UNIVERSITEIT VAN PRETORIA
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Evaluating the impacts of energy and environmental policy on South African households

by

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A thesis submitted in fulfilment of the requirements for the degree of

PhD (Economics)

Department of Economics

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University of Pretoria

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2020

To Heinrich and Gabriela Karina

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Statement of Authorship

I declare that the thesis, which I hereby submit for the degree of PhD (Economics) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at another university.

SIGNATURE: JBN DATE: 14 August 2020

NRF Acknowledgement

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinion expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

Personal Acknowledgements

I would like to thank my husband Heinrich for believing in me, supporting me and for always being my sound board. Thank you for all the advice, editing and infinite discussions over the years. Thank you for motivating me and being my pillar – I love you. Gabriela Karina, my daughter, your fighting spirit gave me strength and inspiration to keep going even when things were tough. Setting a good example for you encouraged me day after day to not quit. I always want to set a good example for you, make you proud and encourage you to always do better. Te amo mi noonie.

To my parents, Carlos and Nancy, thank you for always being there for me no matter the distance. To my sister Josephine, thank you for your support and for always trying to help and understand what I am doing. Your daily phone calls have been great. Uncle Pancho, thank you for making my education a priority and for pushing and supporting me to go to Australia to study. I would not have made it this far without your backing. Liza, thank you for always checking on us. To the Bohlmann family, I appreciate your support.

I would like to thank my supervisor Prof. Roula Inglesi-Lotz for all the dedication and guidance provided during this long journey. Thank you for the countless hours you spent reading my drafts, providing me with comments and suggestions, planning my thesis and helping me getting through the finish line. I will forever be thankful. As a woman, you are a source of inspiration, and as a Professor, the knowledge you share and your dedication to your students are invaluable to us.

The Department of Economics have been a place that has taught me many lessons and has shaped my professional career. I would like to thank all the Professors that have supported me and provided me with an excellent education – Prof. Koch, Prof. van Heerden, Prof. van Eyden, Prof. Viegi and Prof. Bittencourt, thank you for all the lessons throughout the years. Prof. Margaret, words are not enough to thank you for all the support, reassurance and inspiration. I am looking forward to continuing working with you.

To my friends in South Africa and abroad, I really appreciate you. Ulonka, thank you for the encouragement and chats. Leoné thank you for the sanity coffees. Bianka, my sister, your unconditional friendship means the world to me, can't wait to see you again. Alejandro, I did it brother, thank you for always being there. Nelly Karina, this one is also for you!

Ancora Imparo

Executive Summary

This thesis investigates how different policies and measures designed to reduce CO_2 emissions – i.e. carbon tax and energy efficiency policies – in South Africa will affect South African households. The contribution of this study lies with evaluating South African households at a disaggregated income level from low to high-income appreciating the fact that households at different levels are impacted differently by the implementation of policies at national level. In order to evaluate such impacts, the study started with profiling the households' electricity consumption patterns in South Africa through the years and comparing them with the rest of the world. The next objective was to comprehend – implementing an Auto Regressive Distributed Lag (ARDL) econometric model – the determinants of electricity consumption of the residential sector in the country. Finally, by using a Computable General Equilibrium (CGE), the study examined various policy scenarios designed to reduce emissions and its effects on different households, particularly the low-income ones that do not have the capital to absorb the impacts. The results showed that low-income households are affected differently than the rest of South African households by the national policies implemented to reduce CO_2 emissions and combat climate change. However, given the way the carbon tax and energy efficiency policies are designed, low-income households should be affected minimally.

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Acronyms

AFOLU	Agriculture, Forestry and Other Land Use
BAU	Business-as-Usual
BCA	Border Carbon Adjustment
CGE	Computable General Equilibrium
COP	Conference of the Parties
COP21	Conference of the Parties Paris Agreement
CoPS	Centre of Policy Studies
DoE	Department of Energy
DEA	Department of Environmental Affairs
FBE	Free Basic Electricity
Gg	Gigagram
GHG	Greenhouse Gas
INDC	Intended Nationally Determined Contribution
INEP	Integrated National Electrification Programme
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IRP	Integrated Resource Plan
kWh	Kilowatt-Hour
Mt	Megatonnes
NCCRP	National Climate Change Response Policy
NDP	National Development Plan
NEDLAC	National Economic Development and Labour Council
NEES	National Energy Efficiency Strategy
NERSA	National Energy Regulator of South Africa
NIDS	National Income Dynamics Study

PAM	Policies and Measurements
PPD	Peak, Plateau, Decline
UPGEM	University of Pretoria General Equilibrium Model
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value Added Tax

Chapter 1: Introduction

1.1 Introduction and Background

South African policymakers do not have a shortage of important and complex problems to solve. Many issues overlap with each other and require a holistic and integrated approach to understand and solve. This thesis simultaneously studies two of the most pressing policy issues that have hindered South Africa's growth and development – delivering a more sustainable energy and environmental profile whilst accounting for the large differences between household income groups.

South Africa has a dual economy where the highest income decile of the economy earns over 50 percent of income – compared to the lowest 20 percent who earn only 3 percent of total income (IMF, 2020). It is therefore no surprise that South Africa has one of the highest inequality rates in the world – with a Gini coefficient over 0.6 – which can be attributed to its legacy of exclusion and continued low rates of economic growth that has led to extreme levels of unemployment and poverty (IMF, 2020, World Bank, 2019).

The South African economy has historically relied on large-scale energy intensive sectors such as mining and manufacturing which require a dependable supply of electricity. The electricity sector in South Africa is responsible for almost 80 percent of total greenhouse gas (GHG) emissions in the country (DEA, 2019a). This contributes to South Africa being one of the top emitters of GHG emissions in the world according to the latest 2019 data (DEA, 2019a; IEA, 2020).

As an upper middle-income developing country, South Africa faces the challenges of having to promote economic growth while reducing its environmental footprint (World Bank, 2013; 2019; IEA, 2020). Given the persistent inequality levels in the country, South Africa needs to take into consideration the effects of reducing GHG emissions on different households – especially poorer households that, compared to industries and the electricity generation sector, are least responsible for GHG emissions and therefore climate change.

The South African government has outlined its strong commitment to play its part in the global efforts to mitigate GHG emissions. South Africa is a member of the United Nations Framework Convention on Climate Change (UNFCCC) and a signatory member of the Conference of the Parties Paris Agreement (COP21) which has led to its commitment to determine, plan and regularly report on the contribution it undertakes towards the mitigation of GHG emissions that eventually lead to global warming. South Africa voluntarily committed to reducing its GHG emissions by 34 percent in 2020 and 42 percent in 2025 compared to its business-as-usual baseline path (National Treasury, 2013a). The main frameworks highlighting South Africa's commitment to reduce GHG emissions and combat climate change are defined in the National Climate Change Response Policy (NCCRP) of 2011 (DEA, 2011b) and the National Development Plan (NDP) of 2012 (The Presidency, 2012),

During COP21, South Africa's commitment to contribute to the global effort in mitigating climate change whilst transitioning to a green economy was reaffirmed. South Africa submitted its final Intended Nationally Determined Contribution (INDC) to the UNFCCC in 2016. In this document, it was reiterated that South Africa's emissions are expected to follow the Peak, Plateau, Decline (PPD) benchmark; where emissions are predicted to peak by 2025 in a range with a lower limit of 398 Megatonnes (109 kg) (Mt) CO_2eq and upper limits of 583 Mt CO_2eq and 614 Mt CO_2eq for 2020 and 2025 respectively; plateau for approximately a decade after the peak within the range with a lower limit of 398 Mt CO_2eq and upper limit of 614 Mt CO_2eq; before beginning to decline in absolute terms from 2036 to a range with lower limit of 212 Mt CO_2eq and upper limit of 428 Mt CO_2eq by 2050 (DEA, 2011a; 2011b).

According to the South African Department of Environmental Affairs' 2019 National GHG emissions report, South Africa's gross[1] GHG emissions increased from 439238 Gg CO_2eq in 2000 to 540854 Gg CO_2eq in 2015 – an average increase of 1.4 percent per annum for the period 2000-2015 (DEA, 2019a, 2019b). South Africa's emissions are mainly due to its energy sector which is reliant on coal. In 2015, total emissions from the energy sector were estimated to be 429907 Gg CO_2eq, representing 79.48 percent of total gross emissions for South Africa – compared to the residential sector's GHG emissions that were estimated at 4.8 percent of total gross emissions for South Africa (DEA, 2019a, 2019b). Thus, South Africa's GHG emissions continue to show increasing trends and these trends are expected to continue to rise between 2020 and 2025 in line with the PPD trajectory (DEA, 2019b).

At present, South Africa's energy and environmental policies aimed at reducing GHG emissions are planned in conjunction with the country's PPD benchmark and Integrated Resource Plan (IRP) – which details a range of potential electricity-generation mix options; and a set of complementary policies and measures (PAMs) including, most notably, the carbon tax (DoE, 2019). Given the high inequality levels in South Africa, its climate change policies need to be formulated in a way that low-income households are less affected. Policies need to be designed in a way that South Africa's commitments to reduce GHG emissions are balanced

[1] Gross GHG emissions are total emissions excluding FOLU (Forestry and Other Land Use)

with the needs of reducing poverty, promoting economic growth and maintaining trade competitiveness. Studies focusing on the impact of PAMs aimed at reducing GHG emissions cover a broad range of issues. However, in South Africa, the direct and indirect impacts of different mitigation policies on households have not been fully considered in a general equilibrium model that recognises multiple household groups according to income levels.

In a nutshell, this thesis focuses on evaluating the impact of different energy and environmental policies on South African households as well as the broader economy. Across a series of chapters, this thesis thoroughly evaluates energy consumption patterns in the residential sector, the determinants of electricity demand, and how policies designed to reduce GHG emissions – the carbon tax and improved energy efficiency – will affect different household groups.

1.2 Motivation and Research Design

The economy-wide effects of choices regarding policy measures designed to combat climate change can be far-reaching. The impact of proposed policies on low-income households and vulnerable industry groups are of particular concern, especially given the country's weak economic performance, high unemployment and elevated levels of inequality. As mentioned above, this thesis will ultimately evaluate how different policies aimed at reducing GHG emissions – more specifically the carbon tax and energy efficiency gains – will affect the South African economy as a whole, and South African households at different income levels. This is in line with research by van Heerden et al. (2006), where the main goal was to achieve a triple-dividend of reducing GHG emissions and poverty while promoting economic growth.

In order to understand how different policies aimed at reducing GHG emissions will affect households within the South African context, certain tasks need to be performed: i) understand household's electricity consumption patterns in South Africa and its comparison with the rest of the world; ii) understand the determinants of electricity consumption in the South African residential sector; iii) identify the main policies and measures designed to reduce GHG emissions that South Africa is implementing and planning to implement in the near future; and iv) evaluate different policy scenarios regarding GHG emissions reduction and its effects on households at different income levels.

The main contribution of this study lies with evaluating South African households at a disaggregated income level from low to high-income, appreciating the fact that households at different levels are impacted differently by the implementation of policies at national level.

Additionally, this study applies different empirical techniques in order to evaluate such impacts, the study starts with profiling households' electricity consumption patterns in South Africa through the years and comparing them with the rest of the world. The next objective is to comprehend – using an Auto Regressive Distributed Lag (ARDL) econometric model – the determinants of electricity consumption of the residential sector in the country. Finally, by using a Computable General Equilibrium (CGE) model, the study examines the effects on households of the carbon tax and efficiency gains in the renewable electricity sector as two different policies designed to reduce GHG emissions.

1.3 Research Objectives

The main purpose of this thesis is to analyse and understand the patterns of energy consumption as well as the determinants of electricity consumption in the South African residential sector – by different income groups – in order to analyse the effects on households of different policies that are designed to reduce GHG emissions. The following key objectives guide the study:

Objective 1: Analysing the South African residential's sector energy profile.

- To conduct an extensive profile of household's energy consumption in South Africa. This includes a review of the different policies targeting energy provision and consumption that are in place in South Africa.
- To analyse the trends in energy consumption in the residential sector by evaluating households at different income levels and comparing their energy consumption patterns.
- To analyse the sources of energy used by different households to satisfy their basic energy needs for cooking, heating and lighting.
- To analyse the status quo of the South African energy consumption by households and to conduct and international comparison with other neighbouring, developing and developed countries.
- To evaluate the state of households' access to electricity, the type of energy used by households and households' expenditure on electricity and energy in South Africa from the National Income Dynamics Study (NIDS) by the Southern Africa Labour and Development Research Unit (SALDRU).

Objective 2: Evaluate the determinants of residential electricity demand in South Africa per household income bracket

- To identify the determinants of residential electricity demand in South Africa at both aggregate and disaggregated (by low, middle and high) income levels.
- To analyse the income and expenditure patterns of South African households at both aggregate and disaggregate income levels in order to identify other goods and services that might be considered complements or substitutes to electricity by South African households.
- To estimate short and long-run price and income elasticities of residential demand for electricity at both aggregate and disaggregated income levels.

Objective 3: Economy-wide and household impact of two different policies – the carbon tax and energy efficiency gains in the non-coal electricity sector – which are designed to reduce South Africa's GHG emissions.

- To briefly evaluate South Africa's current emissions database.
- To evaluate the different PAMs considered and applied in South Africa
- To improve and update the University of Pretoria Computable General Equilibrium Model (UPGEM) by adding the elasticities estimated regarding household's response to changes in income and electricity prices; linking it to an updated emissions database; splitting households into different income categories based on the latest available data; and adding detailed tax information that will allow us to accurately model the effects of two different PAMs aimed at reducing emissions – the carbon tax and energy efficiency gains in the non-coal electricity sector.

1.4 Outline of the Study

This thesis contains seven different chapters. Chapter 1 – the current chapter – introduces the topic under investigation by providing a brief background and the motivation of the study. Additionally, it provides the main purpose and objectives of the study. Chapter 2 provides a detailed background of the South African economy; its energy consumption patterns, and; its emissions profile. It also provides information with regards to the income and expenditure patterns of South African households and the main factors influencing electricity consumption. The chapter concludes by describing the different energy policies in South Africa with special focus on the emissions mitigation strategy in the country. Chapter 3 reviews the most recent literature relevant to this study. This includes a review on energy consumption in the residential sector; a review of the empirical studies on the determinants of electricity consumption worldwide – including developed and developing countries; and a review of the different studies focusing on different research that have focussed on policies designed to combat climate change in South Africa – with special focus on the carbon tax and energy efficiency policies.

Chapters 4 to 6 are the core chapters of this study. Chapter 4[2] presents a detailed energy consumption profile of the South African residential sector. Chapter 5[3] evaluates – using an Auto Regressive Distributed Lag (ARDL) econometric model – the determinants of residential electricity demand in South Africa per household income bracket. Chapter 6 evaluates – using a dynamic CGE model – the impact of different energy and environmental policies on South African households. The chapter includes a discussion of the CGE methodology, specific details of the CGE model and simulation design steps, modelling results and policy analysis. Chapter 7 summarises the study's findings, provides some concluding remarks, policy recommendations and avenues for future research.

[2] Chapter 4 has been published in a peer-reviewed journal as: Bohlmann, J.A. & Inglesi-Lotz, R. (2018). 'Analysing the South African residential sector's energy profile'. *Renewable and Sustainable Energy Reviews*, 96:240-252.
[3] Chapter 5 is currently under review in a peer-reviewed international journal.

Chapter 2: Background

This chapter provides the background on the key topics and issues related to the core of this thesis including an overview of the South African economy, the South African energy sector, the residential sector and its electricity consumption profile, the South African emissions profile, its emissions, and the different policies and measures implemented and planned in South Africa to reduce GHG emissions. Section 2.1 provides an overview of the South African economy. Section 2.2 provides an overview of the energy sector in South Africa, including the current state of electrification and key energy-related legislation in the country. Section 2.3 provides a background on the global and South African trends in energy consumption in the residential sector. Section 2.4 focusses on the South African environmental profile, the different policies and measures planned and implemented in South Africa and sheds light into the relevant topics related to climate change mitigation. Section 2.5 provides information on the South African household's basic basket of goods and services consumption expenditure.

2.1 Overview of the South African Economy

For long the largest and most developed economy on the African continent, South Africa features many institutions on par with the best in the world. Its monetary and fiscal policy institutions are well regarded, and it is often argued that these institutions have kept the South African economy going during tough times. Large, well-developed, manufacturing and service sectors are prominent features of the economy along with its primary mining and agriculture sectors that produce a significant amount of export earnings every year.

However, despite improving the lives of many, a number of challenges remain twenty-five years after achieving democracy. Underwhelming economic growth, averaging just above 3 per cent since 1994, has limited the government's ability to successfully deal with the challenges it has been presented with. Inequalities in income, education and access to services remain a major concern. These structural problems have contributed to the country's persistently high level of unemployment. The lack of access to basic infrastructure such as roads, water and electricity has been addressed in many areas, but much work remains to be done in this regard. Due to the policies of spatial segregation during the Apartheid era, the location of some rural areas has made it very costly to deliver these basic services. However, as the government continues to deliver on its promise of increased access to all and more services are rolled out, the need for increased capacity of basic infrastructure such as electricity has become an urgent policy matter.

The South African economy is currently faced with low levels of economic growth coupled with rising debt to GDP ratio, high unemployment and high income inequality (IMF, 2020b; Statistics South Africa, 2020a; 2020b). Economic growth in the South African economy remains low; real annual GDP increased by 0.2 percent in 2019 following an increase of 0.8 percent in 2018. For the fourth quarter of 2019, South Africa's gross GDP decreased by 1.4 percent – following a contraction of 0.8 percent in the third quarter of 2019 which led to economy to fall into its third recession since 1994 (Statistics South Africa, 2020a, 2020b).[4] The latest GDP figures by Statistics South Africa showed that seven out of the ten primary South African industries contracted in the fourth quarter of 2019 (Statistics South Africa, 2020a, 2020b). Agriculture is one of the industries that has been highly impacted by climate change in South Africa; severe droughts have been a threat over the last couple of years. The drought has brought late rains and heatwave conditions across the country, which in turn has affected the production of field crops (Statistics South Africa, 2020a; 2020b). This has led to the *Agriculture* sector experiencing its fourth consecutive quarter of negative growth – fourth quarter of 2019 – with its growth falling by 7.6 percent (Statistics South Africa, 2020a; 2020b). Another industry that has been affected by the drought is the *Electricity, gas and water supply* industry; flooding at some power stations, disruptions to coal supply, and the heatwave affecting water levels at damns which consequently led to water restrictions are all factors that have been contributing to the sluggish performance of the industry (Statistics South Africa, 2020a, 2020b).

South Africa's GDP per capita has been estimated at 6554 US dollars (2018), and it has been declining over the last 5 years – in 2018 it declined by -0.3 percent and in 2019 it declined by -1.1 percent; and it is expected to decline by -0.7 in 2020 and 0.5 in 2021 (IMF, 2020b). This negative per capita income contributes to the inequality issues in the country. According to the IMF (2020), the main drivers of diminished economic growth – and consequently per capita income – in South Africa are weak private investment and productivity growth.

South Africa has had persistent fiscal deficits; this has been mainly driven by continuous large expenditures on bailing out state-owned enterprises (SOEs) – including ESKOM – despite their weakening performances (IMF, 2020b). According to the IMF (2020b) and National Treasury (2020), the government deficit is projected to surpass 60 percent of GDP for the 2019/20 fiscal

[4] A recession can be defined as two (or more) consecutive quarters of negative growth (real GDP quarter-on-quarter). South Africa experience its first recession since 1994 from Q4: 2008 to Q2: 2009. The second recession took place over Q1 and Q2 of 2018.

year and is expected to reach 70 percent in the 2020/21 fiscal year. This results in significant debt accumulation and leaves South Africa with no fiscal space. Consequently, South Africa is not in a position to raise revenue to fund its social and economic development programme, which aims at decreasing the income inequalities in the country (National Treasury, 2020).

The South African government has acknowledged its dire fiscal position and its main focus is on promoting rapid and persistent economic growth that will lead to an equitable South Africa (National Treasury, 2020). One of the identified sectors to achieve this is the electricity sector, the government is focusing on ensuring an adequate electricity supply for business and households. This will be done by encouraging greater private sector participation in electricity generation which involves investment in greener technologies as well as providing universal access to electricity to the South African population (National Treasury, 2020).

