.673.

Using an Engle-Granger Error Correction model, Inglesi (2010) analysed the factors driving aggregate electricity demand in South Africa for the period 1980-2005. The author used real GDP, real electricity consumption, average electricity price, real disposable income and population as determinants of electricity consumption. Inglesi (2010) concluded that electricity demand in the long-run is driven by disposable income and the price of electricity. Whilst in the short-run it is driven by GDP and population. The long-run price elasticity of electricity is -0.56 and the long-run income elasticity is 0.42.

Most studies in the literature that evaluate the determinants of electricity demand assume that the price elasticity is constant over time. However, Inglesi-Lotz (2011) estimates a time varying price elasticity of electricity in South Africa for the period 1980-2005 by employing the Kalman filter econometric technique. Results showed that the demand for electricity was close to unit elastic during the 1980s and beginning of 1900s, from 1991/92 it decreased from -1.077 in 1986 to -0.0045 in 2005 – inelastic demand. Since the beginning of 1990s, the price has not played a significant role in the increase of electricity consumption – this can be explained by the low electricity prices in South Africa during the 1990s and early 2000s.

3.2.2 Sectoral studies

Studies such as Inglesi-Lotz & Blignaut (2011) and Blignaut, Inglesi-Lotz & Weideman (2015), estimated electricity consumption at a sectoral level for South Africa. Using panel data analysis, Inglesi-Lotz & Blignaut (2011) estimated the price elasticities of demand for electricity by sector (industrial, commercial, agricultural, transport and mining sectors) for the period 1993-2006 – the authors did not investigate the effects in the residential sector. Results show that the industrial sector was the only one with statistically significant price elasticity over the study period. Electricity consumption in the agriculture, transport and mining sectors is not affected by price or their production. The results suggest that the relation between electricity consumption and electricity prices differ from industry to industry.

Blignaut, Inglesi-Lotz & Weideman (2015) estimated electricity price elasticities for different industrial sectors in South Africa for the period 2002-2011 using panel data econometric techniques. One novelty of this study is that it included the period post-2008; a period were South Africa experienced electricity pricing reforms and electricity shortages, which significantly increased electricity prices in the country . However, the authors did not study the residential sector. From the period post-2007, the authors found statically significant and negative price elasticities for 9 of the 11 sectors considered. This indicates that the majority of industrial sectors in South Africa have become much more sensitive to changes in the price of electricity following 2007/2008. This results are an indication to policy makers that tariff restructuring might influence consumer behaviour significantly.

3.2.3 Residential

Anderson (2004), used a Heckman sample selection model to analyse the determinants of electricity demand on prepaid electricity users. The author used expenditure data and found the income and price elasticity of demand is estimated to be 0.32 and -1.35 respectively, indicating that the price of electricity is expected to have a significant impact on electricity consumption of prepaid users (Anderson, 2004).

Ziramba (2008) estimated the residential demand for electricity in South Africa for the period 1978-2005. The author used real GDP per capita and the price of electricity as the main explanatory variables following the bound testing approach to cointegration by Pesaran (2001) used in Narayan and Smyth (2005). The long-run income elasticity is 0.31 and the short run income elasticity is 0.30; indicating that income electricity consumption is a normal good – increases in income lead to increases in electricity. The long-run price elasticity is -0.04 and the short-run value is 0,02; however, price elasticities are statically insignificant in both the long and short-run. The results suggested that income is the main determinant of electricity demand while electricity price was found to be insignificant.

Ye et al. (2018) estimated the determinants of residential energy demand in South Africa by combining data from the South African Income and Expenditure Survey and the National Energy Regulator of South Africa (NERSA). The authors concluded that household income and electricity prices are key determinants of energy demand in the South African residential sector. As expected, the authors found that household demand is higher for appliance-rich households in urban areas, this is also influenced by the amount of people occupying the

In this study, the determinants of electricity demand at both the aggregate and at disaggregated income levels are estimated by applying the bounds testing approach to testing cointegration methodology as used by Narayan and Smyth (2005) and Ziramba (2008)[5]. This study contributes to the current South Africa literature by evaluating the period 1975-2016, which accounts for the electricity price re-structuring (increases in electricity prices) that happened in South Africa from 2008, that is believed to have affected consumer's behaviour towards electricity consumption and to our knowledge has not been studied. Additionally, this research adds a major contribution to the South African literature

[5] We acknowledge that the literature (including Okajima & Okajima (2013) and Zhu et al. (2018)), have identified other methodological approaches to estimating the determinants of electricity demand. However, we believe that the bounds testing approach to testing cointegration methodology is appropriate for the South African case and our specific study.

by determining whether South African households consider electricity and food as complementary or substitute goods, and whether this relationship differs amongst different income groups.

4 Methodology and Data

As presented in the background and literature review sections, the most common variables to use when estimating aggregate electricity demand include income, price of electricity, price of a substitute of energy and temperature variables. In this study, we estimate the determinants of residential electricity demand in South Africa at both the aggregate income level and at different income levels – low-, middle- and high- – as a function of gross national disposable income, electricity prices, food prices and a dummy variable accounting for the possible impact of the 2007/08 load-shedding wave and the 2008 electricity price restructuring that South Africa experienced[6]. All variables – except the dummy – are in their natural logarithms.

The estimated aggregate model takes the following form:

$$\begin{aligned} lnElec\_Cons_t = {} & \beta_0 lnFood\_Price_t + \beta_1 lnYd_t \\ & + \beta_2 lnElec\_Price\_Int_t + \varepsilon_t \end{aligned} \tag{1}$$

where $lnElec\_Cons$ is the natural log of total residential electricity consumption and it is measured in kWh. $lnFood\_Price$ is the natural log of food prices, measured as CPI food; lnYd is the natural log of gross national disposable income, measured in Rand millions; and $lnElec\_Price\_Int$ is an interactive variable that combines the natural log of the real residential electricity price, measured in c/kWh and the 2008 dummy variable that accounts for the possible structural break caused by load-shedding and electricity price re-structuring in South Africa from 2008.

In this study, β_0 is expected to define whether electricity consumption and food are substitute or complement goods. Therefore, if $\beta_0 > 0$ food and electricity are substitute goods and if $\beta_0 < 0$ they are complements goods[7]. According to economic theory, β_1 is expected to be positive, higher gross disposable income will lead to increases in residential electricity consumption through higher

[6] We tested the model by including prices of paraffin and gas as a substitute of energy but found the variables to be insignificant. Additionally, when evaluating the "South African household's basic basket of goods and services consumption expenditure" (as presented in section 2.2), we found that gas and paraffin did not contribute as much as electricity to the South African household budget. Therefore, these variables were not included in the empirical regression specification.

[7] This is based on the concept of cross-price elasticity of demand, which is defined as the percentage change in the quantity demanded in response to a given percentage change in the price of another good (Perloff, 2014). When the cross-price elasticity is negative, the goods are said to be complements – people buys less of one good when the price of the other good increases. Therefore, in this study:

Substitute goods $\rightarrow \beta_0 > 0$; ↑Food price; ↓Food demand; ↑Electricity consumption

Complement goods $\rightarrow \beta_0 < 0$; ↑Food price; ↓Food demand; ↓Electricity consumption economic activity which leads to higher purchases of electrical equipment. β_2 is expected to be negative, increases in residential electricity prices will lead to less electricity consumption in the residential sector.