2.2 Overview of the Energy Sector in South Africa

The South African economy is reliant on many energy-intensive industries such as the mining and iron and steel industry. South Africa has one of the world's largest coal reserves which uses to meet around 75 percent of its energy needs with over 50 percent of the coal consumed in the country going towards electricity generation (EIA, 2015; 2016). Along with Nigeria, South Africa has consistently ranked as one of the largest economies in Sub-Saharan Africa. However, South Africa has the highest energy consumption on the continent; it accounts for approximately 30 percent of total primary energy consumption in Africa (EIA, 2015; 2016).

According to the 2017 BP Statistical Review of World Energy, in 2016, 85 percent of South Africa's total primary energy consumption came from coal, followed by 26.9 percent from oil; 4.6 percent from natural gas; 3.6 percent from nuclear; 1.8 percent from renewables and less than 1 percent from hydro (BP, 2017). Due to its reliance on and abundance of coal, South Africa is the leading CO_2 emitter in Africa and one of the top 15 emitters in the world (EIA, 2015; 2016).

Eskom – the state-owned electricity company which operates the national electricity grid – produces around 90 percent of South Africa's electricity. The remainder of the electricity generated in South Africa is produced by independent power producers (IPPs)[5] and municipalities (Eskom, 2016a; Statistics South Africa, 2017a). Eskom's fleet consists of 28

[5] IPPs form part of the renewable energy programme run by the South African Department of Energy that aims at promoting private and public growth in energy generation.

power stations with a total nominal capacity of 42 810MW; the various IPPs have a total nominal capacity of 3392MW. In 2016 Eskom's total energy output was 219 979GWh (Eskom, 2016a).

The electricity sector in South Africa is regulated by the National Energy Regulator of South Africa (NERSA). Regulating national electricity prices as well as promoting private investment in the form of IPPs and other off-grid technologies to secure a stable grid and promote access to electricity to all are the key objectives of NERSA (EIA, 2015; Eskom, 2016a)

2.2.1 Current State of Electrification and Key Energy-Related Legislation in South Africa

The democratic transition from the Apartheid regime in South Africa started in the early 1990s. Only then, South Africa's energy policy started developing and focusing on providing electricity access to all. During Apartheid, South Africa's energy policy was tailored to benefit the minority of the population – the majority of the population was forced to live on the outskirts of major cities and did not have access to basic needs including access to electricity (Marquard, 2006). This inequality in access to electricity amongst different population groups has led to the high levels of energy poverty and reliance on other sources of energy such as wood and paraffin that is still present in South Africa especially amongst low-income households (Marquard, 2006).

In the early 1990s, universal access to electricity was one of the priority issues identified by the government as part of the country's development policies (The Presidency, 2012; 2014). Access to electricity is crucial in addressing the country's historical inequalities and helping in promoting economic growth.

'*Ensuring access to affordable, reliable, sustainable and modern energy for all'* is one of the United Nations' 17 Sustainable Development Goals that aim at ending global poverty, promoting economic growth as well as protecting the environment (UN, 2016; 2017). Households require electricity to perform basic daily duties which include cooking, heating, and lighting. Additionally, access to modern and reliable electricity is crucial in the provision of health care, clean water and sanitation, transportation and telecommunications (Ghosh-Banerjee & Portale, 2014). Access to electricity in South Africa has increased from 35 percent of households in 1990, to 58 percent in 1996, and to over 84 percent in 2011 (Statistics South Africa, 2012b; World Bank, 2017a). According to the Department of Energy, 86 percent of South African households were electrified by the end of 2016 (DoE, 2017a).

The success of the South African electrification process can be attributed to the set of policies and programmes targeting the electricity sector that – as mentioned above – were drafted in the early 1990s, more specifically during the 1994-2000 period, as part of the transition from Apartheid. These energy policies focus on the energy requirements of the poor by aiming at expanding access to affordable energy services for both urban and rural households. Additionally, whilst providing access to electricity to all, the government is committed to providing cleaner and safer forms of energy to low-income households (Spalding-Fetcher & Matibe, 2003).

The South African Constitution of 1996 stipulates that all residents have the right to have access to energy, irrespective of geographical location, at affordable prices. Additionally, it specifies that energy should be produced and distributed in a sustainable manner, which as a whole should contribute towards enhancements in the standard of living of the population.

The key legislative and regulatory framework guiding the South African energy sector is the 1998 *White Paper on the Energy Policy of the Republic of South Africa* (referred to as White Paper hereafter). The White Paper highlights the key objectives of the government's electricity policy whose main objective is to create an electricity sector that serves as an engine for growth, development and prosperity for South Africa (DME, 1998). The White Paper recognises that energy access should be universal and that it should come from clean sources. Additionally, it emphasises the importance of households' access to adequate sources of energy for cooking, heating, lighting and communication to improve their overall living standards and to reduce poverty (DME, 1998).

The Integrated National Electrification Programme (INEP) was set up in 2002 as the main electrification programme in South Africa. Through INEP, the South African government uses public sector financing for electrification. Thus, the state plays a crucial role in funding infrastructure development, particularly with regards to the electricity sector (World Bank 20171; 2017b). To date, INEP has been the South African energy-related policy that has had the greatest impact in facilitating energy access, especially for the poor.

However, access to electricity is not the only issue faced by poor households that in spite of being connected to grid electricity are energy poor and are not able to afford the minimum amount of electricity to cover their basic energy needs.

Against this backdrop, in 2003, the government introduced the Free Basic Electricity (FBE) policy to address affordability problems related to energy and aid in reducing energy poverty in South Africa. Under the FBE policy, poor households qualify for 50kW/h of free electricity per month that is '*…deemed sufficient to provide basic lighting, basic media access, basic water heating using a kettle, basic ironing, and power for a small television set and radio*' (Eskom, 2016b). As of March 2015, there were almost 1.2 million households in South Africa that were eligible and configured to receive FBE via installed electricity meters (Eskom, 2016b). However, only over 900 000 customers collected their FBE vouchers (Eskom, 2016b). Overall, this amounts to a total of 870 060MWh of FBE consumed in the 2014/15 financial year; compared to 960 348MWh FBE consumed in the 2013/14 financial year.

The electrification programme has positively impacted the welfare of the South African population. Poorer households who could not afford a connection and the basic use of electricity are now connected to the grid – or have access to other forms of energy – and are more integrated into society. However, despite the progress South Africa has made, around 11 percent of households still does not have access to electricity (IEA, 2016; DoE, 2017; Statistics South Africa, 2013). Thus, as mentioned above, over 10 percent of South African households – mainly low-income ones living in rural areas – rely on substitute sources of energy which contribute to environmental degradation and present health hazards to households (IEA, 2016; DoE, 2017; Statistics South Africa, 2013).

2.3 Global Residential Energy Consumption and South African Households Electricity Consumption

This sub-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 information is important as it provides the background and motivation behind some of the key variables used in Chapter 5 as determinants of electricity demand in the residential sector.

2.3.1 Global Trends in Residential Energy Consumption

Global primary energy needs are expected to grow by approximately 30 percent between 2017 and 2040, with renewable energy growing fast and the use of coal reducing significantly because of environmental concerns (IEA, 2017). Despite electrification efforts being successful around the world and energy consumption shifting towards industrialising and urbanising China, India, Southeast Asia and some parts of Africa, Latin America and the Middle East;

many people will still be left without basic energy services around the world in 2040 (IEA, 2016). It is expected, that by 2040 access to electricity in rural sub-Saharan Africa will still be lagging by around half million people; with almost 2 billion people still depending on solid biomass such as wood as a source of energy for cooking (IEA, 2016).

The trend in energy sources consumed around the world is changing. OECD countries are moving from using LPG gas for heating and cooking towards using natural gas and electricity. Urbanisation in developing countries is further contributing to the movement away from biomass towards LPG gas for cooking (IEA, 2016). However, in developing countries such as South Africa, alternative sources of energy including paraffin and gas both for lighting and cooking are still used (and are expected to continue) in the residential sector. Improvement in access to electricity combined with different policies aiming at replacing paraffin as a cooking fuel given its negative impact on air quality and health will lead to a decreasing trend in paraffin used by households globally (IEA, 2016). Due to technological improvements in buildings – which are now using more efficient boilers and better insulation – electricity consumption in the residential sector is expected to decline worldwide despite more households using electricity for space and water heating (IEA, 2016).

2.3.2 Electricity Consumption in the South African Residential Sector

Since the early 2000s electricity consumption in the residential sector has been increasing over time – with the exception of 2014/2015 where the South African electricity sector experienced another period of severe load shedding[6] which led to a sharp decline in total electricity consumption (including the residential sector) in the country – (DoE, 2019, Eskom, 2015) (Refer to **Figure 1**). The share of electricity consumption by the residential sector in South Africa shows an increasing trend (DoE, 2019). In 2017, the residential sector in South Africa was responsible for almost 24 percent of total electricity consumption – up from 20.1 percent in 2013 and 19.8 percent in 1994 (DoE, 2019; Bohlmann & Inglesi-Lotz, 2018) – refer to **Figure 1**.

The increasing trend in electricity consumption in the residential sector can be attributed to the efforts by the South African Department of Energy through INEP, which had contributed to

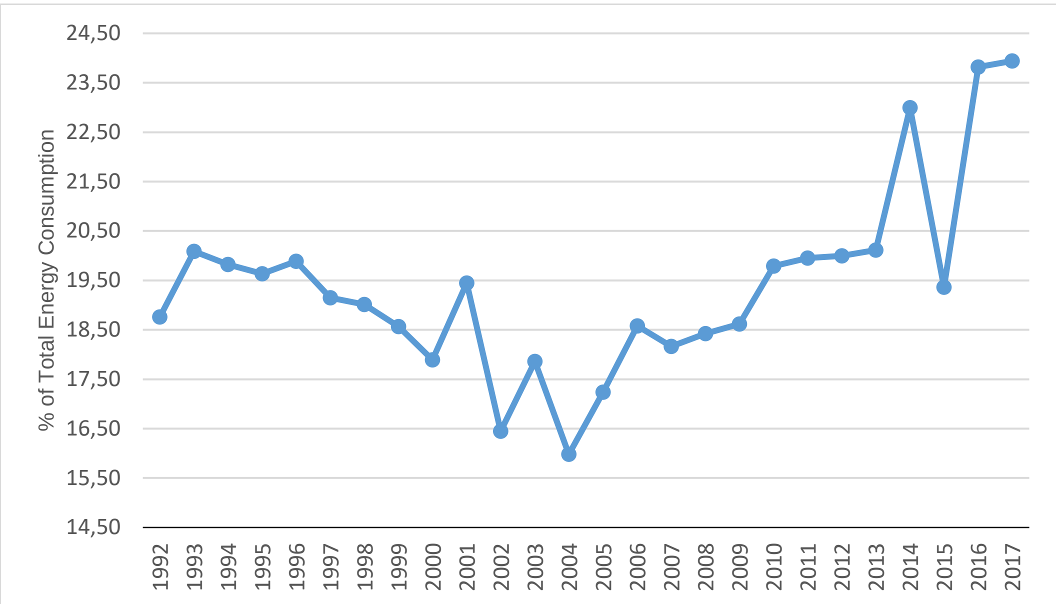
[6] Load shedding or load reduction is the South African term for electricity rationing

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).

As described above, 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).

Figure 1 Residential Sector Share of Total Electricity Consumption

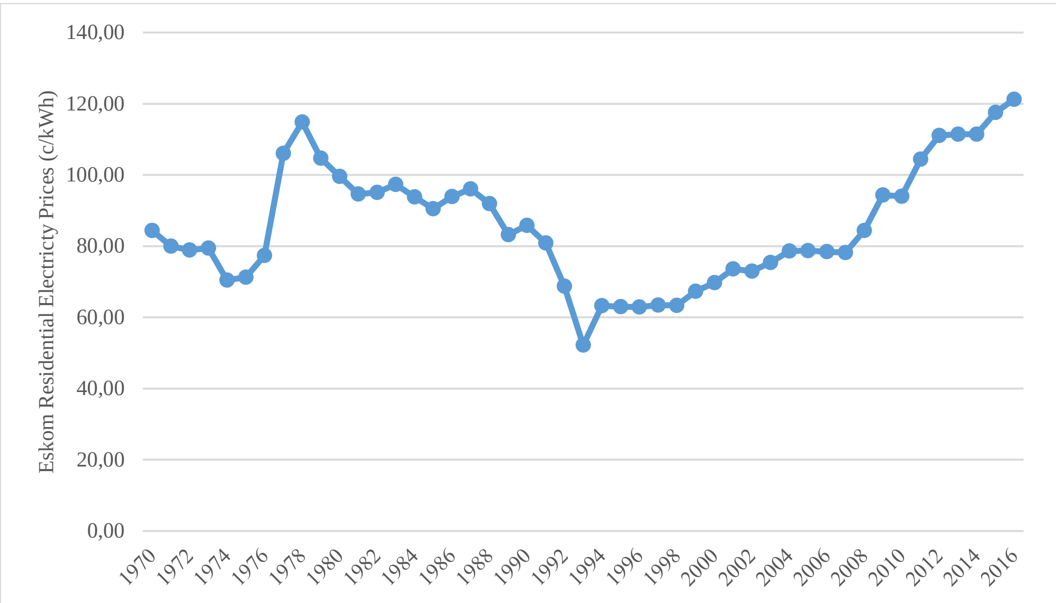


Source: Adapted from DoE (2019)

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 2** for a depiction of electricity prices in the South African residential sector). One of the objectives of Chapter 5 in this study is to investigate whether post-2008, electricity prices have indeed influenced electricity consumption in the residential sector in South Africa.

Figure 2 Eskom Residential Electricity Prices 1970-2016



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

2.4 South Africa's Environmental Profile and GHG Reduction Emissions Background

By absolute CO_2 emissions, South Africa's GHG emissions are ranked amongst the top fifteen countries in the world (National Treasury, 2013a; DEA, 2019a). South Africa is the highest GHG emitter on the continent. The country's high emissions profile is linked to the economy's fossil-fuel dominated electricity sector.

South Africa's GHG gross emissions were estimated at 540854 Gg CO_2eq, increasing from 439238 Gg CO_2eq in 2000 (a 23.1 percent increase) (DEA, 2019b). Between 2000 and 2015, the average annual growth in gross emissions was 1.2 percent (DEA, 2019b). The energy sector was the main contributor to this increase, contributing 79.5 percent of total gross emissions (DEA, 2019b). The energy sector emissions increased from 343790 Gg CO_2eq in 2000 to 429907 Gg CO_2eq in 2015 (Refer to **Table 1** to see the growth in emissions in South Africa between 2000 and 2015). Population growth was the main contributor towards this increase – increasing population leads to increased energy consumption and increase transport use (DEA, 2019b).

Table 1 South Africa's Greenhouse Gas Emissions 2000 vs 2015 - Emissions (Gg CO_2e)

	Emissions (Gg CO_2e)		**Difference (Gg CO_2e)**	**Change (%)**
	2000	**2015**	**2000-2015**	**2000-2015**
Total net emissions (incl. FOLU)	426 214	512 383	86 169	20.2
Total gross emissions (excl. FOLU)	439 238	540 854	101 616	23.1
1. ENERGY	343 790	429 907	86 117	25
2. Industrial Process and Product use (IPPU)	34 071	41 882	7 811	22.9
3. Agriculture, Forestry and Other Land Use (AFOLU) (excl. FOLU)	50 539	49 531	-1 008	-2
3. AFOLU (incl. FOLU)	37 515	21 060	-16 455	-43.9
4. WASTE	10 838	19 533	8 695	80.2

Source: Adapted from DEA (2019b)

For the period 2000-2015, South Africa's emissions per capita have maintained a stable trend (DEA, 2019b). South Africa's emissions per capita increased from 9.93 t CO_2eq per person in 2000 to 10.8 t CO_2eq per person in 2007, then declined to 9.8 t CO_2eq in 2015 (DEA, 2019b).

2.4.1 Energy Efficiency and Energy Efficiency Policy in South Africa

In economics, energy efficiency is defined as *"… all changes that result in decreasing the amount of energy used to produce one unit of economic activity (e.g., the energy used per unit of GDP or value added)"* (Golusin et al., 2013:243). Energy efficiency is associated with economic efficiency and includes technological, behavioural, and economic changes.

The National Energy Efficiency Strategy (NEES), which was released in 2005, sets the energy efficiency strategy for South Africa up to 2015. The NEES, set an economy-wide energy intensity reduction target of 12 percent by 2015. At the sectoral level, the NEES had intensity improvements target as follows: 15 percent for industry and mining; 10 percent for power generation; 9 percent for transport; 15 percent for the commercial and public buildings sector, and 15 percent for the residential sector. According to the Energy Efficiency Target Monitoring System, which evaluated the progress of the NEES, South Africa's energy efficiency policies have progressed since the implementation of the NEES with South Africa moving towards meeting its energy efficiency targets. In 2014, the economy-wide energy efficiency improvements were reported to be 23.7 percent. At the sectoral level, industry and mining improved by 34.4 percent; power generation improved 26 percent; transport improved 14.1 percent; the commercial and public buildings sector improved 0.3 percent, and the residential sector improved 28.2 percent (DEA, 2016).

The Post-2015 National Energy Efficiency Strategy policy (DEA, 2016), represents the official energy efficiency policy of South Africa after the NEES. It identifies areas that can potentially lead to energy efficiency gains in South Africa. Some of the key identified areas and consequently policies that have energy efficiency potential are: the Private Sector Energy Efficiency (PSEE) Project which aims at improving energy efficiency in commercial and industrial companies in South Africa; the Energy Efficiency Leadership Network (EELN) which aims to promote energy efficiency in the broader South African business sector through a platform for knowledge sharing and capacity development; and the Energy Efficiency Standards and Appliance Labelling Programme which aims to ensure that consumers are informed about the relative energy efficiency of an appliance before they decide to purchase (DEA, 2015; 2019).

With regards to the residential sector, several energy savings opportunities have been identified (DEA, 2015). This include:

- The Solar Water Heating (SWH) and Mass Roll Out (MRO) which is expected to contribute to around 12 TWh of electricity savings, which will in turn contribute to a decrease of almost 7 percent decrease in household electricity intensity between 2010 and 2030 – this could translate to a decrease of 12.75 Mt CO_2eq emissions;
- Given low income households energy consumption patterns for cooking which are dominated by the use of biomass (Bohlmann & Inglesi-Lotz, 2018), the propagation of energy efficient technologies for cooking have been identified as key in improving energy efficiency in low-income households. It has the potential of saving 10 PJ for the residential sector.

Overall, the two main PAMs to improve energy efficiency in the South African residential sector are: i) to transform the market for household appliances into a more energy efficiency one; and ii) to reduce substantially the average energy consumption in residential buildings (DEA, 2015). This translates into technological changes improvement in the consumption of energy in the residential sector.

2.4.2 Relevant Policies and Measures (PAMs) Available and Adopted in South Africa

To understand the key PAMs that are planned and adopted in South Africa, it is important to have an overview of what PAMs are and how are they designed. PAMs to reduce GHG emissions can be defined as policy instruments implemented by government and applied across the economy, over a wide range of sectors, in order to help achieve its emission goals (DEA, 2014). According to IPCC (2007), PAMs form part of wide variety of national policies and instruments that are available to governments to create the incentives for GHG mitigation action. PAMs may include different regulatory instruments which include legislation, regulations and standards; economic instruments such as incentives and taxes; government procurement programmes; and government investment.

Most PAMs are quantified according to the activity-based classification system laid out in the Intergovernmental Panel on Climate Change (IPCC) 2006 national inventory guidelines – South Africa follows these guidelines (DEA, 2019). The main economic sectors as defined by the IPCC 2006 guidelines and as defined in the Mitigation Potential Analysis (MPA) study are (IPCC, 2006; DEA, 2014):

- Energy: Power and Non- Power
- Industry: Metals, Chemicals, Minerals, Mining, Buildings, Others
- Transport: Rail, Road, Aviation,
- Waste
- Agriculture, Forestry and Other Land Use (AFOLU)

Conventionally, the design and choice of PAMs has been driven by governments as the main institution designing and implementing the policies. According to IPCC 2007 and 2014, the main instruments that policymakers have used to mitigate GHG emissions are:

- Economic instruments: taxes, subsidies and tradable allowances;
- Regulatory approaches that include technological improvements and performance standards; and
- Information programmes, such as labelling and energy audits; and

At a sectoral level, several PAMs have proven to be environmentally effective (IPCC 2007; 2014):

Energy Sector: reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels; emissions trading; emissions credits; tradable green certificates; feed in tariffs for renewable energy technologies; renewable energy obligations; capital subsidies and insurance for 1st generation Carbon Dioxide Capture and Storage (CCS)

Industry: performance standards; subsidies; tradable permits; voluntary agreements; appliance standards and labelling; demand-side management programmes; incentives for energy service companies (ESCOs)

Transport: mandatory fuel economy; CO_2 standards for road transport; taxes on vehicle purchase; registration of vehicles; taxes on fuel; investment in attractive public transport facilities and non-motorised forms of transport

Waste: financial incentives for improved waste management; renewable energy incentives; waste management regulations

AFOLU: Financial incentives and regulations for improved land management and efficient use of fertilizers and irrigation; financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests; land use regulation and enforcement

South Africa has adopted several PAMs which include taxes on carbon emissions; tariffs for renewables energy; appliance standard labelling; demand-side management programmes; taxes on vehicles purchase; renewable energy incentives, etc.

With respect to South Africa's climate change framework, in 2011, the Department of Environmental Affairs published the National Climate Change Response Policy (NCCRP), which sets out the Government's vision for South Africa's effective climate change response along with its transition, in the long-run, to a lower-carbon economy and society. The NCCRP's main objectives are planned in order to achieve: risk reduction and management; mitigation actions with significant outcomes; sectoral responses; policy and regulatory alignment; informed decision making and planning; integrated planning; technology research, development and innovation; facilitated behaviour change; behaviour change through choice; and resource mobilization (DEA, 2011b). South Africa subsequently set its own domestic targets as outlined in the Nationally Determined Contribution (NDC), which was incorporated as the South African commitment in the Paris Agreement (convened by the UNFCCC). South Africa ratified the Paris Agreement in November 2016. South Africa's plans to mitigating GHG have been paved under a complementary use of carbon pricing and low carbon energy policies in order incentivize the path towards a low carbon economy at a least-cost decarbonisation (National Treasury, 2013b). The carbon tax forms an integral part of ensuring that South Africa meets these targets.

2.4.3 Environmental Taxes in South Africa

The main taxes collected in South Africa are personal income tax (PIT), corporate income tax (CIT) and value added tax (VAT). As part of its efforts to combat climate change, the South African government has introduced several environmental taxes, which are aimed at changing behaviour in its citizens. Some of the main environmental taxes in South Africa are the CO_2 tax on motor vehicle emissions; Electricity levy; Incandescent light bulb levy; International air passenger departure tax; Plastic bag levy; and the recently introduced carbon tax (SARB, 2015a; OECD, 2015; National Treasury, 2020).

According to the 2018 OECD environmentally related taxes report, South Africa's environmental taxes represent 2.69 percent of total GDP and 9.46 percent of the country's total tax revenue – South Africa is in the top 20 countries with the highest environmentally related taxes among the OECD and partner economies (OECD, 2019). In South Africa, taxes on energy represent over 90 percent of total environmentally related tax revenue (OECD, 2015; 2019).

From June 2019, the South African government imposed a carbon tax. The South African government expects to collect a minimum of 1750 million Rands for the period 2020/21 coming from revenues from the carbon tax. **Table 2** shows the South African budget revenue for 2019/20. The South African tax to GDP ratio is 26.3 percent (National Treasury, 2020).

According to the carbon tax paper released by the National Treasury in 2013 called 'Carbon Tax Policy Paper: Reducing Greenhouse Gas Emissions and Facilitating the Transition to a Green Economy' (National Treasury, 2013a), the South African government's key policy instrument for contributing to GHG emissions reduction is a carbon tax that will be phased in to allow for a smooth transition to a low-carbon economy. The carbon tax has been designed to incentivise producers and consumers, especially those in carbon-intensive industries, to move towards cleaner technologies and reduce emissions and will be introduced as part of a suite of policy interventions that will ensure that the main objective of GHG mitigation is achieved (National Treasury, 2013; 2018).

The carbon tax came into effect from 1 June 2019. It was signed into law as the Carbon Tax Act No 15 of 2019 and was announced by the Minister of Finance in the 2019 Budget (National Treasury, 2019). The final Carbon Tax Act incorporates the detailed and revised carbon tax proposed features from the 2013 Carbon Tax Paper, the 2014 Cardon Offsets Paper as well as public comments received from different stakeholders since 2011. The Carbon Tax Act follows the polluter-pays-principle and is designed to encourage large emitters to reduce their emissions. It is also aimed at ensuring that firms and consumers take into account the costs of polluting into their future production, consumption and investment decisions (National Treasury, 2018; Republic of South Africa, 2019). The carbon tax is designed to incentivise firms and consumers towards adopting cleaner technologies (National Treasury, 2018).

Table 2 South African Budget Revenue 2019/20 (R billion)

Tax Revenue	1422.2
of which	
Personal income tax	552.9
Corporate income tax	229.6
Value-added tax	360.5
Taxes on international trade and transactions	61.3
Non-tax revenue	31.5
less: SACU payments	-50.3
Main budget revenue	1403.5
Provinces, social security funds and public entities	180.3
Consolidated budget revenue	1583.8
As percentage of GDP	
Tax Revenue	26.30%
Main budget revenue	25.90%

Source: Adapted from National Treasury (2020)

The carbon tax has been introduced in a phased in manner, this is, to ensure that South Africa moves towards a low carbon economy in a sustainable manner making vulnerable households a priority (National Treasury, 2018). To minimise the impact of the carbon tax in the first phase (up to 2022), the carbon tax has been designed to be accompanied by tax incentives and revenue recycling measures (National Treasury, 2018). The key features of the carbon tax are the following (National Treasury, 2013; 2018; Republic of South Africa, 2019):

- The carbon tax will cover Scope 1 emissions in the tax base. Scope 1 emissions are the direct result from fuel combustion, gasification and non-energy industrial processes, - Scope 1 emissions include carbon dioxide, methane, nitrous oxide, perfluorocarbons, hydrofluorocarbons and sulphur hexafluoride.
- The first phase of the implementation of the carbon tax is set to last from 1 June 2019 until 31 December 2022.
- The second phase will be from January 2023 until December 2030

- In the first phase, the carbon tax provides significant tax-free allowances that range from 60 percent to 95 percent. Including: a 60 percent basic tax-free allowance; an additional 10 percent tax free allowance for process emissions; an additional 10 percent tax free allowance for fugitive emissions; a further tax-free allowance of up to 10 percent available to firms in 'trade-exposed' sectors; a maximum 5 percent tax-free allowance for above average performance; companies with a Carbon Budget qualify for an extra 5 percent tax-free allowance; and a carbon offset allowance of either 5 or 10 percent.
- The tax will be levied at R120 per ton of CO_2eq for emissions above the tax-free thresholds. During the first phase, the total tax-free allowance is up to 95 percent, this implies that the initial effective carbon tax rate will be as low as R6 to R48 per ton of CO_2eq.
- The tax rate is set to increase by the rate of consumer price inflation plus 2 percent up to 31st December 2022 – subsequently it is set to increase in line with inflation.

Revenue from the tax will be recycled to support the transition to a low-carbon economy and to protect poorer households and vulnerable sectors from the impact of the tax during the first phase of the policy implementation. During the first phase, the introduction of the carbon tax will have no impact on the price of electricity.

2.5 South African Households' Basic Basket of Goods and Services Consumption Expenditure – Average Household Expenditure

A key contribution of this thesis 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 essential to understand the income disparity in South Africa and how households at different income levels spend their income. 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, income and expenditure patterns amongst income groups are differentiate and compared.

Chapter 5 in this thesis, evaluates 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 goods and services 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 section evaluates 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) '*Living 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, conclusions can be drawn 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.

2.5.1 Income Inequality in South Africa – Highlighting Income Patterns

Table 3 shows the income per households per decile as well as the share of total income earned in South Africa per households per decile[7]. By evaluating the numbers on the table, the magnitude of the income inequality issue in South Africa can be seen.

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[8]. When grouping the different

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

[8] 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

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.

2.5.2 Average Household Expenditure – Highlighting How Households Spend Their Income

When evaluating average household expenditure in aggregate, the top five main components of household consumption expenditure by South African households are: *Housing, water, electricity, gas and other fuels*; *Transport*; *Food and non-alcoholic beverages*; *Miscellaneous goods and services*[9] and *Furnishing, household equipment and routine maintenance of the dwelling*.

Table 4 presents, the average expenditure pattern of South African households.

In 2005/2006, it was estimated that the average South African household spent R56112 with the largest consumption expenditure group being *Housing, water, electricity, gas and other fuels* – representing 23.6 percent of total expenditure – followed by *Transport* and *Food and non-alcoholic beverages* representing 19.9 and 14.4 percent of total expenditure respectively (StatsSA, 2008).

During 2008/2009, the average South African household spent R71905. The biggest contributor to total expenditure was again *Housing, water, electricity, gas and other fuels* – representing 24.9 percent of total expenditure. The second largest expenditure item in this period was *Food and non-alcoholic beverages* representing 19.4 percent of total expenditure, followed by *Transport* at 15.3 percent (StatsSA, 2011). On average, South African households spent approximately R95160 in 2010/2011. Yet again, *Housing, water, electricity, gas and other fuels* represented the main component of total expenditure at 32 percent. The second and third largest expenditure items were *Transport* (17.1 percent) and *Miscellaneous goods and services* (14.7 percent) (StatsSA, 2012). Lastly, 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

[9] Miscellaneous goods and services include expenditure on financial services, personal care items and medical aid

expenditure item in this period (16.3 percent), followed by *Miscellaneous goods and services* at 14.7 percent).

In conclusion, 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 in the following sub-section, this picture looks very different when looking at households at disaggregated levels of income.

Table 3 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

Table 4 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		
Note:	1st	2nd	3rd	4th	5th							

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

2.5.3 Disaggregated Household Expenditure – Focusing on 2014/2015 Data

Table 5 and **Table 6** provide insight into household expenditure per income decile. This highlights how, given the income inequality levels in South Africa, looking at households at different income levels presents a clearer view of the consumption patterns of South African households.

Based on the latest available data from the '*Living Conditions of Households in South Africa'*, report from Statistics South Africa (2017a), this section provides details related to: i) out of total household consumption expenditure by main expenditure group what percentage is consumed by low-income (decile 1) households and what percentage is consumed by high-income households (decile 10) (**Table 5**); and ii) the top five main components of household consumption expenditure by low and high income households (**Table 6**).

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 thesis; 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 5**.

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 10), which consumed 51.3 percent of total consumption on *Housing, water, electricity, gas and other fuels* (StatsSA, 2017a) – refer to **Table 5**.

As shown in **Table 6**, 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 6**).

For high-income (decile 10) households, at 35.6 percent, *Housing, water, electricity, gas and other fuels* is the main contributor to their total consumption expenditure. The second largest contributor to consumption expenditure for high-income (decile 10) households was *Transport* contributing 19,6% to their total household consumption expenditure. The third largest expenditure group for high-income (decile 10) households is, *Miscellaneous goods and* *services* contributing 17.3 percent to total high-income (decile 10) household consumption expenditure (StatsSA, 2017a) (Refer to **Table 6**).

It is important to notice the vast difference in consumption patterns between high and low-income households. For example, for high-income households, *Food and non-alcoholic beverages* represents the fifth largest expenditure to their consumption expenditure, only contributing 5.8 percent to their total consumption expenditure. This is a huge contrast when compared to low-income households that as mentioned above, spend 31.1 percent of their total expenditure on *Food and non-alcoholic beverages* (Refer to **Table 6**).

Table 5 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 6 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 fuels	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
Note:	1st	2nd	3rd	4th	5th						

Source: Adapted from Statistics South Africa (2017a)

2.5.4 Household Expenditure on Electricity and Food

Table 7 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 8**. When looking 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:11-118).

The information ins this sub-section was key in informing the variables used to estimate the determinants of electricity demand in the residential sector in Chapter 5.

Table 7 South African Household's Expenditure Patterns on Electricity

Average annual household consumption expenditure by third expenditure group and expenditure deciles - especifically 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 8 South African Household's Expenditure Patterns on Food

Average annual household consumption expenditure by secondary expenditure group and expenditure deciles - especifically 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)

Chapter 3: Literature Review

This chapter presents a literature review related to the main objectives of this thesis. Section 3.1 gives an overview of the South African literature on energy and electricity consumption in the residential sector. Section 3.2 provides a review of the empirical studies on the residential demand for electricity. Section 3.3 provides a review of the studies available in the literature that have used CGE models to evaluate the impacts of policies designed at reducing GHG emissions.

3.1 Literature on Energy Consumption in the Residential Sector in South Africa

The international literature on energy and electricity consumption in the residential sector is vast. It includes research on factors influencing residential energy consumption, factors influencing energy efficiency in the residential sector, and different analysis including various econometric techniques that study the evolution of energy consumption in developed and developing countries (Donatos et al., 1991; Akmal & Stern, 2001; Al-Faris, 2002; Dergiades & Tsoulfidis, 2008; Achão & Schaeffer, 2009; Dai et al., 2012; Lopez-Rodriguez, 2013; Cuddington & Dagher, 2015).

Similarly, the electricity consumption literature in South Africa includes studies of the determinants of aggregate and sectoral electricity consumption – incorporating the industrial and residential sector (Blignaut & de Wet, 2001; Ziramba, 2008; Amusa, et al. 2009; Odhiambo, 2009; Inglesi, 2010; Inglesi-Lotz & Blignaut, 2011; Inglesi & Pouris, 2010; Inglesi-Lotz, 2011; Kohler, 2014; Blignaut et al. 2015). However, research on the South African residential sector with special focus on the deeper understanding of the energy characteristics and the positioning of the sector in the rest of the world, has not been conducted in a systematic manner to date. Detailed studies on the residential sector energy consumption patterns are important towards determining appropriate policies and measurements that will allow for future increases in electricity access in the residential sector whilst working on policies aimed at reducing CO_2 emissions.

Most studies in the South African literature focus on the determinants of electricity demand – primarily on the economy in its entirety or mainly energy-intensive sectors; much less focus has been given to the residential sector – with the exception of Anderson (2004), Ziramba (2008; 2009) and Ye et at. (2018). An important gap in the literature is the analysis of changes over time in household energy-use characteristics. Therefore, this section focuses on literature dealing with the South African residential sector and its energy consumption patterns.

In South Africa, policies regarding access to basic services including access to electricity in rural areas were not a priority during the Apartheid era (1948 – 1991) where only a third of the population had access to electricity (Ziramba, 2008; Amusa, et al. 2009; Odhiambo, 2009; Inglesi, 2010; Inglesi-Lotz & Blignaut, 2011). Electricity access became a national policy priority for the South African government only post-Apartheid starting in the early 1990s and especially in 1994. Against this background, the South African literature regarding residential energy consumption post-1994 focussed on the effects of access to electricity on rural households' energy consumption and not on the trends and patterns of households' energy demand (Davis, 1998; Thom, 2000; DME, 2003).

Davis (1998) studied energy consumption patterns in rural areas in South Africa focusing particularly in identifying the effects of access to electricity on fuel choices used for everyday tasks such as cooking, heating and lighting. Davis (1998) study found that there is evidence of an 'energy ladder', whereby as income rises, households in rural areas trend away from low-quality fuels like biomass and wood towards more convenient and modern fuels such as electricity and gas to fulfil their energy needs for basic everyday tasks. However, access to electricity was also found to influence the energy transition process. As income rises, electrified households tend to be more dependent on electricity. Additionally, the fuel choice patterns of low-income electrified households were found to be similar to that of non-electrified households; electricity is seen as an additional source of energy. Davis (1998) study was very detailed with regards to energy consumption patterns in rural areas. However, there was a lack of comparison with regards to how energy consumption in rural areas compares to the rest of the country as well as the key electrification policies that were implemented in South Africa up to 1998.

Thom (2000) also studied aspects of electricity and energy consumption in South Africa. The study attempts to explain how access to electricity influences electrical appliance ownership in rural households. Additionally, the study described how rural households who are electrified tend to use electricity and other sources of energy for lighting, cooking and to use electrical appliances such as radios. This study was based on a project by the Energy and Development Research Centre on '*The Role of Electricity in the Integrated Provision of Energy to Rural Areas*' that secured availability of reliable and detailed data for the period 1995 to 1998. By 1999, the electrification of rural households had increased to around 46 percent, compared to 12 percent in 1994.

The main findings suggest that even though many households had become owners of electric appliances such as radios, televisions, kettles, irons and refrigerators, still the level of adoption of these technologies is low and dependent on income levels – the higher the income, the higher the use of electric appliances. Thom (2000) suggests that to meet their basic energy needs, most households in rural areas use a combination of fuels which includes paraffin and candles. It is apparent, that having access to electricity simply adds electricity to the mix of fuels used by rural households; however, it does not fully substitute the use of other fuels. Even though grid electricity is most commonly used for lighting, it was observed that rural households also use electricity for cooking. Yet, low-income households do not use electricity as the single fuel for cooking, they still rely on firewood and paraffin. The relatively low cost of paraffin has led to its continued use for cooking and water heating even after electrification.

Thom (2000) highlighted how the South African electrification program has been implemented as a 'blanket' program and has failed to recognise the fact that some rural households are still not able to afford to pay for electricity beyond the free-electricity allocation, which leads to rural households still relying on other sources of energy to satisfy their basic energy needs.

Madubansi and Shackleton (2005) confirmed one of the key findings by Thom (2000), concluding that, regardless of widespread access to electricity in the country, households still rely on a mix of electricity and other fuels such as paraffin and firewood for lighting, cooking and thermal use. This confirms, as highlighted in the literature and confirmed by Thom (2000), that households view electricity as a complement to other fuels sources instead of as a substitute. Thus, Mabudansi and Shackleton (2005) concluded that as electrification increases in rural areas, energy consumption and the total number of fuels used by households increases. However, despite the increase in expenditure on all sources of energy, the study reported that in 2003, rural households spent around 60 percent of their total energy expenditure in electricity. This is explained by the relatively high monetary value of grid-based electricity relative to alternative energy sources such as wood or kerosene.

Over the last decade, little has been done to track the South African residential sector's energy consumption patterns as well as its path through development, political and policy changes, and technological advancements. Understanding the roots of South Africa's energy behaviour will ultimately aid in prescribing appropriate policies and pressing issues for energy research. Chapter 4 in this thesis, presents research that aims at filling this gap in the literature.

3.2 Literature on the Determinants of Electricity Consumption

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 study attempts.

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 and Smyth, 2005). 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). 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) – have included price 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.

Some of the most relevant international studies regarding the determinants of electricity consumption included Narayan and Smyth (2005) and Narayan, Smyth and Prasad (2007). Narayan and Smyth (2005) estimated for the period 1969-2000 the short and long-run elasticities of residential demand for electricity in Australia using – for the first time – the bounds testing approach to testing cointegration; and adding more explanatory variables such as the price of an energy substitute. The authors explained electricity consumption using two different models. Both models include income per capita and temperature but introduced own price and price of a substitute differently. One model included the price of electricity and price of a substitute of energy (gas) as two separate variables; and the second model introduced prices as the ratio of the real price of electricity to the real price of natural gas. Narayan and Smyth (2005) found that as expected, the income elasticity of demand was positive; the own price and cross-price electricity demand were negative; and that temperature was positive but only significant in the long run.

Narayan, Smyth and Prasad (2007), used a panel unit root test and panel cointegration techniques to estimate the long and short-run income and price elasticities for residential demand for electricity in G7 countries for the period 1978-2003. The motivation to study the G7 countries was based on: i) the fact that in 2005, the G7 countries as a whole generated over 40 percent of the world's electricity, making them the main contributors to CO_2 emissions in the world; and ii) the fact that pricing policies have been identified as effective instruments to improve the efficient use of energy. However, before implementing pricing policies, the price elasticity of demand for electricity needs to be known.

Narayan, Smyth and Prasad (2007) estimated two different models, one that included electricity prices and gas prices (price of a substitute of electricity) separately – in order to understand the magnitude of the impact of electricity prices versus gas prices in determining electricity consumption – and one model that included the ratio of the real price of electricity to the real price of gas. The authors concluded that the variables in both models are cointegrated. The long-run results showed that all variables have the expected sign and are statistically significant. In the short run, as expected, the coefficient of electricity prices has a negative sign and is significant. However, the coefficients of income and natural gas are statistically insignificant. The authors inferred that these results imply that in response to an increase in electricity prices, households switch towards consuming natural gas; however, when the price of electricity stabilises, it takes households several periods to revert back to using electricity.