The disaggregated model, which estimates residential electricity demand for different income groups – low, middle and high -separately, is estimated as follows:

$$lnElec\_Cons\_Low_t = \beta_0 lnFood\_Price_t + \beta_1 lnYd\_Low_t + \beta_2 lnElec\_Price\_Int_t + \varepsilon_t \quad (2)$$

$$lnElec\_Cons\_Middle_t = \beta_0 lnFood\_Price_t + \beta_1 lnYd\_Middle_t + \beta_2 lnElec\_Price\_Int_t + \varepsilon_t \quad (3)$$

$$lnElec\_Cons\_High_t = \beta_0 lnFood\_Price_t + \beta_1 lnYd\_High_t + \beta_2 lnElec\_Price\_Int_t + \varepsilon_t \quad (4)$$

The economic a priori expectations for the disaggregated models are the same as for the aggregated model. However, we are interested in unveiling whether the relationship between food and electricity – complements or substitute goods – is the same across all income levels.

The main difference between the three models is the amount of electricity consumed per income group and the gross disposable income per income group – food prices and electricity are equal for all income groups

4.1 Data description

The variables used in this study are residential electricity consumption, food prices, gross national disposable income, electricity prices and a 2008 dummy variable. The main data sources for this study are the South African National Energy Council, the South African Department of Energy, the South African Reserve Bank, Eskom, the International Energy Agency (IEA) and the World Bank. Annual observations for the period 1975-2016 are used.

Table 4 describes the data source and time series for all the variables used in this study. The sample period was constrained by availability of data regarding CPI food by the South African Reserve Bank that only reported CPI food form 1975.

4.1.1 Residential Electricity Consumption:

Data regarding residential electricity consumption for the period 1950-1989 was gathered from the South African Energy Statistics No 1 report for the period 1950-1989 (National Energy Council, 1990:27); and from the IEA (2019) for the period 1990-2015. The National Energy Council (1990:34), defined residential electricity consumption as total quantity of electricity consumed domestically, this was divided amongst sector, including households – the residential sector.

According to the IEA (2019) total electricity consumption is the sum of consumption by the different end-use sectors and it is divided into energy demand in the following sectors: industry, transport, buildings (including residential and services) and other (including agriculture and non-energy use). Residential electricity consumption includes 'consumption by households, excluding fuels used for transport. Includes households with employed persons' (IEA, 2019). Residential electricity consumption is measured in GWh.

For electricity consumption disaggregated by income groups, the shares of expenditure out of total expenditure in electricity data gathered in section 2 –

were used. The shares of expenditure per deciles were grouped into low-income (deciles 1-4), middle-income (deciles 5-8) and high-income (deciles 9-10). This resulted in the shares of electricity consumption per income group as presented in Table 5, where the shares represent residential electricity consumption by low-, middle- and high-income households as a percentage of total residential electricity consumption. For example, low-income households – on average – consume 14.77% of the total electricity consumed in the residential sector.

4.1.2 Residential Electricity Prices:

Data for residential electricity prices was gathered from the Department of Energy's (previously known as the Department of Minerals and Energy) various Energy Price Reports (2002-2017). In the reports, the residential electricity prices are captured under "*Domestic and Street Lighting*", and the prices recorded are only applicable to Eskom's direct sales (it does not reflect the prices charged by municipalities). Prices are measured in c/kWh (real prices 2016=100).

This study did not consider residential electricity prices determined by NERSA because the structure is quite comprehensive and given that this is not a study which uses household level data – hence the exact tariff charged for each household could not be matched – there is no detailed time series available that could be used. Additionally, NERSA defines different tariffs for domestic/residential customers, these tariffs are divided into domestic low and domestic high customers (NERSA, 2018). Thus, it was decided that using the residential electricity prices captured in the Energy Reports was more suitable for this study.

4.1.3 Disposable Income:

Aggregate data for gross national disposable income was gathered from the SARB for the period 1950-2016 (SARB, 2019). For the disaggregated models, income shares per income quantile were gathered from the World Development Indicators (WDI) (World Bank, 2017a). The WDI provides income shares for South African households over time. This shares – as shown in Table 6– represent the percentage share of income by quantiles, were low-income is defined by the bottom 20% of income earners, middle-income is includes the middle 60% of income earners and high-income includes the top 20% of income earners for South Africa since 1993 up to 2014. This shares were applied to the aggregated data for gross national disposable income to divide gross national disposable income per income group.

4.1.4 Food Prices:

Data for food prices – food CPI - was gathered from SARB for the period 1975-2016 (SARB, 2019).

4.1.5 Dummy 2008:

This dummy variable is set to account for the possible structural break caused by load-shedding and the electricity price re-structuring that happened in the country in 2008. This variable takes the value of 1 for the period 2008-2017 and 0 otherwise

4.1.6 Electricity Price Interactive variable ($lnElec\_Price\_Int$):

This is an interactive variable that combines the natural log of the real residential electricity price, measured in c/kWh and the 2008 dummy variable that accounts for the possible structural break caused by load-shedding and electricity price re-structuring in South Africa from 2008. This is the price variable used as one of the determinants of electricity demand in the South African residential sector.

4.2 Econometric methodology

To estimate the determinants of electricity consumption, the bounds testing autoregressive distributed lag (ARDL) model is preferred for the analysis of level relationships (Pesaran and Shin, 1999; Pesaran et al., 2001; Narayan and Smyth, 2005; Ziramba, 2008; Inglesi-Lotz and Gupta, 2013). Apart from detecting the existence of a long-run relationship among time series, this method can also estimate the size of this relationship. ARDL does not require prior knowledge of the order of integration of the time series variables, provided that the series are up to second order of integration. The aim is to estimate, for the period 1975-2016, residential electricity consumption in South Africa. This estimation will be done at an aggregated level – for all South African households – and at disaggregated level by estimating it per income levels which we have decided to group into low-income; medium-income and high income – as highlighted in the introduction and background sections, this will shed light in stressing the high inequality levels still persistent in the South African economy.

As depicted in Pesaran et al. (2001) and Narayan and Smyth (2005), the bounds testing approach requires two stages of modelling. Firstly, the long-run relationship amongst the variables in equations (1), (2), (3) and (4) is established. Secondly, once that it is determined that variables are cointegrated, the long-run and short-run coefficients of equations (1), (2), (3) and (4) are estimated[8].

In the first step of the ARDL analysis, the existence of cointegration is evaluated. For this, Δy_t is estimated as a conditional Error Correction Model (ECM) of the form:

$$\Delta y_t = \pi_{yy} y_{t-1} + \pi_{yx.x} x_{t-1} + \sum_{i=1}^{p} \vartheta_i \Delta y_{t-1} + \sum_{j=0}^{q} \phi_j^{'} \Delta \mathrm{x}_{t-j} + \theta w_t + \mu_t \tag{5}$$

where y_t is the dependent variable, x_t is a vector of regressors, π_{yy} and π_{yx} are long-run multipliers and w_t is a vector of exogenous components (Δ denotes the variable is in its differenced form.