As mentioned in section 3.1 above, 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 focussed 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.

Some of the key studies that have focussed on studying aggregate electricity demand in South Africa 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. The author focussed on estimating the long-run (12 years) own-price elasticity of electricity demand. The author concluded that the 12-year own-price elasticity of electricity in South Africa is -0.90. According to the author, this indicates that prices could be used as an effective policy instrument to promote reductions in electricity consumption in South Africa (Pouris, 1987). The income elasticity in the long run was reported to be 0.71

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.

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. These results are an indication to policy makers that tariff restructuring might influence consumer behaviour significantly.

Anderson (2004), Ziramba (2008; 2009) and Ye et at. (2018) studied the determinants of electricity consumption in the residential sector specifically. 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 household as well as the size of the dwelling.

This sub-section presented a thorough evaluation of the literature related to the determinants of electricity consumption worldwide and in South Africa. **Table 9** contains a selection and summary of literature on electricity consumption most relevant to the thesis' topic.

Table 9 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

3.3 Literature Related to GHG Emissions Reduction Using CGE Modelling

Over the years, the South African government has closely worked with the private sector and academia to develop broad policy frameworks that identify climate change as a key challenge (Davis Tax Committee, 2015). Therefore, there has been several studies modelling the broad impact of a carbon tax for South Africa (van Heerden et al., 2006; Pauw, 2007; Devarajan et al., 2009; Alton et al., 2014; van Heerden et al., 2016). These modelling exercises have focussed on the decision-making process regarding the best mitigation policy to follow by informing policy design and analysing the implications on different areas in the economy including macroeconomic indicators, industries and other stakeholders.

Details have been given and studied regarding how the carbon tax and different policies designed to combat climate change will balance South Africa's commitment to reduce GHG emissions with the need of reducing poverty, promoting economic growth and maintaining trade competitiveness. South Africa's Intended Nationally Determined Contribution (INDC), which were submitted as part of the ratification of the Paris Agreement, specify the route that the country will follow to achieve the transition path towards a low-carbon economy, along with the suite of policies intended to achieve this goal. However, not enough detail is given regarding the clear effects these policies will potentially have on different households.

In the South African literature, with regards to the effects of climate change policies on specific households, only van Heerden et al. (2006) show in detail how different environmental taxes and its different recycling schemes will impact on the welfare of different households. Using a CGE model that includes more detail with regards to electricity generation types, households' price elasticities of electricity consumption and updated macroeconomics values; chapter 6 in this thesis adds value by providing an updated analysis of the effects that two different PAMs aimed at reducing GHG emissions in South Africa – the carbon tax and energy efficiency gains in the non-coal electricity sector – will have on different households as well as in the economy as whole. That is, this study not only focuses on the carbon tax, but it also takes into account how improvements in energy efficiency – a technological change – in the electricity sector affect households' welfare at different income levels.

CGE models have been widely used in analysing the effects of policies design to mitigate GHG emissions on the overall economy. Babatunde et al. (2017) did a systematic literature review of all the available peer-reviewed papers evaluating the climate change mitigation measures and policy interventions using CGE modelling. The authors concluded that CGE modelling is one of the preferred tools used to address climate change mitigation topics at a global, regional and national level. The main research themes focussed on the carbon tax, energy efficiency, emissions reduction target and renewable energy. With regards to the type of CGE model used, the authors found that static CGE models are employed more often than dynamic ones (Babatunde et al., 2017).

Van Heerden et al. (2006) employed a static, multi-sector CGE model, to evaluate the economy-wide impacts as well as the prospective for a double or triple dividend of different environmental taxes – including a tax on GHG; a fuel tax; a tax on electricity use; and an energy tax – and different recycling options in South Africa. The authors were able to quantify the effects of different policies on different household groups. A triple dividend (i.e., reducing emissions, reducing poverty, and increasing GDP) was found when any of the environmental taxes is fully recycled to subsidize food prices. Additionally, the authors concluded that the carbon tax has a higher environmental effect than the other environmental taxes (van Heerden et al., 2006).

Devarajan et al. (2011) used an static CGE model of South Africa to examine the impact of different environmental taxes including a carbon tax, a sales tax on energy commodities, and a sales tax on pollution-intensive commodities in lowering GHG emissions on the South African economy by 15 percent. Devarajan et al. (2011) found that the carbon tax would yield modest effects on South African welfare and employment levels, followed by the sale tax on energy commodities and the sale tax on pollution-intensive commodities. Additionally, Devarajan et al. (2011) concluded that the welfare of medium-skilled labour will be more impacted than the low-skilled labour group. This study did not evaluate the impact of the different policies on households at a disaggregated level.

Alton et al. (2014) used a dynamic multi-sector CGE model with detailed electricity generation sectors to examine the impact of a carbon tax in South Africa. The authors found that the impacts of a carbon tax over different scenarios are relatively small. Relative to the baseline, by 2025, real GDP is expected to decline between 1 and 1.23 percent (Alton et al., 2014). It was concluded that the impact of the carbon tax will be relatively small on the industrial sector – this is given the different tax-free allowance assumptions.

Van Heerden et al. (2016), provided a thorough evaluation of the impacts of the carbon tax with different recycling schemes on the South African economy. The authors used a dynamic 53-sector CGE model. Results showed, that for the period 2016-2035, the carbon tax will be effective in reducing GHG emissions. However, the carbon tax is shown to have a negative effect on GDP growth relative to the baseline. The effectiveness of the carbon tax is dependent on the level of tax exemptions. Interestingly, the authors showed that different recycling schemes reduce the effectiveness of the carbon tax, this is due to the fact that different recycling schemes are designed to promote economic growth (van Heerden et al., 2016). It was concluded that the better recycling scheme that yielded the lowest negative impact on GDP growth was recycling the tax revenue to all industries in the form of a production subsidy (van Heerden et al., 2016). Chapter 6 in this thesis will follow closely the assumptions and recycling schemes followed in van Heerden et al. (2016); however, this thesis contributes to the literature in focusing on the effects of the carbon tax on South African households.

Nong (2020), developed a global CGE model which included an emissions database that incorporated both CO_2 and non-CO_2 emissions. According to the author, the inclusion of non-CO_2 emissions allows for better evaluation of the impacts of energy policies. The main objective of the paper was to evaluate the impacts of the carbon tax in South Africa. Results suggested that the ideal and most cost-effective carbon tax rate is $9.15 (which is equivalent to the effective tax of R120 per ton of CO_2eq). At this rate, South Africa will reduce emissions between 12.3 and 15.6 percent – taking into account CO_2 and non-CO_2 emissions – with a GDP decline of between 1.17-1.59 percent. Despite the contraction in the economy, results show that renewable energy sectors will expand their production and the economy will move towards a low carbon and sustainable path (Nong, 2020).

Research that focuses on studying the effects of energy efficiency as a mitigation measure in moving towards a low carbon economy using CGE models is wide (Böhringer et al., 2006; Wang et al., 2009; Antimiani et al., 2014; Gunatilake et al., 2014; Mahmood & Marpaung, 2014; Cabalu et al., 2015; Babatunde et al., 2017; Bataille & Melton, 2017; Timilsina, 2017). However, to our knowledge, studies in South Africa have not focussed in energy efficiency – particularly in the electricity sector. In addition to evaluating the effects of the carbon tax, this study will employ a dynamic CGE model to evaluate the effects of the carbon tax and energy efficiency on the South African economy focusing on its impact on low-income households.

Chapter 6 in this thesis follows closely the study by van Heerden et al (2006). However, in terms of the methodology used, the way the scenarios are designed, and the policy shocks applied to the economy, the methodology used by Roos et al. (2020) is implemented.

Roos et al. (2020) implemented a dynamic multi-regional CGE model of the South African economy, with substantial Government Financial Statistics (GFS) detail – including tax and spending – to evaluate the economy-wide and regional impacts of raising VAT and increasing spending on education and health. The study was based on the South African government's announcement to cover its tax revenue shortfall by raising an additional R36 billion in the fiscal period 2018/19 (Roos et al., 2020). The extra tax revenue will come from a 1 percent increase in VAT – taking the effective VAT rate to 15 percent – from April 2018.

The authors acknowledge that increasing the VAT rate increases the cost of living for all South Africans. Therefore, the policy simulation was designed in manner in which the funds raised from the increase in VAT were recycled back into the provincial governments to finance expenditure programmes including education and health (Roos et al., 2020). In this thesis, a similar approach is followed by recycling the revenue collected from the carbon tax in expenditure such as health and education that benefits low-income households the most.

Roos et al. (2020) concluded that increasing VAT have different effects in different regions; overall the effects on GDP are negative in all regions. Regarding employment, the results suggest that the tax causes the real cost of labour to increase which in turn decreases employment in the short run. In the long run, real wages adjust and employment moves back towards the baseline level.

3.4 Conclusion

After thoroughly evaluating both the global and the South African literature on energy and electricity consumption in the residential sector, the residential demand for electricity and the literature that have used CGE models to evaluate the impacts of policies designed at reducing GHG emissions; certain gaps in the literature were identified. Firstly, the South African literature, does not evaluate energy consumption patterns in the residential sector thoroughly – the main focus in the literature has been on studying energy consumption patterns across the entire economy. Therefore, Chapter 4 in this thesis provides an up-to-date and in-depth analysis of the South African residential sector's energy profile.

Secondly, in the literature, the determinants of residential electricity demand in South Africa have been evaluated at an aggregate income level and have not taken into account the possible structural break experienced in the South African economy in 2008 due to the Global Financial Crisis, the South African electricity crisis and consequent electricity price re-structuring. Chapter 5 in this thesis, identifies the determinants of residential electricity demand – including the 2008 structural break – and estimates both income and prices elasticities at both aggregate and disaggregate household income levels.

Chapter 4: Analysing the South African Residential Sector's Energy Profile[10]

[10] This chapter has been published in a peer reviewed journal as: Bohlmann, J.A. & Inglesi-Lotz, R. (2018). 'Analysing the South African residential sector's energy profile'. Renewable and Sustainable Energy Reviews, 96: 240-252.

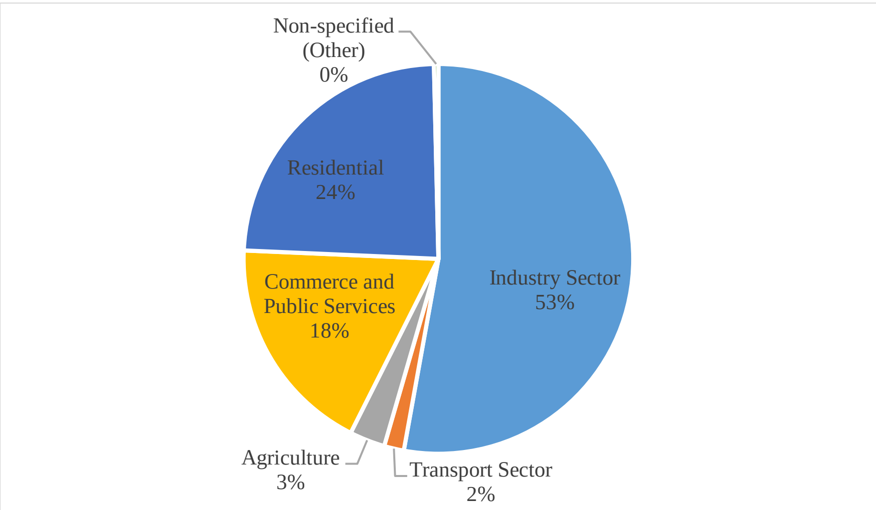
4.1 Introduction

The U.S. Energy Information Administration defines energy consumption in the residential sector as '*…all energy consumed by households excluding transportation uses*' (EIA, 2016) Residential energy consumption includes energy consumed by households for heating, cooking, lighting and water heating (IEA, 2016). Total energy consumption in the residential sector is significantly influenced by different factors such as: income levels, energy prices, energy access, weather, households' characteristics, and appliances used and its energy efficiency. Therefore, the type of energy, as well as the amount of energy consumed in the residential sector differ significantly around the world, especially between developed and developing countries and between regions such as Europe and Africa (IEA, 2016).

The residential and the commercial sector consume a significant share of energy internationally – approximately 21 percent of the total energy delivered worldwide (IEA, 2017). Thus, analysing the residential sector's energy consumption patterns is of upmost importance in predicting the challenges and opportunities on the future design and implementation of energy policy.

As shown in **Figure 3**, data derived from the South African Energy Balances (DoE, 2019), in 2017, the residential sector in South Africa was responsible for 24 percent of total electricity consumption – up from 22 percent in 2016 and 19.8 percent in 1994 (DoE, 2016). **Figure 3** highlights how the residential sector is one of the largest sectors with regards to electricity consumption in South Africa.

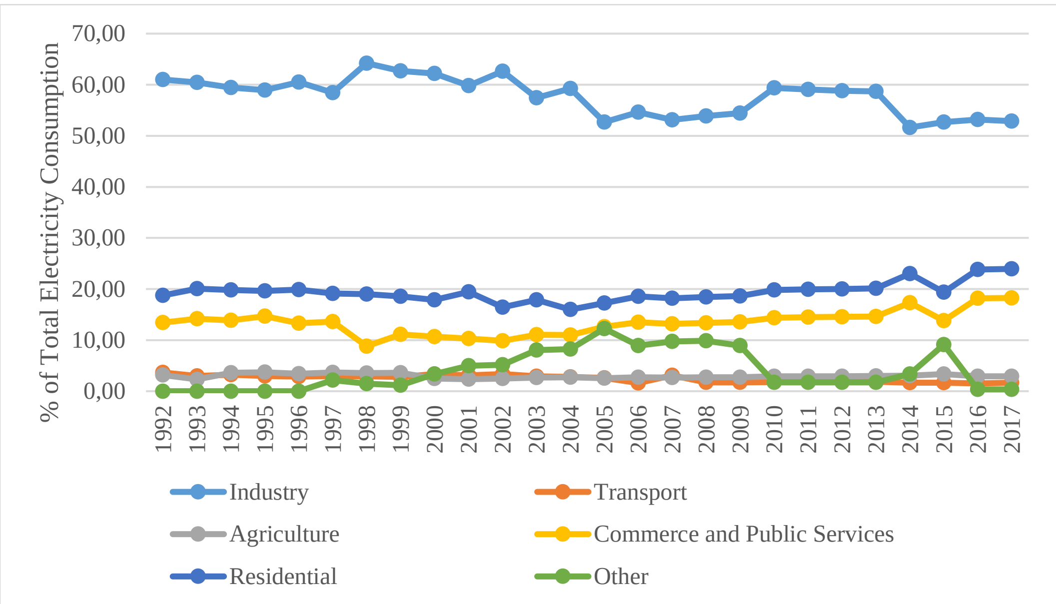
Figure 3 South African Sectoral Electricity Consumption in 2017



Source: Adapted from DoE (2019)

As depicted in **Figure 4**, with the exception of 2015 when the country experienced electricity shortages, the amount of electricity consumed by the residential sector - along with the *commerce and public services* sector – as a share of total electricity consumption has been increasing over time, especially since the early 2000's (DoE, 2019). During this period, overall energy consumption in the South African residential sector increased continuously along with the rise in population, number of households and real incomes. According to the 2011 census – the latest South African census – South Africa's population is over 55 million people, with around 14.5 million households (Statistics South Africa, 2012a). The latest United Nations report on household size and composition around the world confirms that households tend to be smaller today than in the past – adding to the global and local rise in the number of households over the last two decades (United Nations, 2017). As per 2015 estimates, South African households have an average size of 3.30 (Statistics South Africa, 2012a). Additionally, energy consumption per South African household has also been increasing due to changes in consumer preferences as well as the different electrification programmes that South Africa has in place, which have provided electricity connections to over 85 percent of households in the country (DoE, 2017).

Figure 4 South African Electricity Consumption per Sectors 1992-2014



Source: Adapted from DoE (2019)

The main purpose of this chapter is to evaluate the trends, evolution and characteristics of energy consumption in the South African residential sector. In doing so, a comprehensive view of the energy consumption patterns of the residential sector in South Africa is presented by i) evaluating the evolution of energy consumption in the residential sector in South Africa, and ii) analysing the key characteristics that influence the residential sector's energy consumption. An important question the chapter aims to answer is whether there were changes in the sector's behaviour since 2008; a period that was characterised by load shedding and electricity tariff restructuring in South Africa.

This chapter is organised as follows: Section 2 describes the methodology and data used in the chapter. Section 3 provides the main descriptive analytics findings including the trends and key characteristics of energy consumption in South Africa; the sectoral consumption of electricity, the patterns of electricity and energy consumption in South Africa and a brief international comparison of South Africa's electricity consumption patterns against other SADC, BRIC and G-7 countries. Section 4 concludes the chapter.

4.2 Methodology and Data

This section presents the observed energy consumption trends in the South African residential sector and the methodology and data used in this chapter.

4.2.1 Method: Descriptive

This chapter conducts a descriptive analysis towards understanding the South African residential sector's energy characteristics. It focuses on studying the South African residential sector, emphasising the evolution of the electrification process in South Africa; the evolution of energy consumption within the residential sector; the behaviour of households in using energy to satisfy their basic needs of cooking, lighting and eating; and its geographical distribution.

The main sources of information to report on the evolution in the South African energy consumption patterns will be: i) the latest published South African General Household Survey titled *'GHS Series Volume V Energy 2002-2012: In-depth analysis of the General Household Survey data'* (Statistics South Africa, 2013), which measures and reports on different energy sources indicators, providing an in-depth analysis of energy used in South Africa over time;

and ii) the latest Survey of Energy-Related Behaviour and Perceptions[11] titled '*A Survey of Energy-Related Behaviour and Perceptions in South Africa: The Residential Sector*' (DoE, 2013a), which gathers information about the energy related behaviour and patterns regarding energy uses, energy poverty and energy pricing in South Africa. These surveys are data intensive that were overseen by Statistics South Africa, the South African Human Science Research Council (HSRC) and the Department of Energy. Therefore, we believe that the data collected for these surveys are reliable and representative of the South African population. Details on the data collection process for these surveys can be found in the above-mentioned reports (Statistics South Africa, 2013; DoE, 2013a; DoE, 2012).

4.2.2 Data Discussion

The main data sources for this chapter are the Department of Energy, the International Energy Agency, the World Bank and the different waves of the National Income Dynamics Study (NIDS) by the Southern Africa Labour and Development Research Unit (SALDRU). Data regarding access to electricity and electrification statistics for South Africa was gathered from the Department of Energy (DoE, 2017; DoE, 2013b) and the International Energy Agency (EIA, 2015; IEA, 2017). Additionally, key statistics regarding access to electricity for South Africa were collected from the World Bank's World Development Indicators Data (World Bank, 2017b). The World Development Indicators report compiles data from officially recognised international sources, representing the main collection of key indicators by the World Bank (World Bank, 2017b).

This chapter deals with the residential sector holistically, appreciating the sector's importance to the future electricity demand of the country both directly and indirectly through its demand for other goods and services and hence, it looks at some household characteristics that might influence the electricity demand and whether these have changed after 2008. To do so, we evaluate the 4 different waves of the NIDS data. The NIDS project and survey data collection started in 2008 with the aim of closely following over 28000 people from different backgrounds, ages and income categories over time (Woolard et al. 2010). NIDS is the first nationally representative panel study in South Africa, it aims to track '*changes in incomes, expenditures, assets, access to services, education, health and other dimensions of wealth*

[11] These surveys were intended to become an annual study conducted by the South African Department of Energy. However, the surveys were only conducted in 2011 and 2012 providing the latest official available data in South Africa on energy-related behaviours in the residential sector.

being' for over 28000 individuals from 7300 originally interviewed households (Woolard et al. 2010; SALDRU, 2013).

Surveys such as NIDS are important for government, policymakers and other stakeholders since it allows them to understand and track whether individuals are making progress in the society whilst highlighting and following the elements influencing these dynamics.

The NIDS survey is repeated every two years; therefore, it follows how the members of the original 7300 interviewed households move over time whilst examining the evolution in livelihoods of these individuals and households. It is important to note, that NIDS follows and re-interviews individuals, it does not follow households; therefore, whilst the number of individuals interviewed stays the same across waves, the number of households might increase over time (Woolard et al. 2010; SALDRU, 2013).

The NIDS study is conducted by SALDRU, based at the University of Cape Town's School of Economics (Woolard et al. 2010). Since 2008, there have been four waves of NIDS. The first wave of this panel – Wave 1 – was conducted in February 2008, and the data and respective report were released in July 2009 (SALDRU, 2016a). Wave 2 of NIDS was conducted during 2010, with the respective data and results released in 2011; during this wave, people from Wave 1 were re-interviewed providing a fair picture of how South African households have adapted over two years of difficult socio-economic circumstances after the global financial crisis (SALDRU, 2016b). The third wave – Wave 3 – of the survey was conducted between April and December 2012; this wave re-interviewed households from Waves 1 and 2 (SALDRU, 2016c). Fieldwork for the fourth wave of NIDS was conducted during 2014; as per previous waves, Wave 4 re-interviewed households from earlier waves, collecting information on developments in their lives over 2008-2014 period (SALDRU, 2016d). For the reduced sample to be nationally representative and to account and adjust for sample design and non-responses, the NIDS data has household level probability weights.

The NIDS panel dataset is relevant to this study since it includes questions regarding South African households' access to electricity. Additionally, it provides information about the other types of energy used by households and it gives some indication concerning household expenditure on electricity and energy in South Africa.

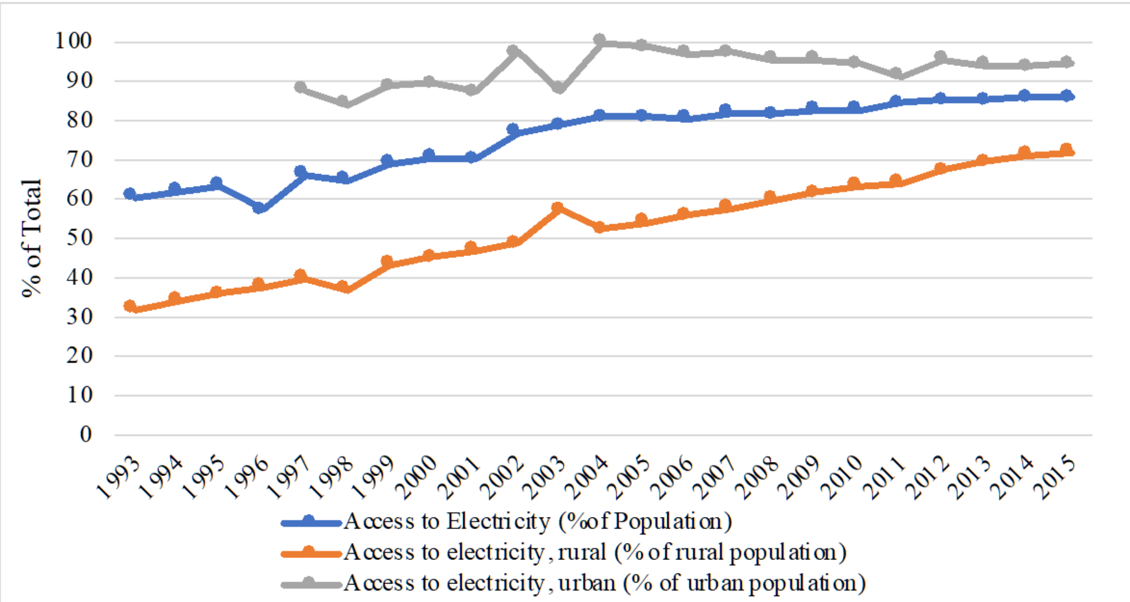
4.3 Main Findings: Descriptive Analysis

This section provides evidence of the patterns of energy and electricity consumption by the residential sector in South Africa. It includes the trends in access to electricity and how it relates to energy poverty and the main alternative sources of energy used by South African households to meet their basic energy needs. Additionally, it discusses the results gathered from evaluating the NIDS database on access to electricity, electricity expenditure and energy used. It also provides a brief international comparison with regards to electricity consumption in South Africa and the rest of the world.

4.3.1 Trends, Geographical and Demographical Characteristics of South African Households' Access to Electricity

The different electrification programmes and policies that the South African government has implemented over the years have been crucial in influencing access to electricity and energy consumption in the residential sector. Access to electricity in South Africa increased from 60.8 percent in 1994 to 86 percent in 2016 (**Figure 5**) (World Bank, 2017; DoE, 2017). The majority of non-electrified South African households reside in the KwaZulu-Natal and Eastern Cape provinces (DoE, 2012; 2013)

Figure 5 South African Access to Electricity

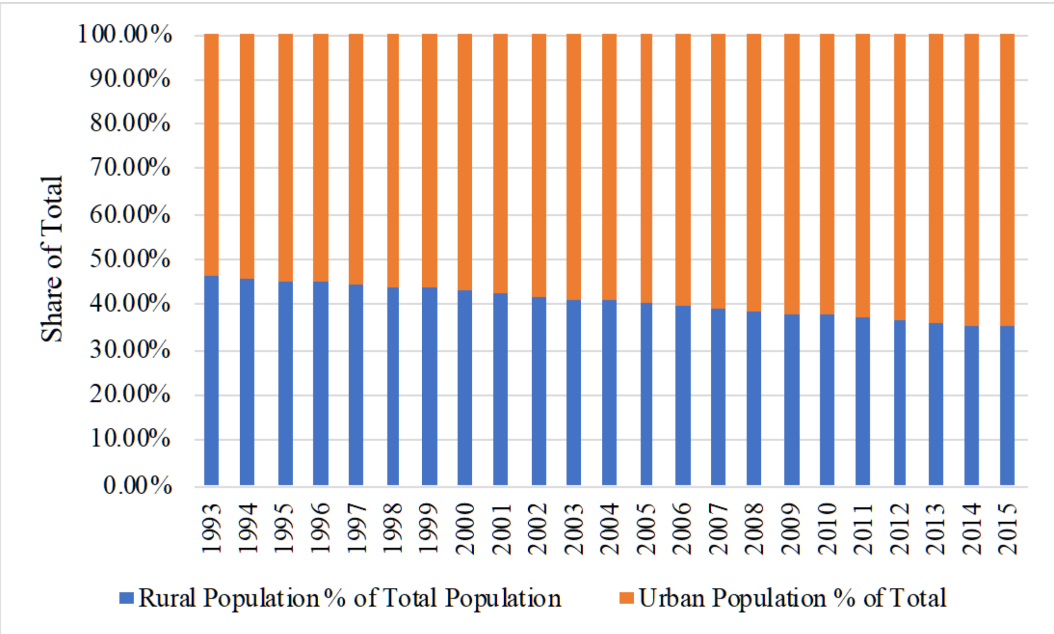


Source: Adapted from The World Bank (2017a, 2017b)

Between 1994 and 1999, over 500000 new connections were made annually in South Africa; this steady increase in electrification can be attributed to the national electrification programme. Between 2013 and 2016, over 890000 new connections were made (DoE, 2016; 2017). The progress made with regards to access to electricity in South Africa has been positive but it was not enough to achieve the Integrated National Electrification Programme (INEP)'s goal of achieving universal access to electricity by 2014. As a result, in 2011, the Department of Energy revised the timeline of INEP's commitment to achieving universal access to electricity to 2025. This is set to be attained by using a combination of both grid and non-grid technologies in the supply of electricity (DoE, 2017).

The proportion of urban vs rural households in a country influences economic development and access to electricity. As shown in **Figure 6**, the share of the rural population as a percentage of the total population in South Africa has been declining over time. According to 2015 estimates, the rural population in South Africa represented 35 percent of the total population; in comparison, the rural population in South Africa was over 50 percent in 1994 (World Bank 2017a; 2017b). This partly highlights some of the economic progress that has been achieved in the country since 1994 due to a broad range of development programmes that have been implemented (The Presidency, 2014). Additionally, as shown in **Figure 5**, access to electricity for both the rural and urban populations have been increasing over time.

Figure 6 South African Rural vs Urban Population Share



Source: Adapted from The World Bank (2017a, 2017b)

By the end of 2015, approximately 72 percent of rural households in South Africa had been connected to the grid compared to 1994 when only 34 percent of rural households were electrified (**Figure 5**) (World Bank 2017a; 2017b). On average, households in urban areas that have access to electricity are more likely to use electricity than those in rural areas.

Data further shows that the proportion of households with access to electricity is lower in households in which the head is 'Black African' than in households in which the head is from other population groups (Statistics South Africa, 2013; 2017b). Households that are male-headed are less likely to be electrified than those headed by a female. The age of the household head is closely correlated with access to electricity; almost 90 percent of households in which the head is over the age of 60 are electrified compared to almost 75 percent of child-headed households. Poorer households – in the first income quantile – are less likely to be electrified than those in the wealthiest quantile, 78.8 and 93.8 percent respectively. As expected, nationally and across all households, formal dwellings are more likely to be electrified than informal dwellings (Statistics South Africa, 2013).

4.3.2 Energy Poverty

As stipulated in the Free Basic Electricity (FBE) programme, the 50kWh of electricity that poor households receive for free each month should be sufficient to cover their main electricity needs (DME, 2003). The implementation of the FBE programme has been influential in households' use of electricity (Statistics South Africa, 2013; DoE, 2013). Poor households that receive FBE are more likely to use electricity and less wood and other biomass for cooking than poor households that do not receive FBE and must pay for electricity. However, free access to electricity does not seem to have a significant impact on lighting. Between 2005 and 2011, only 25 percent of poor households claimed their free basic electricity quota. A reason for this may be that the majority of poor households, who qualified for FBE reported that they are not aware of the FBE policy and do not know if they are getting the service (Statistics South Africa, 2013; DoE, 2013). In 2005, out of the households receiving free basic electricity, 45.8 percent consumed extra units of electricity, compared to only 27.2 percent in 2011 (Statistics South Africa, 2013).

Despite the FBE programme increasing the use of electricity by poor households, the energy poverty issue is still a reality for many South African households who despite being electrified do not access electricity simply because they cannot afford it. Consequently, these households are considered energy poor – spending more than 10 percent of household income on energy – and are heavily dependent on alternative sources of energy such as biomass for cooking and heating. Illegal electricity connections are a direct consequence of this reality; in 2012, 1 percent of household reported that they do have an illegal electricity connection – down from 2 percent in 2011 (DoE, 2012; 2013).

According to the latest household income and expenditure survey, South African households spent around 75 percent of their household expenditure on basic needs such as *housing, electricity and water*, *food and transport* (Statistics South Africa, 2012c)[12]. Households in the bottom income decile spent around 6 percent of their household consumption expenditure on electricity and other fuels; compared to households on the top income decile who only spent 1.7 percent (Statistics South Africa, 2012c). Households in the upper expenditure decile spent 1.7 percent of their household consumption expenditure on electricity and 0.1 percent on liquid fuels compared to 4.5 percent and 1.4 percent for households in the lower decile (Statistics South Africa, 2012c).

Poor households tend to pay less towards electricity in nominal terms, while that represents a larger proportion of their total monthly income: 50 percent of households nationally spent close to 5 percent of their total monthly income on electricity (2012 data). It is also shown that a significant number of households are energy poor, with almost 10 percent of households found to spend 20 percent or more of their income on electricity. According to Statistics South Africa (2013), energy poor households are most prevalent in the Eastern Cape and Gauteng. Nevertheless, the number of South African households considered energy poor declined from 47 percent in 2011 to 43 percent in 2012 (DoE, 2012; 2013). When classified by income level, in 2012, almost 75 percent of households in the first quantile were energy poor; with only 18 percent of households in the richest quantile.

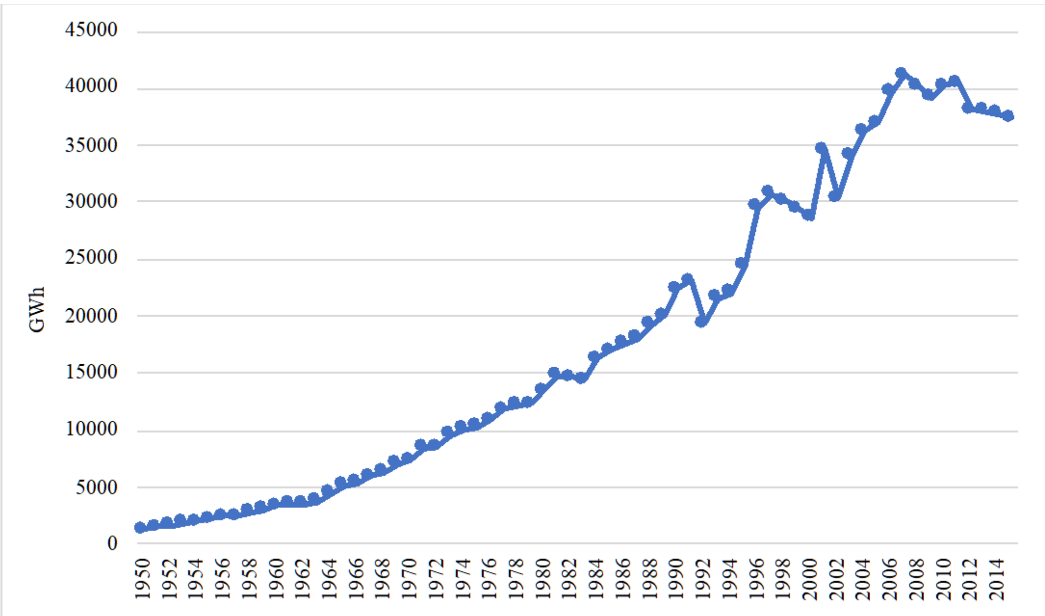
These statistics related to energy poverty explain why despite the advances made with regards to electrification in South Africa over the last 20 years, and given that historically, electricity prices in South Africa have been amongst the lowest in the world, some low income-electrified households continue to use other energy sources to meet their basic energy needs (Statistics South Africa, 2013; DoE, 2013).

[12] More details regarding household's income and expenditure will be presented in Chapter 5

4.3.3 Electricity Consumption and Prices in the South African Residential Sector

As shown in **Figure 7**, total energy consumption by the residential sector has increased significantly since 1950. Some key trends can be observed from the data on electricity consumption by the sector. Firstly, after 2003, when the FBE programme was implemented, residential electricity consumption increased steadily up to 2007. Secondly, after 2008, a period characterised by load shedding and electricity price restructuring, it can be seen that residential electricity consumption declined. The reasons for this change in behaviour may be attributed to: i) increased tariffs that incentivised energy savings and demand management behaviour; ii) the global financial crisis that affected the income levels of households; iii) load shedding that has given motivation to many consumers to search for alternatives, such as off-grid or self-generation (gas or solar). Offsetting this effect post-2008 was a continuation in the decline of the average size of South African households – from 3.8 in 2008 to 3.3 in 2015 – combined with an increase in the total number of households, which resulted in less occupancy but more households overall.

Figure 7 Electricity Consumption in the South African Residential Sector: 1950-2015

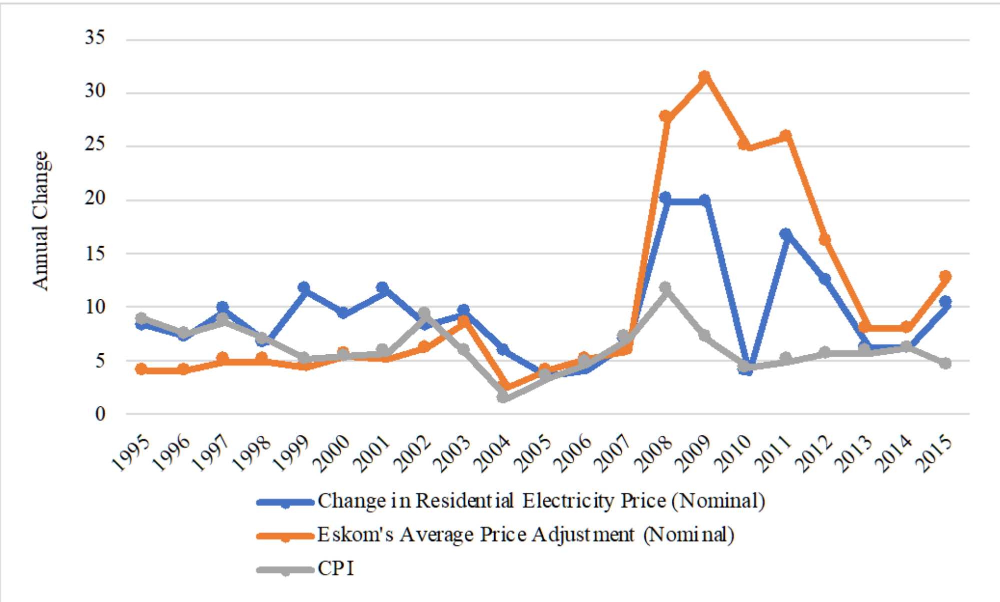


Source: Adapted from National Energy Council (1990) and IEA (2017)

The demand curve for electricity is unambiguously downward sloping. However, the relationship between changing electricity prices and electricity consumption over time is often blurred by shifts in the electricity demand curve in line with economic and population growth.

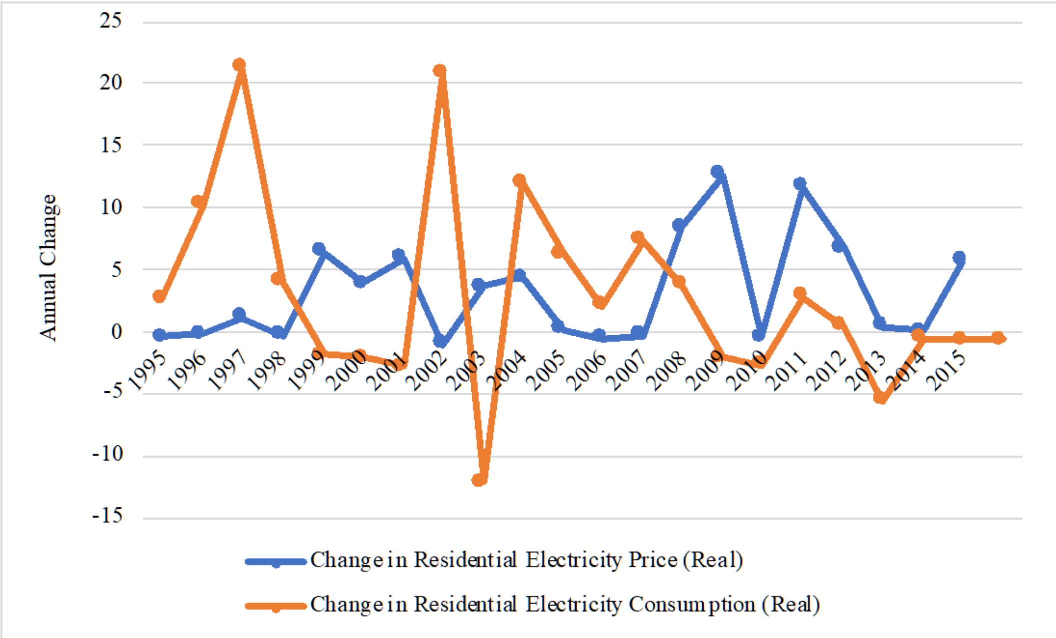
Up to the 2008 electricity price restructuring phase, annual increases in the nominal residential price of electricity in South Africa were on average slightly higher than the average price adjustment of electricity. Annual changes in the nominal residential price of electricity were in line with CPI up to 2008 (**Figure 8**). Between 2008 and 2012, Eskom raised electricity prices at a rate far outpacing inflation. Various reasons contributed to this rapid increase in the price of electricity, including historical price factors, capital expansion and rising costs associated with supply constraints. Household consumption of electricity fell slightly during the 2008-09 period. On face value, this supports the observation that residential electricity consumption patterns in South Africa did change after the 2008 price restructuring. However, this period coincided with the aftermath of the global financial crisis and subsequent recession and care should therefore be taken in ascribing causation. Due to a combination of factors such as demand-side management, an uptake in off-grid solutions and low economic growth, growth in household consumption of electricity has remained subdued in the aftermath of the large price increases during the 2008-2012 period. In general, real consumption of electricity has closely followed the pattern of low economic growth during the 2013-2015 period (**Figure 9**).

Figure 8 Annual Changes in Nominal Electricity Prices



Source: Adapted from DoE (2017b), StatsSA (2017c), Eskom (2017)

Figure 9 Real Annual Changes in Residential Electricity Consumption vs Annual Changes in Residential Electricity Prices



Source: Adapted from IEA (2016), DoE (2017b)

<u>*4.3.4 South African Energy and Electricity Consumption Patterns*</u>

This sub-section discusses the energy consumption patterns as well as types of energy consumed by South African households to satisfy their basic energy needs.