In this study we estimate the ECM following Case I from Pesaran et al. (2001:295) where the model has no intercepts and no trends.

Given the ECM, and following Pesaran et al. (2001) and Narayan and Smyth (2005), to test for the absence of a conditional level relationship between y_t and x_t, the following null and alternative hypotheses are tested:

$$H_o : \pi_{yy} = 0, \pi_{yx.x} = 0^{'} \tag{6}$$

$$H_1 : \pi_{yy} \neq 0, \pi_{yx.x} \neq 0^{'} \tag{7}$$

where equation (6) describes H_o, the null hypothesis of no cointegration.

These hypotheses are examined using the standard F-statistics proposed by Pesaran et al. (2001), where regardless of the degree of integration of the variables, the asymptotic distribution of the obtained F-statistic is non-standard and where critical value bounds exist for all the classifications of the regressors into purely $I(1)$, purely $I(0)$ or mutually cointegrated. If the computed F-statistic falls outside the critical value bounds, a conclusive inference can be made regarding cointegration without needing to know the integration status of the regressors. If the F-statistic is higher than the upper bound of the critical values, the null hypothesis of no cointegration is rejected. If the F-statistic is smaller than the lower bound of the critical values, the null hypothesis of no cointegration cannot be rejected. If the F-static falls inside the bounds of the critical values, inference is inconclusive and knowledge of the order of integration of the variables is needed before conclusive inference can be made (Pesaran et al., 2001:290; Narayan & Smyth, 2005:469).

5 Empirical results

As described in section 4, in the first step of the ARDL analysis we tested for the presence of long-run relationships for equations 1-4. The calculated F-statistics for the aggregated income group model (equation 1) and for the disaggregated income models (equations 2-4) are reported in Table 8 under ARDL F-stat.

[8] All the mathematical derivations of the long and short run parameters can be found in detail in Pesaran et al. (2001) as well as in E-Views (2020:283-300).

For each model, the ARDL F-statistic is higher than the upper bound critical value; therefore, the null hypothesis of no cointegration is rejected and it can be concluded that there is a long-run cointegration relationship amongst the variables in each model[9].

Since it was established that there is a long-run cointegration relationship amongst the variables in each model, model (1) was estimated using the following ARDL (m, n, p, q) specification (where m=1, n=1, p=0, q=1):

$$lnElec\_Cons_t = \sum_{i=1}^{m} \alpha_0 lnElec\_Cons_{t-i} + \sum_{i=1}^{n} \alpha_1 lnFood\_Price_{t-i} + \sum_{i=0}^{p} \alpha_2 lnYd_{t-i} + \sum_{i=1}^{q} \alpha_3 lnElec\_Price\_Int_{t-i} + \varepsilon_t \tag{8}$$

model (2) – low-income households – was estimated using the following ARDL (m, n, p, q) specification (where m=1, n=1, p=0, q=0):

$$lnElec\_Cons\_Low_t = \sum_{i=1}^{m} \alpha_0 lnElec\_Cons\_Low_{t-i} + \sum_{i=1}^{n} \alpha_1 lnFood\_Price_{t-i} + \sum_{i=0}^{p} \alpha_2 lnYd\_Low_{t-i} + \sum_{i=0}^{q} \alpha_3 lnElec\_Price\_Int_{t-i} + \varepsilon_t \tag{9}$$

model (3) – middle-income households – was estimated using the following ARDL (m, n, p, q) specification (where m=1, n=1, p=1, q=0):

$$lnElec\_Cons\_Middle_t = \sum_{i=1}^{m} \alpha_0 lnElec\_Cons\_Middle_{t-i} + \sum_{i=1}^{n} \alpha_1 lnFood\_Price_{t-i} + \sum_{i=1}^{p} \alpha_2 lnYd\_Middle_{t-i} + \sum_{i=0}^{q} \alpha_3 lnElec\_Price\_Int_{t-i} + \varepsilon_t \tag{10}$$

model (4) – high-income households – was estimated using the following ARDL (m, n, p, q) specification (where m=1, n=1, p=1, q=0):

$$lnElec\_Cons\_High_t = \sum_{i=1}^{m} \alpha_0 lnElec\_Cons\_High_{t-i} + \sum_{i=1}^{n} \alpha_1 lnFood\_Price_{t-i} + \sum_{i=1}^{p} \alpha_2 lnYd\_High_{t-i} + \sum_{i=0}^{q} \alpha_3 lnElec\_Price\_Int_{t-i} + \varepsilon_t \tag{11}$$

The empirical results for each of the models which were obtained through normalizing on the log of residential electricity consumption ($lnElec\_Cons$), in the long run are presented in Table 8 for the aggregate income model and the three models of disaggregated income.

[9] The critical value bounds are from Table CI(i) in Pesaran et al. (2001:300)

5.1 Food price – cross-price elasticity of demand

The cross-price elasticity of demand yielded interesting results. For all models, in the long-run, the food price coefficient is positive and significant. This indicates, that for all South Africans – at an aggregated and disaggregated income levels – food and electricity are considered substitute goods (as food prices increase, demand for food decreases and demand for electricity increases). However, as expected, the magnitude of this relationship is marginally different for each income group. In the aggregate model, the cross-price elasticity of demand is 0.142; while for low-income households the cross-price elasticity of demand is 0.122 and for middle income households it is 0.149 and for high income households it is 0.144.

5.2 Own price elasticity of demand

In the long-run, the price elasticity of demand is negative and significant for all the models. This is a novelty of this study, which is the first South African study – to our knowledge – that finds that electricity prices do affect electricity consumption in the residential sector. The main motivation for these results lies behind the fact that this study includes the effects of the electricity price re-structuring that occurred in South Africa in 2008, where prices increased significantly after the 2007/2008 electricity crisis.

In the aggregated model, the price elasticity of demand is -0.072. For low-income households the price elasticity of demand is -0.058. For middle income households it is -0.067 and for high income households it is -0.077. As expected, low-income households are more sensitive to changes in electricity prices than high- and middle-income households. These results are in line with the global literature as presented in Narayana & Smyth (2005), Narayan et al. (2007), Dergiades and Tsoulfidis (2008), Nakajima (2010), Okajima & Okajima, (2013), Kwakwa (2017), Doojav & Kalirajan, (2018) and Zhu et al. (2018), where the long-run demand elasticities of electricity consumption in the residential sector range between -0.02 and -0.54 with regard to own price.

These results suggest, that future price policies have the potential of having effects on residential electricity consumption in South Africa, albeit homogeneous changes in prices will yield different results to electricity demand by various income groups.

5.3 Income elasticity of demand

For all models, as expected, the income elasticity of demand has a positive sign and is statistically significant in the long-run. For the aggregate model, the income elasticity of demand is 0.679 indicating that residential electricity consumption is a normal good.