<u>*Expected Energy Consumption Patterns in South African Households*</u>

According to Statistics South Africa (2012a), residential energy is classified in three types: traditional, transitional and modern fuels. Traditional fuels include all solid fuels like firewood. Transitional fuels include solid fuels such as coal and other fuels such as paraffin and LPG gas. Modern fuels consist of electricity which can originate from both the electricity grid or from renewable sources. In line with this classification, residential energy use in South Africa is expected to continue transitioning from traditional fuels towards modern fuels (Statistics South Africa, 2012). Additionally, electricity demand is expected to continue growing at the same growth rate of population (Statistics South Africa, 2012b; 2013).

Due to urbanisation, electrification – especially in rural areas – and increasing purchasing power of households, the energy consumption patterns by South African households continuously change. Even though electrification remains the key factor influencing electricity consumption by households, poorer households are still expected to rely on other sources of energy even after having access to electricity. Therefore, as part of the fuel transition, most South African households have moved towards consuming more transitional fuels, with the share of traditional fuels used for cooking and heating decreasing.

Prevalence of Traditional Fuels and Biomass Consumption in South African Households

Due to their easy access and low costs incurred by the residential consumers, traditional fuels such as firewood and other forms of biomass including agricultural waste and charcoal, are used for cooking. The use of these fuels can be hazardous, and can negatively affect health, the environment and the socio-economic development of households (Statistics South Africa, 2013). The consequences of not having access to electricity and relying on biomass are vast. Firstly, it has been proven, that households without access to electricity need to spend a significant amount of time fetching and harvesting biomass; this translates in fewer hours spent at work and hence less income earned. Secondly, the burden of collecting biomass tends to fall on women, placing unfair physical and time pressure on them. Thirdly, burning of traditional biomass inside households contributes to health-threatening indoor air pollution. Finally, unsustainably harvesting biomass can lead to heightened deforestation and land degradation (Statistics South Africa, 2013).

Over time, poorer South African households have been more dependent on low-cost biomass fuels for cooking and heating. In South Africa, the use of solid fuels such as firewood is more concentrated on poorer provinces with large rural populations like Eastern Cape, North West and Limpopo (Statistics South Africa, 2013).

Main Sources of Energy Used by South African Households

Approximately 14 percent of South African households do not have access to electricity. Therefore, as explained in previous sections, non-electrified and poor households use alternative sources of energy to sustain their basic energy needs. It was observed, that the most common alternative sources of energy are paraffin, firewood, LPG, coal, crop residue and animal dung. There are considerably different patterns of energy consumption between electrified and non-electrified households and between rural and urban households (DoE, 2012; 2013). Households without access to electricity – regardless of their income level and geographical location – tend to use more solid fuels for cooking and both water and space heating than households with access to electricity. Similarly, when compared to urban households, rural households use more substitute sources of energy even if their residences are electrified. The same is true for poorer versus richer households.

Energy Choice for Cooking

It was observed, that households' use of electricity for cooking increased from 58 percent in 2002 to over 75 percent in 2011. Over the same periods, the use of solid fuels including coal, firewood and animal dung declined from 22 percent in 2002 to 12 percent in 2011 (Statistics South Africa, 2012). Between 2011 and 2012, the patterns of energy used for cooking did not really change for electrified households. However, non-electrified households did consume more firewood from 40 percent in 2011 to 54 percent in 2012, and less paraffin in 2012 compared to 2011, from 50 to 38 percent. This can be attributed mainly to increased paraffin prices (DoE 2012; 2013).

At a provincial level, in 2012, more than 80 percent of households in Western Cape, Free Estate, Gauteng and Northern Cape used electricity for cooking. In Limpopo and the Eastern Cape, around 50 percent of households used electricity for cooking. As expected, the use of solid fuels for cooking is more common in both Limpopo and the Eastern Cape than in the other provinces (Statistics South Africa, 2012). Firewood, coal, animal dung and paraffin are the preferred alternative energy sources used for cooking.

Looking at the energy choice for cooking by income quantile, in line with the energy ladder, the use of electricity for cooking purposes increases as household's wealth increases. Conversely, the use of solid fuels and biomass for cooking purposes is negatively related to households' wealth. It was reported that less than 1 percent of households in quantile 5 – high-income households – use substitute sources of energy for cooking.

Energy Choice for Space Heating

Energy used for space heating varies with the different weather seasons. As expected, electricity used for space heating is seasonal. Therefore, households tend to use more electricity for space heating over the winter months than during summer (Statistics South Africa, 2012). Between 2002 and 2012, the use of alternative sources of energy for space heating decreased from 92.8 to 72.3 percent. In spite of access to electricity increasing between 2002 and 2012, electricity used for heating purposes decreased by over 10 percent in 2012 9 Statistics South Africa, 2012). Similarly, there was a decrease on the percentage of households using firewood as an alternative source of energy for space heating from over 23 percent in 2002 to around 16 percent in 2012 (Statistics South Africa, 2012).

In 2012, at a provincial level, around 40 percent of households in North West, KwaZulu-Natal and the Western Cape did not use energy for space heating. Using electricity for space heating is more prominent in Gauteng, North West and Northern Cape and least common in both the Western Cape and Eastern Cape. Firewood as an energy source used for space heating is mostly used in Mpumalanga and Eastern Cape; whilst paraffin is commonly used in the Eastern Cape and Free State (Statistics South Africa, 2012).

Households living in formal housing tend to use electricity for space heating. Yet, more access to electricity does not necessarily translate into increased electricity use for domestic purposes. Less than half of electrified households used electricity for space heating purposes. As measured by income quantiles, the use of electricity for space heating purposes increases with household wealth (Statistics South Africa, 2012).

Energy Choice for Heating Water

Sanitary activities such as bathing, washing clothes and washing dishes are the main activities for which water is heated for. Energy used for water heating purposes is highly linked to income level; wealthier households have been reported to have more electric geysers, washing machines and dishwashers than poorer households (Statistics South Africa, 2012).

Nationally, in 2012, more than 75 percent of electrified households used electricity for heating water, whilst around 12 percent of households used solid fuels and around 7 percent used paraffin. Households residing in formal houses use more electricity to heat water than households in informal dwellings (Statistics South Africa, 2012). Income and electricity use are positively related. It was observed, that as income rises, the use of electricity for heating water increases. Conversely, there is an inverse relationship between income per capita and the use of solid fuels for water heating purposes. Over 85 percent of electrified households used electricity to heat water. On the other hand, households with no access to electricity used paraffin, solid fuels and LPG as alternative energy sources to heat water.

Energy Choice for Lighting

Lighting is key to households’ social development and security. Households need lighting for reading, studying and socialising. Between 2002 and 2011, the use of electricity for lighting in electrified households increased from 76.2 percent to over 87 percent (Statistics South Africa, 2012). As expected, the increase in electricity used for lighting resulted in decreases in paraffin and candles used as alternative energy sources for lighting purposes (Statistics South Africa, 2012). There was no change in the patterns of electricity consumption for lighting by electrified households between 2011 and 2012. In both occasions, electrified households used electricity almost exclusively as a source of lighting – 97 percent, with less than 1 percent of electrified households reporting that they still use candles. However, non-electrified households relying on candles as the main source of energy for lighting, with paraffin being the second most used energy source, decreased from 67 percent in 2011 to 59 percent in 2012.

Understandably, electricity used for lighting is highly correlated to access to electricity. Households in Western Cape and KwaZulu-Natal use more electricity for lighting purposes than households in the rest of the country. Paraffin is commonly used in Eastern Cape, whilst candles are preferred in KwaZulu-Natal (Statistics South Africa, 2012).

The percentage of households using electricity for lighting increases as income per capita increases. Around 95 percent of households in income quantile 5 use electricity for lighting Statistics South Africa, 2012).

4.3.5 NIDS Findings

In this section, we evaluate the key results observed from the NIDS dataset regarding households' access to electricity, the type of energy used by households and households' expenditure on electricity and energy in South Africa. These results are evaluated to determine the different patterns of residential electricity consumption in South Africa for the period 2008-2014.

As mention in the data section, a common feature observed in the NIDS dataset is the increase in the number of households over time (except during Wave 2 in 2010 where the number of households declined compared to Wave 1 in 2008). This increase in the number of households was due to the fact that NIDS follows individuals – and not households – over time. Therefore, as individuals move out of their original households, they are now counted as part of a new household (Woolard et al. 2010).

Table 10 provides estimates for the four different NIDS Waves of the percentage of households that have access to electricity in 2008 (Wave 1), 2010 (Wave 2), 2012 (Wave 3) and 2014 (Wave 4). It can be concluded that electricity access has been increasing over time from 74.4

percent in 2008 to 75.7 percent in 2010, 83.3 percent in 2012 and 87 percent in 2014. Overall, access to electricity is reasonably high across South Africa and the NIDS results are in line with the electrification reports by the South African Department of Energy which estimate a national electrification rate of over 86 percent (DoE, 2017).

Table 10 NIDS Access to Electricity

%	Yes	No	Missing	Refused	Don't Know	Total
Wave 1 (2008) - 7296 Households	74.40	21.57	4.03	-	-	100
Wave 2 (2010) - 6782 Households	75.67	23.98	0.07	0.28	-	100
Wave 3 (2012) - 8033 Households	83.34	16.56	-	0.07	0.025	100
Wave 4 (2014) - 9618 Households	87.02	12.98	-	-	-	100

Source: Adapted from SALDRU Waves 1 to 4 Datasets

With regards to household spending on electricity, an increasing trend can be observed between 2008 and 2014 with 65.9 percent of households spending on electricity in 2008 compared to over 72 percent in 2014 (**Table 11**). An inverse trend is observed with regards to expenditure on other energy sources; whereby, 32.4 percent of households reported to have spent on other energy sources in 2008 compared to 25.9 percent in 2014 (**Table 12**).

Table 11 NIDS Household Expenditure on Electricity

%	Yes	No	Missing	Refused	Don't Know	Total
Wave 1 (2008) - 7296 Households	65.93	33.62	0.36	0.08	0.01	100
Wave 2 (2010) - 6782 Households	-	-	-	-	-	-
Wave 3 (2012) - 8033 Households	73.45	26.23	-	0.09	0.24	100
Wave 4 (2014) - 9618 Households	72.98	26.72	-	0.02	0.28	100

Source: Adapted from SALDRU Waves 1 to 4 Datasets

Table 12 NIDS Household Expenditure on Other Energy Sources

%	Yes	No	Missing	Refused	Don't Know	Total
Wave 1 (2008) - 7296 Households	32.35	66.76	0.78	0.08	0.03	100
Wave 2 (2010) - 6782 Households	-	-	-	-	-	-
Wave 3 (2012) - 8033 Households	28.63	71.18	-	0.14	0.05	100
Wave 4 (2014) - 9618 Households	25.85	74.03	-	0.09	0.03	100

Source: Adapted from SALDRU Waves 1 to 4 Datasets

Between Wave 1 in 2008 and Wave 4 in 2014, a greater share of households are using electricity from mains for cooking, heating and lighting. This seems to be in line with increases in access to electricity. Firewood and paraffin are the preferred alternative energy sources for cooking. For heating, firewood is the preferred energy source. After electricity, paraffin and candles are the preferred energy sources for lighting (**Table 13**, **Table 14** and **Table 15**).

In line with the results reported by Statistics South Africa (Statistics South Africa, 2012), 70 percent of households still rely on other energy sources to satisfy their energy needs. The reliance on these alternative energy sources suggests that lower to middle-income households still perceive electricity as one of the energy options available to consume on a daily basis (Statistics South Africa, 2009; 2012). However, as reported above, households are increasingly using electricity from mains for cooking, heating and lighting. These increases in both electricity access and use of electricity from mains is a positive sign towards electricity becoming the main – and possibly the only – source of energy that South African households will use in future to satisfy their energy needs.

Table 13 NIDS Sources of Energy Used by Households for Cooking

%	Animal Dung	Candles	Coal	Electricity from Generator	Electricity from Mains	Gas	Paraffin	Refuse	Solar Energy	Wood	Neighbour	Other	None	Missing	Don't Know	Total
Wave 1 (2008) - 7296 Households	0.18	0.00	1.03	0.53	64.36	2.67	11.47	-	0.01	19.00	-	0.04	0.10	0.60	-	100
Wave 2 (2010) - 6782 Households	0.16	0.01	1.31	0.24	72.65	1.58	8.14	0.24	0.25	14.49	0.01	0.00	0.52	0.40	0.00	100
Wave 3 (2012) - 8033 Households	0.09	0.00	0.75	0.16	74.90	2.59	5.69	0.07	0.01	15.60	0.00	0.01	0.09	0.04	0.01	100
Wave 4 (2014) - 9618 Households	0.03	0.00	0.55	0.81	77.56	2.87	4.42	0.00	0.09	13.42	0.00	0.05	0.17	0.00	0.02	100

Source: Adapted from SALDRU Waves 1 to 4 Datasets

Table 14 NIDS Sources of Energy Used by Households for Heating

%	Animal Dung	Candles	Coal	Electricity from Generator	Electricity from Mains	Gas	Paraffin	Refuse	Solar Energy	Wood	Neighbour	Other	None	Missing	Don't Know	Total
Wave 1 (2008) - 7296 Households	0.22	0.00	2.44	0.49	52.25	0.82	7.10	-	0.03	25.00	-	0.04	10.20	1.41	-	100
Wave 2 (2010) -6782 Households	0.25	0.00	2.15	0.29	65.50	0.80	7.95	0.25	0.25	17.02	0.00	0.06	5.13	0.32	0.03	100
Wave 3 (2012) - 8033 Households	0.10	0.00	1.46	0.16	64.00	1.10	5.78	0.09	0.05	20.53	0.00	0.00	6.67	0.05	0.02	100
Wave 4 (2014) - 9618 Households	0.05	0.00	1.40	0.60	65.17	1.00	5.20	0.00	0.10	18.01	0.00	0.08	8.38	0.00	0.00	100

Source: Adapted from SALDRU Waves 1 to 4 Datasets

Table 15 NIDS Sources of Energy Used by Households for Lighting

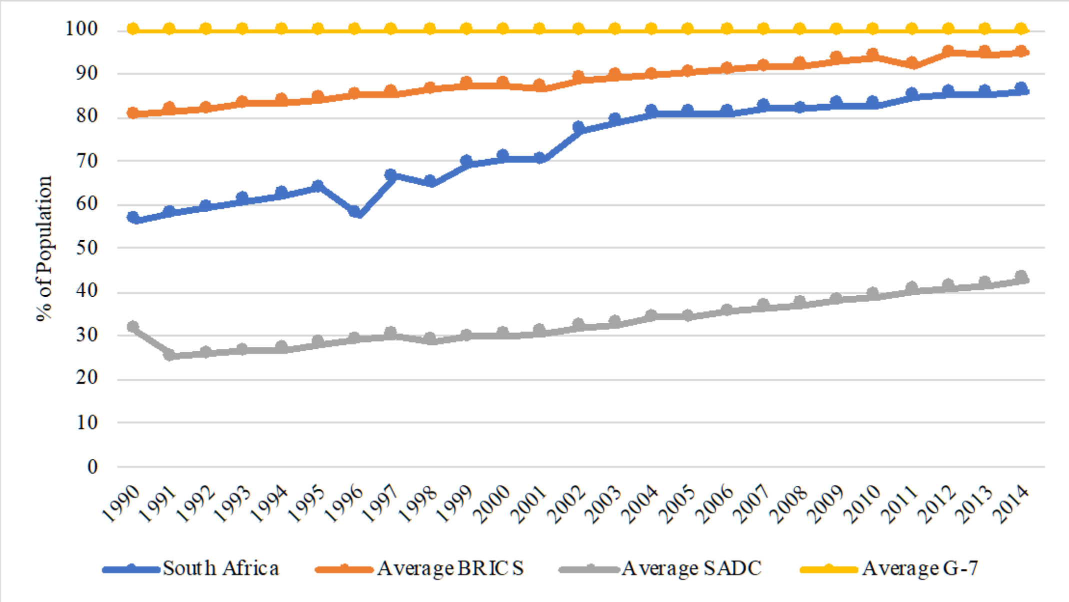
%	Animal Dung	Candles	Coal	Electricity from Generator	Electricity from Mains	Gas	Paraffin	Refuse	Solar Energy	Wood	Neighbour	Other	None	Missing	Don't Know	Total
Wave 1 (2008) - 7296 Households	0.00	18.28	0.00	0.52	76.58	0.11	3.48	-	0.18	0.00	-	0.03	0.16	0.66	-	100
Wave 2 (2010) -6782 Households	0.00	13.86	0.00	0.35	80.51	0.10	3.85	0.22	0.16	0.00	0.00	0.04	0.50	0.40	0.00	100
Wave 3 (2012) - 8033 Households	0.00	12.62	0.00	0.24	84.75	0.14	1.90	0.07	0.19	0.00	0.00	0.00	0.06	0.01	0.01	100
Wave 4 (2014) - 9618 Households	0.00	9.04	0.00	0.61	87.52	0.07	1.86	0.00	0.73	0.00	0.00	0.04	0.11	0.00	0.01	100

Source: Adapted from SALDRU Waves 1 to 4 Datasets

4.3.6 International Comparison of Electricity Consumption[13]

As expected, South African access to electricity compares to the average access to electricity in developing countries such as BRICS, it is higher than the average in SADC countries but it is lagging behind when compared to developed countries – refer to **Figure 10**.

Figure 10 Access to Electricity: South Africa vs SADC, BRIC and G-7 Countries



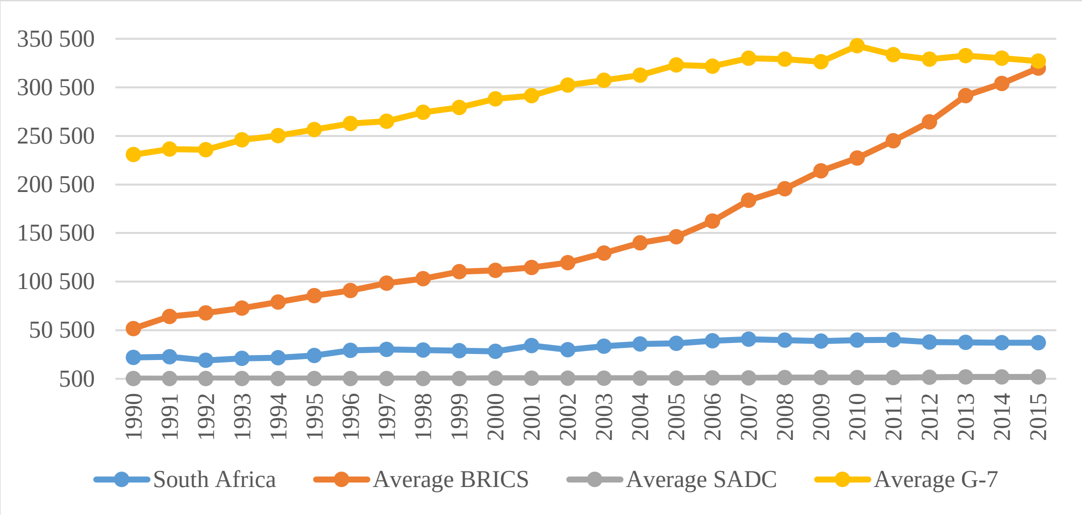
Source: Adapted from The World Bank (2017a)

Residential electricity consumption in South Africa is well below the average of both the G-7 countries and the BRICS countries. On the other hand, the average size of South African households is on par with the average household size in other BRICS countries; smaller than the SADC average and; bigger than those in G-7 countries – refer to

Figure 11. When controlling for differences in the population size amongst the different country groups, it can be seen that electricity consumption per capita in South Africa is above the average of both the BRICS and SADC, but still, below the G-7 countries – refer to **Figure 12**.