For low-income households the income elasticity of demand is 0.738. For middle income households it is 0.665 and for high income households it is 0.651. These results indicate that low-income households are more sensitive to changes in income – as disposable income increases for low-income households; they will consume more electricity than high-income households would if they had the same increase in disposable income. These results are in line with the literature (Narayana & Smyth, 2005; Narayan et al., 2007; Dergiades and Tsoulfidis, 2008; Nakajima, 2010; Okajima & Okajima ;2013, Kwakwa, 2017; Doojav & Kalirajan, 2018 & and Zhu et al., 2018), where the long-run demand elasticities of electricity consumption in the residential sector range between 0.13 and 0.71 with regard to income.

6 Discussion and Conclusion

This study examined, for the period 1975-2016, the residential demand for electricity in South Africa as a function of gross national disposable income, residential electricity prices, food prices and a dummy variable accounting for the structural break caused by load-shedding and the electricity price re-structuring in the country in 2008. Given the income inequality levels in South Africa, this relationship was investigated for all South African households in aggregate as well as for low-, middle- and high-income households separately.

The key contributions of this study are three-fold. Firstly, this study moves away from studying the determinants of residential electricity demand at an aggregate income level only and focuses on separating households into low-, middle- and high- income brackets. Secondly, this study collected time-series data on the different income brackets in South Africa and provided a comprehensive background. Finally, drawing on the food-energy nexus in the literature and the South African income inequality and socioeconomic disparity context, this study included food prices as an extra determinant of residential electricity demand – this resulted in the estimation of the food cross-price elasticity of demand.

This study collected detailed data on income, price and residential electricity consumption in one data set. The methodology used to estimate the determinants of residential electricity demand was the autoregressive distributed lag (ARDL) model. The empirical results indicate long-run cointegration between residential electricity consumption, gross national disposable income, electricity prices and food prices. Disposable income elasticities, have a positive sign for the aggregate and all income groups; indicating that as income increases, South African households consume more electricity. Therefore, electricity can be considered a normal good. As expected, price elasticities are negative and significant, indicating that electricity prices do influence electricity demand for South African households post-2008 – this is the first South African study that has found negative and significant residential price elasticities.

Additionally, this study, determined whether South African households consider electricity and food as complementary or substitute goods, and whether this relationship was different amongst different income groups. At both the aggregate and disaggregate income levels, the results showed that food and electricity are substitute goods for all South African households.

The main conclusion and most influential point that can be taken from this study is that given the income inequalities of South African households, policies – especially those aimed at reducing electricity consumption in the residential sector – should target each income group differently. For example, the FBE policy was designed to increase access to electricity as well as to make electricity more affordable for low-income households. The results and background presented in this study shed-light into how low-income South African households' spend a large proportion of their income on electricity. This might indicate that there is room for re-evaluating and adapting the FBE policy, maybe providing more than 50 kWh of free electricity per month to low-income households, that way they will have more money to spend in key items such as food. Also, by having access to more electricity, low-income households will reduce their use of other sources of energy such as wood and paraffin, that as presented in Bohlmann & Inglesi-Lotz (2018) can be detrimental to their health and also causes loss of time that could be dedicated to being economically productive.

From a policy perspective, the results obtained with regards to the price elasticity of demand for South African households are key. The results showed that electricity prices do influence electricity demand for South African households post-2008 – coefficients were negative and significant for all the models. This indicates that there is room to have price-oriented policies that are specifically designed to reduce electricity consumption – this is in line with the policy implications highlighted by Zhu et al (2018), where the authors identified the feasibility of using prices in the long-run as a mechanism for adjusting household electricity consumption. This could have the added benefit of aiding in reducing GHG emissions in South Africa – via a reduction in overall electricity consumption.

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Table 1 Average share of annual household consumption expenditure by main expenditure group and income deciles

	Income deciles										Average	Total share per main expenditure group
	Lower	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Upper**		
Average household size	2.8	3.3	3.8	4.4	4.7	4.9	4.6	4.4	3.8	3.6	4.03	
Main expenditure group	**Share of total expenditure group**											
Food and non-alcoholic beverages	2.5	4.4	5.9	7.4	8.7	10.2	11.9	13.1	14.7	21.2	12.9	100
Alcoholic beverages and tobacco	2.6	3.8	5.2	6.6	8.1	9.4	11.2	13.9	18.3	20.9	0.9	100
Clothing and footwear	1.7	3.1	4.4	5.8	7.4	9.4	11.7	14.3	17.5	24.7	4.8	100
Housing, water, electricity, gas and other fuels	0.9	1.4	1.8	2.3	3.0	4.0	6.0	10.5	18.8	51.3	32.6	100
Furnishings, household equipment and routine maintenance of the dwelling	0.6	1.3	1.9	2.4	3.2	4.5	6.3	8.5	16.8	54.4	5.2	100
Health	1.0	1.6	2.3	2.8	3.6	4.5	7.7	9.0	16.9	50.7	0.9	100
Transport	0.7	1.2	1.6	2.1	2.7	3.8	5.6	9.0	16.7	56.6	16.3	100
Communication	1.5	2.5	3.2	4.1	5.1	6.6	8.4	11.7	19.1	37.7	3.4	100
Recreation and culture	0.4	0.8	1.4	1.9	2.8	4.4	7.7	11.5	20.5	48.7	3.8	100
Education	0.1	0.3	0.5	0.8	1.6	3.0	4.7	11.5	22.4	55.1	2.5	100
Restaurants and hotels	0.8	1.6	2.5	3.3	4.5	5.2	7.0	10.3	16.3	48.5	2.1	100
Miscellaneous goods and services	0.4	0.8	1.2	1.6	2.4	3.5	5.3	9.3	20.0	55.3	14.7	100
Other unclassified expenses	0.2	0.7	0.7	2.2	2.9	2.4	8.1	11.7	18.9	52.2	0.1	100

Source: Adapted from Statistics South Africa (2017a)

Table 2 Average share of annual household consumption expenditure by main expenditure group per income deciles

	Income deciles										Average
	Lower	2	3	4	5	6	7	8	9	Upper	
Average household size	2.8	3.3	3.8	4.4	4.7	4.9	4.6	4.4	3.8	3.6	4.03
Main expenditure group	**Share of total expenditure**										
Food and non-alcoholic beverages	31.1	32.4	31.9	31.1	28.5	25.5	21.6	15.9	10.5	5.8	12.9
Alcoholic beverages and tobacco	2.2	1.9	1.9	1.9	1.8	1.6	1.4	1.2	0.9	0.4	0.9
Clothing and footwear	8.0	8.5	8.7	9.0	9.0	8.8	7.9	6.4	4.6	2.5	4.8
Housing, water, electricity, gas and other	29.0	26.2	24.7	24.2	24.8	25.3	27.5	32.2	33.9	35.6	32.6
Furnishings, household equipment and routine maintenance of the dwelling	3.0	3.8	4.1	4.1	4.2	4.6	4.6	4.2	4.9	6.0	5.2
Health	0.8	0.8	0.9	0.8	0.8	0.8	1.0	0.8	0.8	1.0	0.9
Transport	11.8	10.7	10.7	11.3	11.1	12.0	12.9	13.8	15.1	19.6	16.3
Communication	5.0	4.8	4.6	4.5	4.4	4.4	4.0	3.8	3.6	2.7	3.4
Recreation and culture	1.4	1.7	2.2	2.3	2.7	3.3	4.1	4.1	4.3	3.9	3.8
Education	0.3	0.4	0.5	0.7	1.0	1.4	1.6	2.7	3.0	2.9	2.5
Restaurants and hotels	1.6	2.0	2.2	2.2	2.4	2.1	2.1	2.1	1.9	2.2	2.1
Miscellaneous goods and services	5.7	6.8	7.6	7.8	9.1	10.0	11.1	12.9	16.3	17.3	14.7
Other unclassified expenses	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Total	100	100	100	100	100	100	100	100	100	100	100