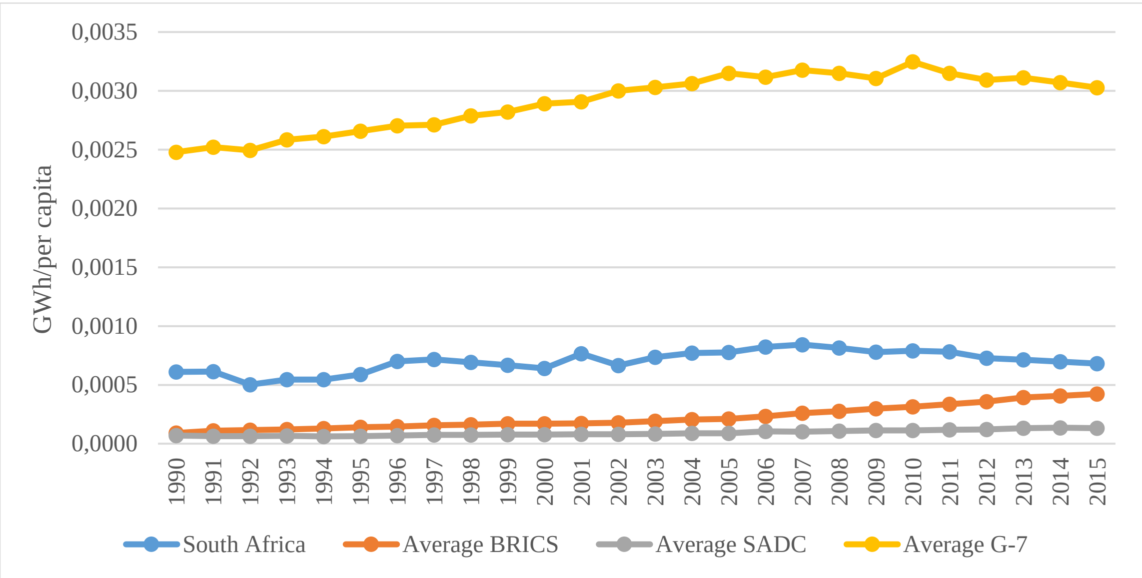
[13] Electricity consumption and residential electricity consumption data for the SADC region is not widely available; especially for Comoros, Lesotho, Madagascar, Malawi, Mauritius Namibia, Seychelles and Zambia. Therefore, the average residential electricity consumption presented for the SADC region only includes countries for which data was available. This applies for data used in Figures 8-10.

Figure 11 Residential electricity Consumption: South Africa vs SADC, BRIC and G-7 Countries



Source: Adapted from The World Bank (2017a)

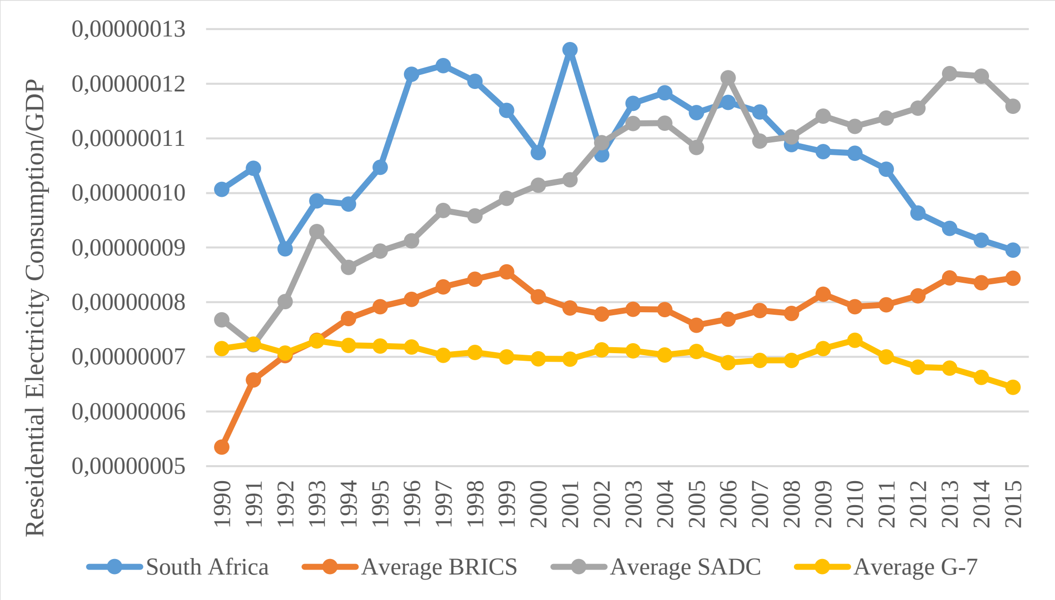
Figure 12 Residential Electricity Consumption Per Capita: South Africa vs SADC, BRIC and G-7 Countries



Source: Adapted from The World Bank (2017a)

In terms of residential electricity consumption as a share of GDP. It was observed that on average, the South African residential sector consumes more energy than all the other countries with the exception of the post-2008 period, where the average residential consumption as a share of GDP surpassed the average of all countries including South Africa – refer to **Figure 13**.

Figure 13 Residential Electricity Consumption As a Share of GDP: South Africa vs SADC, BRIC and G-7 Countries



Source: Adapted from The World Bank (2017a)

4.4 Conclusion

After analysing the trends, evolution and characteristics of energy consumption in the South African residential sector, it is evident that the country still faces significant socio-economic disparities. More than 70 percent of low-income households rely on sources of energy other than electricity to satisfy their basic energy needs, whilst medium and high-income households are reported to have near-universal electricity access. South African households that have access to electricity use it to cover their basic energy needs of lighting, cooking and heating. However, as observed in the data analysis, electrified households still rely on other sources of energy such as coal, paraffin, candles, gas and firewood to meet these needs. Households without access to electricity primarily depend on candles, firewood, paraffin and coal to meet their energy needs.

With an electrification rate of almost 90 percent, South Africa has made great progress in that field. Even so, there is still a considerable amount of rural and low-income households that are energy poor and cannot afford using electricity to cover all their basic energy needs, despite being electrified and enjoying the benefits of the Free Basic Electricity programme. Therefore, these households still view electricity as an additional source of energy and are still dependent on different sources of energy such as wood and paraffin to satisfy their energy needs. As per Davis (1998) and Statistics South Africa (2012c), this proves that South Africa has a typical energy ladder where households progressively move away from low-quality energy sources such as wood and paraffin towards convenient and versatile modern sources of energy such as electricity and gas as income rises.

Electrified households use electricity as their main source of energy for lighting; only about 3 percent of electrified households rely on candles and paraffin for lighting. The main source of energy for lighting for non-electrified households is candles – which is used by around 60 percent of non-electrified households – followed by paraffin. The use of electricity for cooking has increased over time, but still approximately 20 percent of households use other sources of energy for cooking purposes. For non-electrified households, firewood, coal, crop residue, animal dung and paraffin are the main energy sources for cooking. With regards to the use of electricity for heating domestic space, it was found that around 40 percent of all households use alternative energy sources or opt for wearing warmer clothing and blankets. Around 45 percent of electrified households use electricity for domestic heating, only a minimal percentage of households uses other sources of energy such as firewood and paraffin. For non-electrified households, firewood is the main source of energy for space heating purposes, with paraffin being the second most used source. For heating water for bathing purposes, most households rely on a single source of energy. Around 65 percent of South African households use electric appliances to heat water for bathing purposes. Electrified households tend to use either a geyser or a kettle, whereas non-electrified households tend to prefer using firewood or paraffin.

Results from the NIDS dataset indicated that electricity access is reasonably high across South Africa. Also, households' spending on electricity is increasing; inversely expenditure on other sources of energy such as paraffin and wood is declining. In line with increases in access to electricity, South African households are using more electricity from mains to satisfy their daily energy needs.

With more households expected to be connected to the grid and with new grid connections planned to be – at least partially – based on renewable energy sources, electricity consumption patterns by South African households are expected to change over time.

Chapter 5: Examining the Determinants of Electricity Demand by South African Households per Income Level

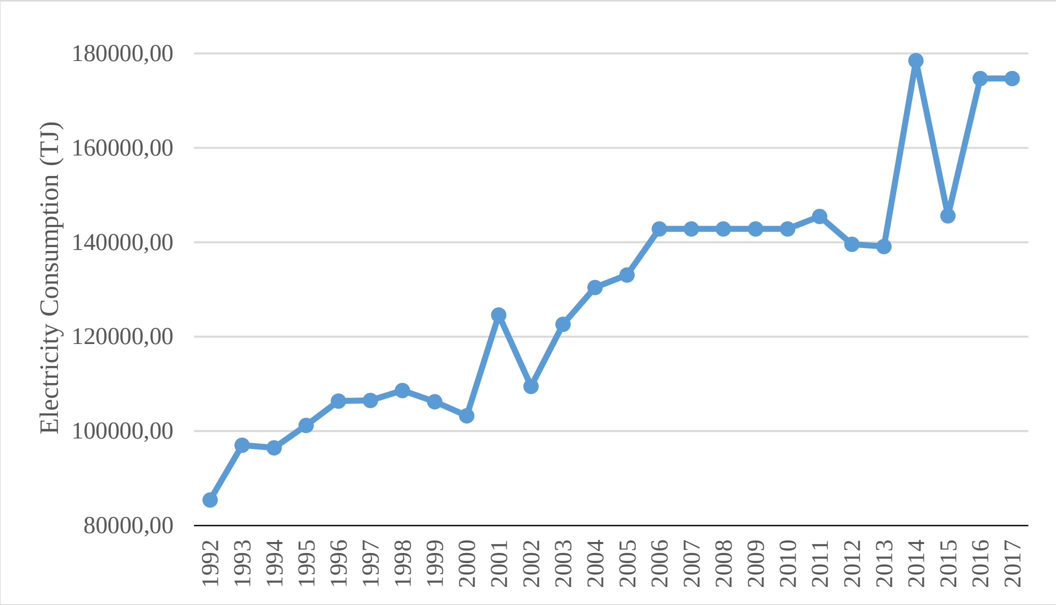
5.1 Introduction

As detailed in Chapter 4, 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 14**, with the exception of 2014/15, where South Africa experienced its second wave of load shedding and consumers were forced to reduce its electricity consumption[14]. 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 kW/h of free electricity per month to low-income households to help them cover their basic energy needs (DME, 2003; Bohlmann & Inglesi-Lotz, 2018).

This chapter 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. 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).

[14] A supply-side shock due to lack of electricity supply

Figure 14 Electricity Consumption in the South African Residential Sector: 1992-2017



Source: Adapted from DoE (2019)

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 consumption of these items which could be either complementary or substitute goods.

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 chapter 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, energy-efficiency gains in the electricity sector and demand side management policies that aim at reducing electricity consumption in the residential sector. In estimating these parameters, 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 is implemented.

Thus, the main contribution of this chapter 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 chapter 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 chapter amalgamates 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 chapter includes food prices as an extra determinant on the households' decision to consume electricity.

Additionally, this chapter 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. Additionally, the parameters estimated in this chapter, will be used in updating the relevant elasticities and parameters in the University of Pretoria's General Equilibrium Model (UPGEM) that will then be used in future research in analysing the economy-wide effect of different policies and measures aimed at reducing GHG emissions in South Africa.

The remainder of this chapter is structured as follows: Section 2 presents the methodology and data. The empirical results are provided in section 3. Section 4 summarises the main findings and concludes the chapter.

5.2 Methodology and Data

5.2.1 Theoretical Framework

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 chapter, 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 are estimated[15]. All variables – except the dummy – are in their natural logarithms.

The estimated aggregate model takes the following form:

$$lnElec\_Cons_t = \beta_0 lnFood\_Price_t + \beta_1 lnYd_t + \beta_2 lnElec\_Price\_Int_t + \varepsilon_t \quad (1)$$

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 chapter, β_0 is expected to define whether electricity consumption and food are substitute or complement goods. Therefore, if β_0>0 food and electricity are substitute goods and if β_0<0 they are complements goods[16]. 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 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:

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

[15] The model was tested by including paraffin as a substitute of energy but he variables was found to be insignificant.

[16] 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 chapter:

- Substitute goods → β_0>0 ; ↑Food price; ↓Food demand; ↑Electricity consumption
- Complement goods → β_0<0; ↑Food price; ↓Food demand; ↓Electricity consumption

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

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

The economic a priori expectations for the disaggregated models are the same as for the aggregated model. However, this chapter tries to unveil 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

5.2.2 Data Description

The variables used in this chapter are residential electricity consumption, food prices, gross national disposable income, electricity prices and a 2008 dummy variable. The main data sources for this chapter 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 16** describes the data source and time series for all the variables used in this chapter. 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.

Table 16 Variables Used in the ARDL Model[17]

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

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 South African household's expenditure patterns on electricity in Chapter 2. 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 17**, 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.

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

Table 17 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)

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 chapter 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 were more suitable for this chapter.

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 18** – 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. These shares were applied to the aggregated data for gross national disposable income to divide gross national disposable income per income group.

Table 18 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)

Food Prices

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

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

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.

The summary of descriptive statistics is given in **Table 19**

Table 19 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

5.2.3 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.[18]

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:

[18] 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).

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

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.

In this chapter the ECM is estimated 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:

$$H_o: \pi_{yy} = 0, \pi_{yx.x} = 0' \qquad (6)$$

$$H_1: \pi_{yy} \neq 0, \pi_{yx.x} \neq 0' \qquad (7)$$

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).

5.3 Empirical Results

As described in section 4, the first step of the ARDL analysis tests for the presence of long-run relationships for equations 1-4. The calculated F-statistics for the aggregated income group model (equation 1) are reported in **Table 20** under ARDL F-stat; for the disaggregated income models (equations 2-4) the ARDL F-statistics are reported in **Table 21**. For each model, the ARDL F-statistic is higher than the upper bound critical value; therefore, the null hypothesis of no cointegration cannot be accepted and it can be concluded that there is a long-run cointegration relationship amongst the variables in each model[19].

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):

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

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):

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

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):

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

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):

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

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

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 20** for the aggregate income model and in **Table 21** for the three models of disaggregated income.

5.3.1 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. For middle-income households, expenditure on the *Food and non-alcoholic beverages* category and on the *Housing, water, electricity, gas and other fuels* category is almost equal. Therefore, changes in prices of food will affect changes in the quantity of electricity consumed more directly for middle-income households than for low and high-income households.

5.3.2 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 chapter, which is the first South African study 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 chapter 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, 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.

5.3.3 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, where the long-run demand elasticities of electricity consumption in the residential sector range between 0.13 and 0.71 with regard to income.

Table 20 Empirical Results – Aggregate Model

Dependent variable: LELEC_CONS		
Aggregate Quantile		
Period	1950-2017	
Indepent Variables	**Coefficient**	**p-value**
Lfood_price	0.1421	0.0000
Lelec_price_int	-0.0716	0.0001
Lyd	0.6799	0.0000
ARDL F-stat	7.6507	
Upper bound CV (1%)	4.84	
Lower bound CV (1%)	3.42	
Cointegration conclusion	cointegration	
Upper bound CV (5%)	3.63	
Lower bound CV (5%)	2.45	
Cointegration conclusion	cointegration	
Upper bound CV (10%)	3.1	
Lower bound CV (10%)	2.01	
Cointegration conclusion	cointegration	
Food - electricity relationship	substitutes	
Statistical significance of Lfood_price	statistically significant	
Statistical significance of Lelec_price_int	statistically significant	
Statistical significance of Lyd	statistically significant	

Table 21 Empirical Results – Disaggregate Model

Dependent variable: LELEC_CONS_LOW			Dependent variable: LELEC_CONS_MIDDLE			Dependent variable: LELEC_CONS_HIGH		
Low-Income			**Middle-Income**			**High-Income**		
Period	1950-2017		Period	1950-2017		Period	1950-2017	
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
Lelec_price_int	-0.0579	0.0143	Lelec_price_int	-0.0663	0.0025	Lelec_price_int	-0.0765	0.0001
Lyd_Low	0.7375	0.0000	Lyd_Middle	0.6646	0.0000	Lyd_High	0.6508	0.0000
ARDL F-stat	6.5314		**ARDL F-stat**	6.9336		**ARDL F-stat**	7.2748	
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	
Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclusion	cointegration	
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	
Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclusion	cointegration	
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	
Cointegration conclusion	cointegration		Cointegration conclusion	cointegration		Cointegration conclusion	cointegration	
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 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	

5.4 Conclusion

This chapter 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 chapter are: i) filling the gap in the South African literature where electricity demand has been dealt with in aggregate (Pouris, 1987; Ziramba, 2008), or per economic sector (Inglesi-Lotz and Blignaut, 2011) or at a micro-level (Ye et al., 2018); this chapter offered a proposed framework by separating the households into low-, middle- and high- income brackets; ii) the data on different income brackets are not easily available for a long time period; this chapter amalgamated all information available on this in one dataset, it also provided a thorough background on the average expenditure patterns of South African households; and iii) taking into consideration, the socioeconomic conditions of South African households and the food-energy nexus in the literature, this chapter included food prices as an extra determinant on the households' decision to consume electricity – this resulted in the estimation of the food cross-price elasticity of demand.

A key objective of this chapter was to amalgamate detailed income, price and residential electricity consumption in one data set. 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 – it is important to note that these prices do not represent the prices charged by municipalities to customers, these prices indicate the prices applicable to Eskom's direct sales. For electricity consumption disaggregated by income groups, the shares of expenditure out of total expenditure in electricity were calculated as an average from the different Income and Expenditure of Households and Living Conditions of Households in South Africa published by Statistics South Africa. Gross national disposable income data was gathered from the South African Reserve Bank, and it was then disaggregated by income quantiles using the different South African income shares reported in the World Bank's World Development Indicators. Residential electricity prices were gathered from the different Energy Reports by the South African Department of Energy.

The methodology used to estimate the determinants of residential electricity demand was 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. 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.

Besides examining the determinants of residential demand for electricity in South Africa, and based on the socioeconomic conditions of South African households and the food-energy nexus in the literature, this chapter 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.

Chapter 6: Impact of Energy and Environmental Policy on Households

6.1 Introduction

Over the last few decades, much of policy-related research in the energy space, both locally and internationally, have focussed on dealing with the mitigation of greenhouse gas (GHG) emissions. Finding new, renewable and cleaner energy sources that will enable future economic development without further damaging our planet has been key in this mitigation efforts. Our current uses of fossil fuels have contributed to observed global warming and rapidly rising demand for crude oil, which overall are threatening the world's economy (IPCC, 2014). In the case of developing countries such as South Africa, the goal of reducing GHG emissions and mitigating climate change needs to be achieved whilst working to ensure economic growth and development by taking into consideration its effects on different household – especially poorer households that, compared to industries and the electricity generation sector, are least responsible for GHG emissions and therefore climate change.

At the moment, the world is experiencing an environmental failure – more broadly known in economics as a market failure – whereby the costs of pollution are not being fully reflected in the final prices of goods and services. In other words, the current price of production largely excludes environmental or externality costs. In order to correct for this failure and include these external costs in the prices of goods and services, governments need to intervene by creating regulations and policies that influence the decision-making process and behaviour of producers and consumers (National Treasury, 2013b). This is already happening to some extent in some markets (e.g. emissions tax on motor vehicles provide incentive for development of cleaner technologies) around the world and in South Africa with the "*Post-2015 National Energy Efficiency Strategy*" which aims to reduce energy efficiency as a barrier to future progress in order to encourage permanent growth and the introduction of the carbon tax in early 2019 (DoE, 2016; National Treasury, 2015; 2019).

To achieve its GHG emission reductions, South Africa is looking at adopting a mix of policies and measurements (PAMs). One of these PAMs – and its main instrument to date – is a carbon tax policy as outlined in May 2013 by the South African National Treasury and implemented since June 2019 (National Treasury, 2013a; Republic of South Africa, 2019). South Africa's National Treasury recognises that a carbon tax as a proposed carbon pricing mechanism is not sufficient; hence, they have highlighted that carbon pricing and low carbon energy policies need to be implemented simultaneously in order to adequately incentivise a least-cost decarbonisation path in South Africa (National Treasury, 2013c). Therefore, sectoral emission targets, carbon-budgets at company level as well as energy efficiency gains in different sectors – including the residential sector – are some of the PAMs being considered.

As explained in the Department of Energy's (2015) document, energy efficiency incentives have become a second preferred PAM. Promoting energy efficiency has the potential to directly affect energy demand, decrease costs of energy infrastructure expansion, and most importantly, help in diminishing GHG emissions.

Given the high inequality levels in South Africa, its climate change policies need to be formulated in a way that low-income households are less affected. The South African GHG mitigation plan allows for a smooth transition to a low-carbon economy and it has been designed to incentivise producers and consumers, especially those in carbon-intensive industries, to move towards cleaner technologies and reduce emissions whilst minimising the potential adverse impacts on low-income households (National Treasury, 2013a, Republic of South Africa, 2019).