Source: Adapted from Statistics South Africa (2017a)

Table 3 Selected empirical results on electricity consumption analysis

Source	Study Period	Methodology	Country	Price Elasticity	Income Elasticity
Pouris (1987)	Time-series 1950-1983	Unconstrained distributed lag model	South Africa	LR: -0.90	LR: 0.71
Anderson (2004)	Household-level 2000	Heckman Selection Model	South Africa	-1.35	0.32
Narayan & Smyth (2005)	Time-series 1969-2000	ARDL bounds testing approach	Australia	Model 1: LR: -0.5409, SR: -0.2631; Model 2: LR: -0.4744, SR: -0.2705	Model 1: LR: 0.3226, SR: 0.0121; Model 2: LR: 0.4079, SR: 0.0415
Narayan, Smyth & Prasad (2007)	Panel 1978-2003	Panel Cointegration, OLS & DOLS	G7 countries	Model 1: LR: -1.4502, SR: -0.1068; Model 2: LR: -6.8666, SR: -0.0001	Model 1: LR: 0.3119, SR: -0.1917; Model 2: LR: 0.3495, SR: 0.0096
Ziramba (2008)	Time-series 1978-2005	ARDL bounds testing approach	South Africa	LR: -0.04; SR: -0.02	LR: 0.31; SR: 0.30
Inglesi (2010)	Time-series 1980-2005	Engle-Granger Error Correction Model	South Africa	LR: -0.56	LR: 0.42
Inglesi-Lotz (2011)	Time-series 1980-2005	Kalman filter	South Africa	-1.077 to -0.045	0 to 1
Ye et al. (2018)	Household-level 2010/2011	2 part econometric model (probit/OLS)	South Africa	-0.305	0.128

LR: Long-Run; SR: Short-Run

Source: Authors' Own Compilation

Table 4 Variables used in the ARDL model[1]

Description of variable	Acronym of variable	Units of measurement	Source	Time Series
Sectoral Consumption Electricity - Households	Elec_Cons	GWh	National Energy Council (1990)	1950-1989
Total Residential Electricity Consumption	Elec_Cons	GWh	International Energy Agency (IEA)	1990-2015
Food Price	Food_Price	CPI	South African Reserve Bank (SARB)	1975-2016
Gross National Disposable Income	Yd	Rand Millions	South African Reserve Bank (SARB)	1950-2016
Residential Electricity Prices	Elec_Price	c/kWh	Department of Energy (DoE) Energy Price Reports 2002-2016	1970-2016

Source: Authors' Own Compilation

[1] The final selected sample in the model was 1975-2016

Table 5 Electricity consumption shares

	Electricity Shares
Low-income	14.77
Middle-Income	35.77
High-Income	49.46
Total	100

Source: Adapted from Statistics South Africa (2008a; 2011: 2012: 2017a)

Table 6 Income Shares

Series Name	1993	1996	2000	2005	2008	2010	2014
Low-Income (bottom 20%)	2.9	2.7	3.1	2.6	2.6	2.5	2.4
Middle-Income (middle 60%)	32.8	31.4	34.3	26.4	28.8	28.6	29.5
High-Income (top 20%)	64.3	65.9	62.7	71	68.7	68.9	68.2
Total	100	100	100	100	100	100	100

Source: Adapted from World Bank (2017a)

Table 7 Summary of descriptive statistics in natural logs

	LELEC_CONS	LELEC_CONS_HIGH	LELEC_CONS_LOW	LELEC_CONS_MIDDLE	LYD	LYD_HIGH	LYD_LOW	LYD_MIDDLE	LELEC_PRICE	LFOOD_PRICE
Mean	10.08137	9.377360	8.168794	9.053306	14.55840	14.13599	10.98185	13.40387	4.432043	2.731958
Std. Dev.	0.439272	0.439272	0.439272	0.439272	0.422022	0.448598	0.375934	0.373037	0.201168	1.283270
Skewness	-0.350399	-0.350399	-0.350399	-0.350399	0.301791	0.374365	0.126829	0.179586	-0.239117	-0.428805
Kurtosis	1.777320	1.777320	1.777320	1.777320	1.807473	1.825555	1.659855	1.820799	2.235420	1.894997
Jarque-Bera	3.392861	3.392861	3.392861	3.392861	3.051822	3.314028	3.178067	2.595846	1.389371	3.342397
Probability	0.183337	0.183337	0.183337	0.183337	0.217423	0.190708	0.204123	0.273098	0.499231	0.188022

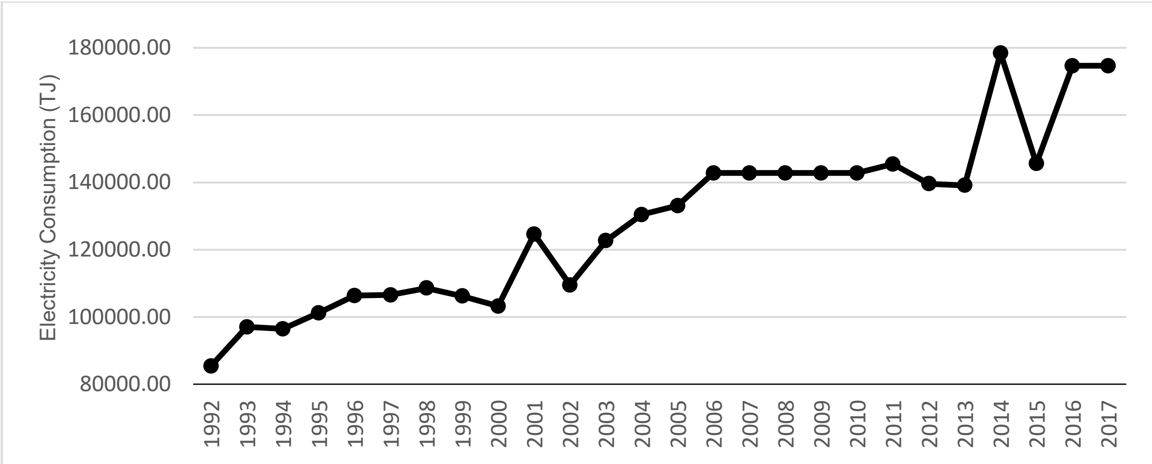
Source: Authors' Own Calculations

Table 8 Empirical Results

Dependent variable: LELEC_CONS_LOW			Dependent variable: LELEC_CONS_MIDDLE			Dependent variable: LELEC_CONS_HIGH			Dependent variable: LELEC_CONS		
Low-Income			**Middle-Income**			**High-Income**			**Aggregate Quantile**		
Period	1950-2017		Period	1950-2017		Period	1950-2017		Period	1950-2017	
Indepent Variables	**Coefficient**	**p-value**	**Indepent Variables**	**Coefficient**	**p-value**	**Indepent Variables**	**Coefficient**	**p-value**	**Indepent Variables**	**Coefficient**	**p-value**
Lfood_price	0.122	0.0055	Lfood_price	0.1486	0.0002	Lfood_price	0.1438	0.0000	Lfood_price	0.1421	0.0000
Lelec_price_int	-0.0579	0.0143	Lelec_price_int	-0.0663	0.0025	Lelec_price_int	-0.0765	0.0001	Lelec_price_int	-0.0716	0.0001
Lyd_Low	0.7375	0.0000	Lyd_Middle	0.6646	0.0000	Lyd_High	0.6508	0.0000	Lyd	0.6799	0.0000
ARDL F-stat	6.5314		**ARDL F-stat**	6.9336		**ARDL F-stat**	7.2748		**ARDL F-stat**	7.6507	
Upper bound CV (1%)	4.84		Upper bound CV (1%)	4.84		Upper bound CV (1%)	4.84		Upper bound CV (1%	4.84	
Lower bound CV (1%)	3.42		Lower bound CV (1%)	3.42		Lower bound CV (1%)	3.42		Lower bound CV (1%	3.42	
Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclus	cointegration	
Upper bound CV (5%)	3.63		Upper bound CV (5%)	3.63		Upper bound CV (5%)	3.63		Upper bound CV (5%	3.63	
Lower bound CV (5%)	2.45		Lower bound CV (5%)	2.45		Lower bound CV (5%)	2.45		Lower bound CV (5%	2.45	
Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclus	cointegration	
Upper bound CV (10%)	3.1		Upper bound CV (10%)	3.1		Upper bound CV (10%)	3.1		Upper bound CV (10	3.1	
Lower bound CV (10%)	2.01		Lower bound CV (10%)	2.01		Lower bound CV (10%)	2.01		Lower bound CV (10	2.01	
Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclus	cointegration	
Food - electricity relationship	substitutes		Food - electricity relationship	substitutes		Food - electricity relationship	substitutes		Food - electricity relationship	substitutes	
Statistical significance of Lfood_price	statistically significant		Statistical significance of Lfood_price	statistically significant		Statistical significance of Lfood_price	statistically significant		Statistical significance of Lfood_price	statistically significant	
Statistical significance of Lelec_price_int	statistically significant		Statistical significance of Lelec_price_int	statistically significant		Statistical significance of Lelec_price_int	statistically significant		Statistical significance of Lelec_price_int	statistically significant	
Statistical significance of Lyd_Low	statistically significant		Statistical significance of Lyd_Middle	statistically significant		Statistical significance of Lyd_High	statistically significant		Statistical significance of Lyd	statistically significant	

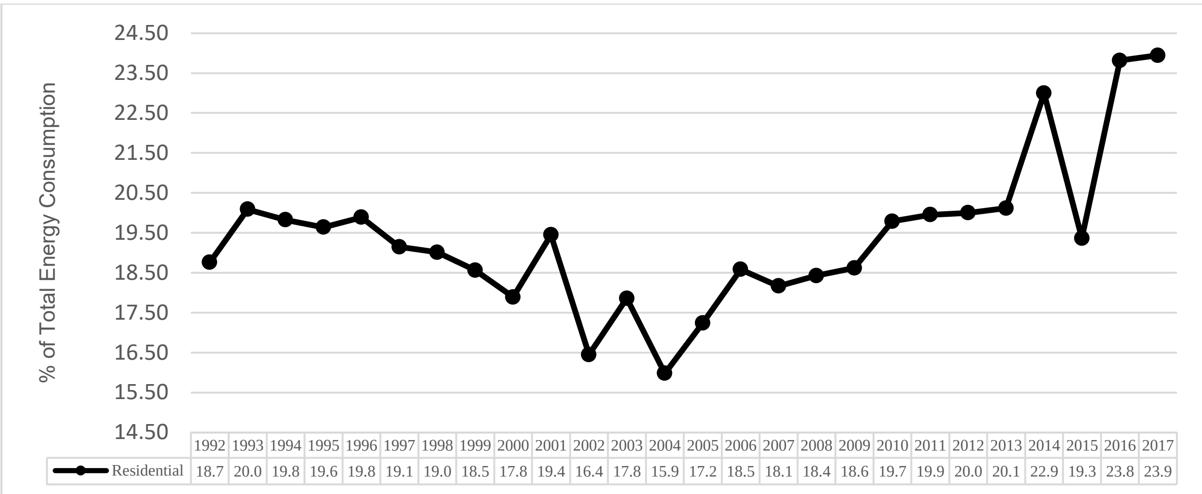
Source: Authors' Own Calculation

Figure 1 Electricity consumption in the South African Residential Sector[2]



Source: Adapted from DoE (2019)

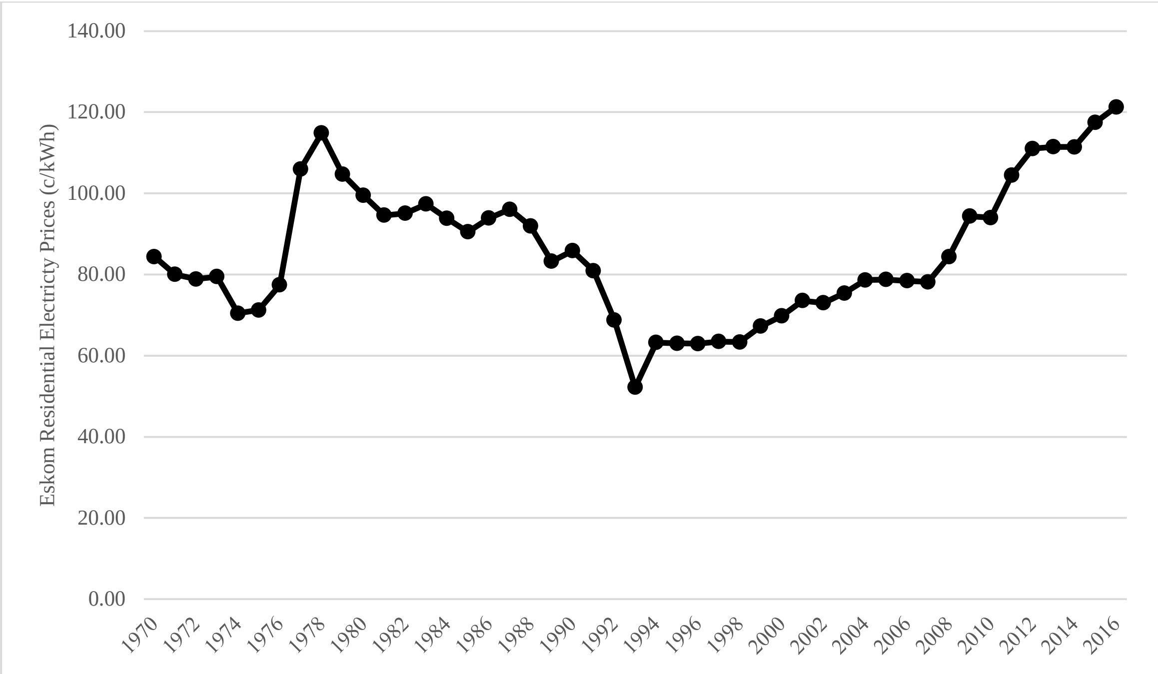
Figure 2 Residential Sector Share of Total Electricity Consumption



Source: Adapted from DoE (2019)

2 TJ stands for Terajoule

Figure 3 Eskom Residential Electricity Prices (c/kWh) 1970-2016



Source: Adapted from the Department of Energy's Energy Price Reports 1970-2016 (Constant 2016=100)

Appendix

Table A. 1 Income per household per Decile

Income per household per decile

	001: R0-R7238 p.a. Decile 1	002: R7239-R11379 p.a. Decile 2	003: R11380-R15257 p.a. Decile 3	004: R15258-R20199 p.a. Decile 4	Low Income Deciles 1-4	005: R20200-R26287 p.a. Decile 5	006: R26288-R36047 p.a. Decile 6	007: R36048-R53343 p.a. Decile 7	008: R53344-R90575 p.a. Decile 8	Middle Income Deciles 5-8	009: R90576-R180511 p.a. Decile 9	010: R180512 - R451264+ p.a. Decile 10	High Income Deciles 9-10	Total
IES 2005-2006	5 294 151 149.95	11 760 725 683.76	16 325 314 603.20	21 619 197 443.03	54 999 388 879.95	28 171 062 000.19	37 428 432 423.38	53 449 604 722.34	85 298 317 109.94	204 347 416 255.84	158 208 622 481.56	498 231 810 208.31	656 440 432 689.87	915 787 237 825.66
IES 2010-2011	6 043 696 744.56	17 074 703 809.16	25 837 031 912.13	35 900 418 028.38	84 855 850 494.22	48 760 705 137.03	67 289 320 060.38	98 651 798 479.25	159 480 244 880.13	374 182 068 556.78	291 897 958 816.75	769 652 416 679.25	1 061 550 375 496.00	1 520 588 294 547.00
LCS 2014-2015	10 433 070 994.98	27 009 921 547.93	41 158 183 021.40	58 310 680 320.24	136 911 855 884.55	77 824 123 298.49	107 928 009 284.13	155 796 424 161.75	242 399 395 258.95	583 947 952 003.32	427 506 903 080.12	1 147 809 107 335.60	1 575 316 010 415.72	2 296 175 818 303.59
Average	7 256 972 963.16	18 615 117 013.62	27 773 509 845.58	38 610 098 597.21	92 255 698 419.57	51 585 296 811.90	70 881 920 589.29	102 632 609 121.11	162 392 652 416.34	387 492 478 938.65	292 537 828 126.14	805 231 111 407.72	1 097 768 939 533.86	1 577 517 116 892.08

Share of income per household per decile

	001: R0-R7238 p.a. Decile 1	002: R7239-R11379 p.a. Decile 2	003: R11380-R15257 p.a. Decile 3	004: R15258-R20199 p.a. Decile 4	Low Income Deciles 1-4	005: R20200-R26287 p.a. Decile 5	006: R26288-R36047 p.a. Decile 6	007: R36048-R53343 p.a. Decile 7	008: R53344-R90575 p.a. Decile 8	Middle Income Deciles 5-8	009: R90576-R180511 p.a. Decile 9	010: R180512 - R451264+ p.a. Decile 10	High Income Deciles 9-10	Total
IES 2005-2006	0.58	1.28	1.78	2.36	6.01	3.08	4.09	5.84	9.31	22.31	17.28	54.40	71.68	100
IES 2010-2011	0.40	1.12	1.70	2.36	5.58	3.21	4.43	6.49	10.49	24.61	19.20	50.62	69.81	100
LCS 2014-2015	0.45	1.18	1.79	2.54	5.96	3.39	4.70	6.79	10.56	25.43	18.62	49.99	68.61	100
Average	0.48	1.19	1.76	2.42	5.85	3.22	4.40	6.37	10.12	24.12	18.36	51.67	70.03	100

Source: Adapted from Quantec (2020)

Table A. 2 Distribution of household consumption expenditure by main expenditure group

Main expenditure group and income	IES 2005/2006			LCS 2008/2009			IES 2010/2011			LCS 2014/2015		
	Rand		Percentage	Rand		Percentage	Rand		Percentage	Rand		Percentage
	Millions	Average	Contribution	Millions	Average	Contribution	Millions	Average	Contribution	Millions	Average	Contribution
Food and non-alcoholic beverages	100 950	8 104	14.4	175318	13914	19.4	159973	12200	12.8	220894	13292	12.9
Alcoholic beverages and tobacco	8 061	647	1.2	8812	699	1.0	13697	1045	1.1	15133	911	0.9
Clothing and footwear	34 628	2 780	5.0	43767	3474	4.8	56169	4284	4.5	82073	4939	4.8
Housing, water, electricity, gas and other fuels	164 876	13 235	23.6	225806	17921	24.9	399753	30486	32.0	558787	33625	32.6
Furnishing, household equipment and rotuine maintenance of the dwelling	48 152	3 865	6.9	48632	3860	5.4	63943	4877	5.1	89596	5391	5.2
Health	11 609	932	1.7	11974	950	1.3	17794	1357	1.4	15532	935	0.9
Transport	139 121	11 168	19.9	138309	10977	15.3	213968	16318	17.1	279614	16826	16.3
Communication	24 518	1 968	3.5	30594	2428	3.4	35430	2702	2.8	58320	3509	3.4
Recreation and culture	32 132	2 579	4.6	38666	3069	4.3	38019	2899	3.0	65358	3933	3.8
Education	16 884	1 355	2.4	25226	2002	2.8	33354	2544	2.7	42069	2532	2.5
Restaurants and hotels	15 346	1 232	2.2	21381	1697	2.4	30329	2313	2.4	36236	2181	2.1
Miscellaneous goods and services	100 592	8 075	14.4	134993	10714	14.9	183604	14002	14.7	252039	15166	14.7
Other unclassified expenses	2 143	172	0.3	2529	201	0.3	1758	134	0.1	907	55	0.1
Total consumption expenditure	699 014	56 112	100	906 007	71 905	100	1 247 792	95 160	100	1 716 558	103 293	100
Number of households	12 457 580			12 600 000			13 112 541			16 618 342		

Source: Adapted from Statistics South Africa (2008a; 2011: 2012: 2017a)

South African Households expenditure on Electricity and Food

Table A. 3 is derived from average household expenditure at the third level (StatsSA, 2017a:11-118). It shows two key facts. Firstly, low-income (decile 1) households contribute 1.58 percent to total consumption expenditure in *Electricity* by South African households – high-income (decile 10) households contribute to over 30 percent. Secondly, for low-income (decile 1) households, *Electricity* contributes to 2.45 percent of total low-income household consumption expenditure; for high-income households *Electricity* contributes to only 1.20 percent of their total consumption expenditure. It is important to highlight, that South African low-income households are energy poor - they spend more than 10 percent of their total income on energy.

Food shares out of total consumption expenditure usually decrease as income rises but, as expected, food shares tend to increase with household sizes (StatsSA, 2017b). This applies to the South African case, where for low-income (decile 1) households, *Food* represents the largest share of their total expenditure share (29.13 percent) as compared to high-income households (decile 10) (5.09 percent) (StatsSA, 2017b). However, out of total expenditure on food, low-income households consume 2.84 percent of the total expenditure on *Food* in South Africa, compared to high-income households who spend 20.63 (StatsSA, 2017b) – refer to

Table A. 4.

If we look at household's detailed expenditure on *Food*, it can be seen the largest portion of food expenditure for poor households is on *bread and cereals* (11.4 percent), with the *meat and fish* subgroup representing the second largest share (5.6 percent). For middle and high-income households, the largest portion of food expenditure goes into the *meat and fish* category, whilst *bread and cereals* representing the second largest subgroup (StatsSA, 2017a:1)

Table A. 3 South African household's expenditure patterns on electricity

	Expenditure deciles										Average	Total
	Lower	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Upper**		
Third expenditure group	**Rand per household per year**											
IES 2005-2006	162	267	378	471	587	778	974	1 367	2 158	3 098	**1 024**	10 240
LCS 2008-2009	382	615	727	851	997	1 234	1 526	2 067	2 808	5 073	**1 628**	16 280
IES 2010-2011	424	689	869	983	1 206	1 560	2 026	2 905	4 221	7 334	**2 222**	22 217
LCS 2014-2015	1 023	1 371	1 714	2 005	2 320	2 685	3 287	4 481	6 236	9 902	**3 502**	35 024
Average	498	736	922	1 078	1 278	1 564	1 953	2 705	3 856	6 352		

Household share out of total expenditure group

	Expenditure deciles										Average	Total
	Lower	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Upper**		
Third expenditure group	**Share of expenditure out of total expenditure in electricity**											
IES 2005-2006	1.58	2.61	3.69	4.60	5.73	7.60	9.51	13.35	21.07	30.25	**1.82**	100
LCS 2008-2009	2.35	3.78	4.47	5.23	6.12	7.58	9.37	12.70	17.25	31.16	**2.26**	100
IES 2010-2011	1.91	3.10	3.91	4.42	5.43	7.02	9.12	13.08	19.00	33.01	**2.33**	100
LCS 2014-2015	2.92	3.91	4.89	5.72	6.62	7.67	9.38	12.79	17.80	28.27	**3.40**	100
Average	2.19	3.35	4.24	4.99	5.98	7.47	9.35	12.98	18.78	30.67		

Percentage distribution of annual household consumption expenditure by third expenditure group and income deciles

	Income deciles										Average
	Lower	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Upper**	
Average household size	2.8	3.3	3.8	4.4	4.7	4.9	4.6	4.4	3.8	3.6	4.03
Third expenditure group	**Share of expenditure in electricity out of total income**										
IES 2005-2006	2.45	2.54	2.80	2.49	2.86	2.38	2.46	2.40	1.95	1.20	**1.82**
LCS 2008-2009	4.38	4.35	3.88	3.60	3.31	3.07	2.68	2.60	1.98	1.66	**2.26**
IES 2010-2011	4.48	4.17	3.89	3.41	3.26	3.22	3.05	2.85	2.41	1.65	**2.33**
LCS 2014-2015	9.62	7.52	6.94	6.31	6.11	5.07	4.50	4.09	3.35	2.04	**3.40**
Average	5.23	4.64	4.37	3.95	3.88	3.44	3.17	2.99	2.42	1.64	

Source: Adapted from Statistics South Africa (2008a; 2011: 2012: 2017a)

Table A. 4 South African household's expenditure patterns on food

	Expenditure deciles										Average	Total
	Lower	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Upper**		
Secondary expenditure group	**Rand per household per year**											
IES 2005-2006	1 936	3 233	4 146	4 970	5 820	6 701	7 745	9 119	10 450	14 069	**6 819**	68 189
LCS 2008-2009	3 678	6 021	7 792	9 323	11 073	12 712	14 705	16 423	19 129	28 270	**12 913**	129 126
IES 2010-2011	3 094	5 440	7 037	8 608	9 947	11 479	12 840	13 869	15 526	19 815	**10 766**	107 655
LCS 2014-2015	3 097	5 528	7 373	9 173	10 771	12 553	14 465	15 827	17 535	24 675	**12 100**	120 997
Average	2 951	5 056	6 587	8 019	9 403	10 861	12 439	13 810	15 660	21 707		

Household share out of total expenditure group

	Expenditure deciles										Average	Total
	Lower	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Upper**		
Secondary expenditure group	**Share of expenditure out of total expenditure in food**											
IES 2005-2006	2.84	4.74	6.08	7.29	8.54	9.83	11.36	13.37	15.33	20.63	**12.16**	100
LCS 2008-2009	2.85	4.66	6.03	7.22	8.58	9.84	11.39	12.72	14.81	21.89	**17.96**	100
IES 2010-2011	2.87	5.05	6.54	8.00	9.24	10.66	11.93	12.88	14.42	18.41	**11.31**	100
LCS 2014-2015	2.56	4.57	6.09	7.58	8.90	10.37	11.95	13.08	14.49	20.39	**11.71**	100
Average	2.78	4.76	6.19	7.52	8.81	10.18	11.66	13.01	14.76	20.33		

Percentage distribution of annual household consumption expenditure by secondary expenditure group and income deciles

	Income deciles										Average
	Lower	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Upper**	
Average household size	2.8	3.3	3.8	4.4	4.7	4.9	4.6	4.4	3.8	3.6	4.03
Secondary expenditure group	**Share of expenditure out of total income**										
IES 2005-2006	30.21	30.56	28.24	27.03	26.09	23.03	19.34	14.21	9.03	5.32	**12.15**
LCS 2008-2009	42.17	42.57	41.60	39.53	37.28	33.19	28.32	21.31	14.52	8.69	**17.96**
IES 2010-2011	32.71	32.90	31.46	29.84	26.88	23.68	19.32	13.61	8.86	4.45	**11.31**
LCS 2014-2015	29.13	30.30	29.84	28.88	26.51	23.73	19.79	14.44	9.42	5.09	**11.71**
Average	33.56	34.08	32.78	31.32	29.19	25.90	21.69	15.89	10.46	5.89	

Source: Adapted from Statistics South Africa (2008a; 2011: 2012: 2017a)