Despite PAMs being designed to also promote economic growth, whilst taking into consideration the persistent income inequalities in the country, research needs to be done to analyse the actual impact of the carbon tax and energy efficiency gains on households at different income levels. This is the main objective and contribution of this chapter. Therefore, this chapter evaluates two of the main policies to reduce GHG emissions in South Africa – the carbon tax and energy efficiency gains stemming from various incentives (specifically, in the non-coal electricity sector in the form of cost-saving technical improvements) – whilst focusing on its effects on different households, especially low-income households.

The carbon tax has been devised to avoid hindering industry competitiveness by reducing the risk of South Africa's exports being subject to border carbon adjustment (BCA) tariffs (National Treasury, 2013a; Republic of South Africa, 2019). The Carbon Tax Bill of 2019 details that the main objective of the carbon tax is to reduce GHG emissions in a sustainable, cost effective and affordable manner (Republic of South Africa, 2019). The carbon tax has been designed under the 'Polluter Pay Principle' whereby, *"…those responsible for harming the environment must pay the costs of remedying pollution and environmental degradation and supporting any consequent adaptive response that may be required"* (National Treasury, 2018:3). This already implies that households should not bear the full weight of the carbon tax. On the other hand, energy efficiency policies are said to provide an array of benefits that have the potential to boost macroeconomic development, and yield social and environmental gains at a society, community and individual level (DoE, 2016). Energy efficiency policies in South Africa have been drawn to mainly provide energy security and move towards environmental sustainability whilst promoting inclusive economic growth (DoE, 2016).

In order to evaluate how households at different income levels are affected by policies imposed at a national level aimed at reducing GHG emissions, an improved and updated CGE model of the South African economy is implemented. The CGE model used in this chapter is a dynamic CGE model similar to other CoPS-style models used in papers such as Bohlmann et al. (2016), Van Heerden et al. (2016) and Roos et al. (2020)[20]. Since the basic details of the carbon tax have remained the same as that on which the Van Heerden et al. (2016) paper was based, we expect to find similar impacts of the carbon tax on key macroeconomic and environmental variables e.g. the impact on GDP or expected reduction in emissions. However, evaluating the impacts of the carbon tax on its own provides the base to evaluate the impact of the carbon tax on different households. In order to contribute to the literature, gaps in the literature that falls within the focus area of this thesis, i.e. households are addressed. Firstly, households are split at different income levels. Secondly, the latest elasticities estimated in chapter 5 with regards to households' response to changes in income and electricity prices are included in the CGE model. Additionally, the model's business-as-usual baseline path is updated to include the latest available macroeconomic projections (IMF, 2020; WEO, 2020). Lastly, following the strategy in Roos et al. (2020) the impact of the projected revenue to be generated from the carbon tax as noted in the 2020 Budget Review is modelled. Similar modelling assumptions to Roos et al. (2020) as far as the model closure is concerned will be used.

After modelling the carbon tax and interrogating its impact on key macroeconomic variables and different household groups (using latest database and elasticities), a second simulation is added to estimate how much technical progress in the non-coal electricity generation could contribute to lowering the price of electricity and subsequent increase household spending – this is based on the different PAMs that South Africa is set to implement. Essentially, as described earlier, this chapter investigates the effects of two different PAMs on households – the carbon tax and cost-saving technical improvements in cleaner energy – using a dynamic CGE model.

In line with the theme of this thesis that focuses on South African households, and South Africa's commitment to reduce GHG emissions while keeping in consideration that it needs to

[20] The details of Van Heerden et al. (2016) and Roos et al. (2020) has been provided in the literature review session.

do so whilst achieving economic growth and reducing poverty and inequalities in the country – trying to protect its most vulnerable households; it is imperative, that the proposed policies to combat climate change be evaluated looking not only at its economy-wide impact, but also looking at how these policies will affect different households at different income group levels. Ultimately, this is the contribution this chapter aims to make.

This chapter is structured as follows: Section 2 discusses the methodology including some relevant features of the CGE model used and the scenario design of the policies evaluated in this chapter. Section 3 discusses the results. Finally, section 4 concludes and provides some policy recommendations.

6.2 Methodology and Database

As shown in the literature review, CGE modelling is well suited and designed for analysing the economy-wide effects of new policies. The choice of methodology is therefore appropriate for the research question posed in this chapter. The theme of this thesis revolves around environmental policy and the impact on households. This chapter analyses the effects of two key policies – the carbon tax and energy efficiency in the non-coal electricity sector – on key economic variables using a variant of the University of Pretoria General Equilibrium Model (UPGEM), a dynamic CGE model of the South African economy.

The ability of CGE models, such as UPGEM, to recognise the many real inter-linkages in the economy, and account for price-induced behaviour and resource constraints in determining the economy-wide effects of a shock on the economy over time, has made it one of the preferred methodologies for practical policy analysis around the world (Adams & Parmenter, 2013). The policy component of this chapter will be conducted using the UPGEM suite of models broadly described in Van Heerden et al. (2016) and Roos et al. (2020).

6.2.1 Model Theory and Database

This chapter draws on the work done in Van Heerden et al. (2016) and Roos et al. (2020), with a couple of notable additions. Both papers used the CGE modelling methodology. Van Heerden et al. (2016) look at the macroeconomic and environmental impacts of the introduction of the carbon tax in South Africa. Roos et al. (2020), looks at the macroeconomic and regional impacts of collecting additional VAT revenue through an increase in the VAT rate in South Africa. This section provides details regarding the CGE model in this chapter and presents more detail with regards to the similarities with Roos et al.'s (2020) approach to modelling increases in taxes in a CGE model with sufficient tax details.

UPGEM is a dynamic CGE model of the South African economy with various energy and environmental extensions[21]. In order to perform more accurate policy analysis, information in the model's business-as-usual (BAU) baseline path was updated to include the latest available macroeconomic projections (IMF, 2020; WEO, 2020). Additionally, the latest elasticities estimated in chapter 5 with regards to households' income elasticities and response to changes in electricity prices are incorporated in the model. These updated parameters that feed into the model's household expenditure equation will improve the accuracy, and ultimately, credibility of the simulation results. Additionally, the model is linked to an emissions database and includes detailed tax information that allows to accurately measure the effects of both the carbon tax and energy efficiency gains in the electricity sector.

Following the strategy in Roos et al. (2020) – where the authors modelled the impact of an increase in VAT by designing the policy shock in a way that it represented the expected revenue to be raised from increasing the VAT rate – the impact of the projected revenue to be generated from the carbon tax – as noted in the National Treasury 2020 Budget Review – is modelled. Similar modelling assumptions to Roos et al. (2020) as far as the model closure is concerned are used.

The model's theory and data structure have been well documented; therefore, only an overview of the model is provided. The model's theoretical structure is based on the renowned MONASH model developed by the Centre of Policy Studies (CoPS) and documented in Dixon & Rimmer (2002; 2005) and Dixon et al. (2013). The UPGEM database used in this chapter is based on the 2011 supply-use (SU) tables published by Statistics South Africa. Following the mapping used in Van Heerden et al (2016), the modified version of UPGEM used in this chapter distinguishes 48 sectors. As required for CoPS-style models, the initial levels solution of the model is provided by the base year data. One of the benefits of dynamic CGE models is its ability for the base data to be updated to reflect the latest available statistics and national accounts data without the need to build a new database. In this chapter, the baseline has been updated to include historical data on key macroeconomics indicators for up to 2019.

[21] This section borrows heavily from the description of UPGEM in Bohlmann, H.R. et al. (2015) and Bohlmann, J.B. et al. (2016) where the same model and database were used.

The database, in combination with the model's theoretical specification, numerically describes the main inter-linkages in the economy. The theory of the model is, essentially, a set of equations that describe how the values in the model's database move through time and move in response to any given shock (see **Figure 15** for a stylised representation of the database). As per van Heerden et al. (2016), the model includes a detailed electricity generation model which incorporates four types of electricity generation including coal, nuclear, gas and other (which includes renewables such as solar, wind and hydro) as illustrated in **Figure 16**. The linkage of the model to an external emissions database, similar to the strategy first introduced for UPGEM in Van Heerden et al. (2006), allows for environmental analysis. Elements of the detailed treatment of taxes in the model is based on Roos et al. (2020). UPGEM is solved using the GEMPACK suite of programs described in Harrison & Pearson (1996). GEMPACK eliminates linearisation errors by implementing shocks in a series of small steps and updating the database between steps.

Figure 15 Stylized Representation of the Core UPGEM Database

			Absorption Matrix					
			1	2	3	4	5	6
			Producers	Investors	Household	Export	Government	Inventories
		Size	IND	IND	1	1	1	1
1	Basic Flows	CxS	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V6BAS
2	Margins	CxSxM	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	n/a
3	Taxes	CxS	V1TAX	V2TAX	V3TAX	V4TAX	V5TAX	n/a
4	Labour	OCC	V1LAB					
5	Capital	1	V1CAP					
6	Land	1	V1LND					
7	Production Taxes	1	V1PTX					
8	Other Cost Tickets	1	V1OCT					

C = Number of commodities

IND = Number of industries

S = Number of sources (domestic, imported)

M = Number of commodities used as margins

OCC = Number of occupation types

	Joint Production Matrix
Size	IND
C	MAKE

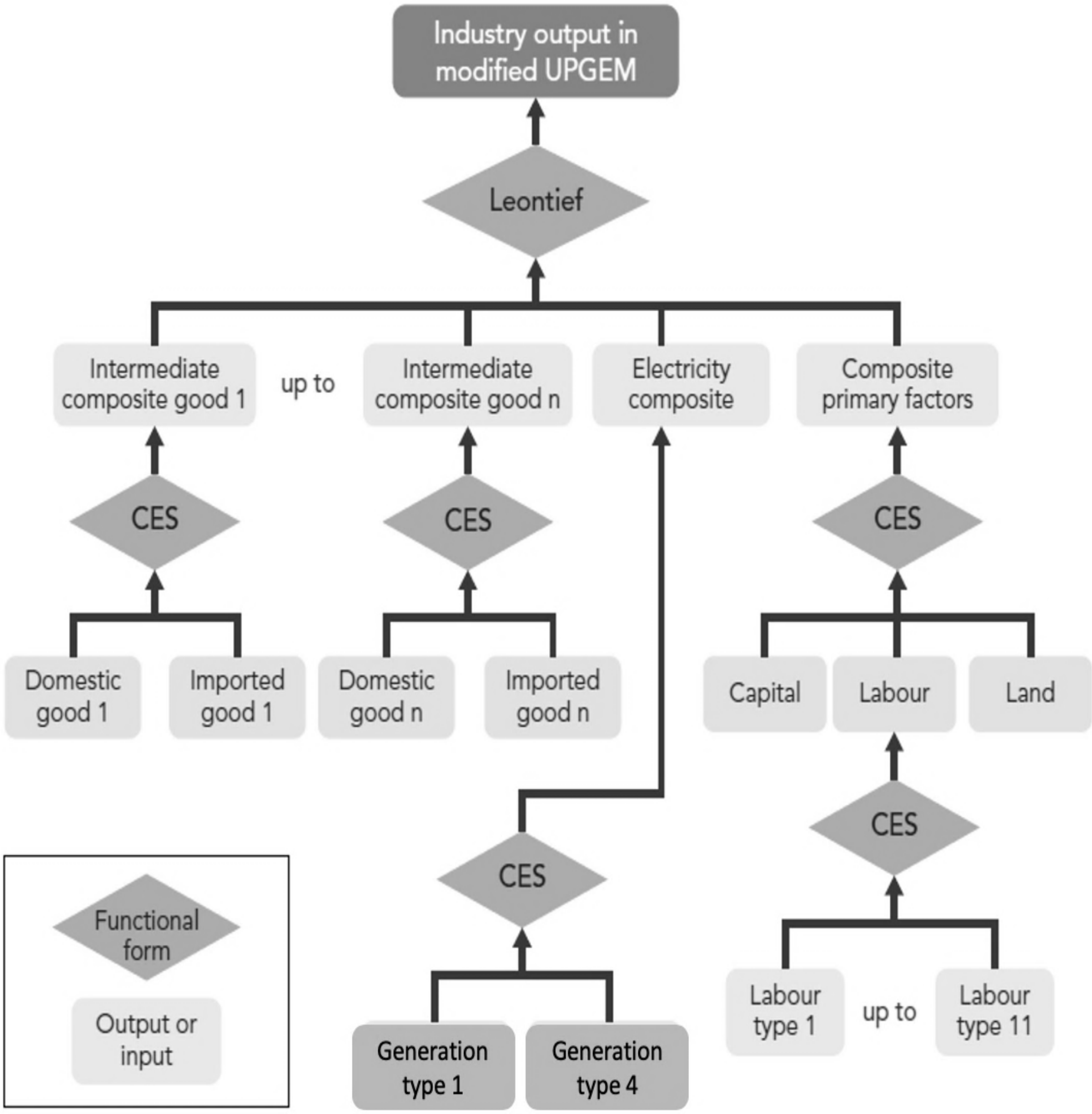
	Tariffs
Size	1
COM	V0TAR

Source: Adapted from Horridge (2000)

Following the CoPS-style of implementing a CGE model, inspired by the pioneering work of Johansen (1960), the general equilibrium core of UPGEM is made up of a linearised system of equations describing the theory underlying the behaviour of participants in the economy. The specifications in UPGEM recognise each industry as producing one or more commodities, using as inputs combinations of domestic and imported commodities, different types of labour, capital and land. The multi-input, multi-output production specification is kept manageable by a series of separability assumptions, as illustrated in **Figure 16**. The primary-factor composite is a CES aggregate of composite labour, capital and, in the case of primary sector industries, land. Composite labour demand is itself a CES aggregate of the different types of labour distinguished in the model's database. In UPGEM, all industries share this common production structure, but input proportions and behavioural parameters vary between industries based on base year data and available econometric estimates, respectively.

The demand and supply equations in UPGEM are derived from the solutions to the optimisation problems which are assumed to underlie the behaviour of private sector agents in conventional neo-classical microeconomics. Each industry minimises cost subject to given input prices and a constant returns to scale production function. Zero pure profits are assumed for all industries. Households maximise a Klein-Rubin utility function subject to their budget constraint. The current UPGEM identifies a single representative household, one of the main contributions of this study is the introduction of multiple households by including a top-down household split by taking into account the household expenditure function so households' consumption can be measured as directly linked to income. Units of new industry-specific capital are constructed as cost-minimising combinations of domestic and imported commodities. The export demand for any locally produced commodity is inversely related to its foreign-currency price. Government consumption typically set exogenously in the baseline or linked to changes in household consumption in policy simulations, and the details of direct and indirect taxation are also recognised in the model. This nested production structure reduces the number of estimated parameters required by the model. Optimising equations determining the commodity composition of industry output are derived subject to a CET function, whilst functions determining industry inputs are determined by a series of CES nests. At the top level of this nesting structure intermediate commodity composites and a primary-factor composite are combined using a Leontief or fixed-proportions production function. Consequently, they are all demanded in direct proportion to industry output or activity. Each commodity composite is a CES function of a domestic good and its imported equivalent. This incorporates Armington's assumption of imperfect substitutability for goods by place of production (Armington, 1969).

Figure 16 Nested Production Structure in UPGEM



Source: Adapted from van Heerden et al. (2016)

The recursive-dynamic behaviour in UPGEM is specified through equations describing: physical capital accumulation; lagged adjustment processes in the labour market; and changes in the current account and net foreign liability positions. Capital accumulation is specified separately for each industry and linked to industry-specific net investment in the preceding period. Investment in each industry is positively related to its expected rate of return on capital, reflecting the price of capital rentals relative to the price of capital creation. For the government's fiscal accounts, a similar mechanism for financial asset/liability accumulation is specified. Changes in the public sector debt are related to the public sector debt incurred during a particular year and the interest payable on previous debt. Adjustments to the national net foreign liability position are related to the annual investment/savings imbalance, revaluations of assets and liabilities and remittance flows during the year. In policy simulations, the labour market follows a lagged adjustment path where wage rates respond over time to gaps between demand and supply for labour across each of the different occupation groups.

Dynamic CGE models such as UPGEM are designed to quantify the effects of a policy change, or exogenous shock, to the economy, over a period of time. The standard CGE methodology described in Dixon et al. (2013) which determines that the best way to examine the effects of an exogenous shock is to compute the differences between a scenario in which the shock has occurred – the policy simulation – and a counterfactual scenario in which the particular shock under examination did not occur – the baseline scenario is followed.[22] Results are then reported as percentage change deviations over time between the first 'baseline' simulation run and the second 'policy' simulation run. The nominal exchange rate is set as the numeraire in the policy run.

To measure the impact of the policies designed to reduce GHG emissions in the South African economy, it is necessary for the model to have GHG emissions in the database. The external emissions database linked to the UPGEM model in this chapter is based on methods employed in Van Heerden et al. (2006) and Van Heerden et al. (2016). The emissions database includes: an energy and emissions accounting model; different equations that allow for inter-fuel substitution in electricity generation; and different mechanisms that allow for the evaluation of emissions reduction in response to policy measures designed to reduce GHG. The emissions database in UPGEM is designed to evaluate emissions according to emitting agent and emitting

[22] A re-run of baseline forecast of the economy is automatically done by GEMPACK in between the base and policy simulations. During this step, the closure of the model is changed to the policy closure that will be used later in the policy simulation and the baseline forecast is recalculated accordingly. From here, any set of additional policy shocks may be applied to the exogenous variables. If a policy simulation where no additional shocks are applied to the policy variables is done, then the original baseline forecast values would be the result of the simulation. This makes it legitimate to interpret differences between results in the policy and baseline runs as the effects of the policy shocks.

activity – it does not include the ability to track emissions at a regional level as is the case with MMRF (Adams et al. 2014). Importantly, the model allows for input-saving technological progress. The emissions and energy data methods used to develop the emissions database in the model is based on Blignaut et al. (2005) and Seymore et al. (2014) who developed energy inventories for South Africa. The emissions database has been updated with the latest available data to reflect South Africa's current emission levels.

Following Roos et al. (2020), this version of the UPGEM database includes various indirect tax rates paid on the use of commodities, including environmental taxes (the carbon tax falls within this category). Different tax types are explicitly modelled, thereby allowing for analysis of detailed changes in tax policy, such as the introduction of the carbon tax and its subsequent increases.

Tax revenue collected on each commodity, from each source, paid by each user across all tax types in UPGEM is calculated as follows:

$$TAX(c,s,u,t) = USE(c,s,u) * TAXRATE(c,s,u,t) \qquad (12)$$

for all c∈COM, s∈SRC, u∈USER,t∈TAXTYPE

where USE is the delivered value, including margins, of commodity c from source s to user u,

and where TAXRATE is a specific tax t levied on each commodity c from source s. These tax rates are naturally exogenous.

Our focus is on is on the sales tax term (that includes environmental taxes as one of the tax types t), which in ordinary change form can be written as

$$\Delta TAX(c,s,u,t) = 0.01 * TAX(c,s,u,t) * [xuse(c,s,u) + puse(c,s)] + USE(c,s,u) * \Delta TAXRATE(c,s,u,t) \qquad (13)$$

for all c∈COM, s∈SRC, u∈USER,t∈TAXTYPE

where xuse is the percentage change in the use of commodity c, from source s by user u; puse is the percentage change in the delivered price of commodity c from source s by used u; and ΔTAXRATE is the ordinary change in the tax rate on commodity c, from source s, paid by user u.

Taxes collected on each commodity adds to the final purchasers' price paid by consumers. In applying the tax shock (an increase in environmental tax revenue collected related to the introduction of a carbon tax) to the model, the first-round effect will be to raise the purchasers' price of the directly affected goods and services. The model, through its system of equations, will subsequently determine the overall effects, considering the various inter-linkages and general equilibrium effects. Since the model is too large to be fully documented in this chapter, readers interested in the finer details of the core model theory are encouraged to consult the original publication of the standard MONASH model in Dixon & Rimmer (2002).

6.2.2 Simulation Design

Many of the simulation design aspects in this chapter follow the standard CGE methodology and customs as described in the literature. As noted earlier, applying a dynamic CGE model entails running two simulations: First is the baseline run that plots a business-as-usual path for the economy based on available macroeconomic forecast data, that excludes the policy shock under consideration (in this case, the introduction of a carbon tax and associated technical change in the electricity generation). Second is the policy run that incorporates all the features of the base run, plus the policy shock under consideration. Results for the policy simulation are then typically reported as percentage change deviations in the value of the underlying variable between the two runs. In this study, the policy simulation period runs up to 2030.

Basic macroeconomic assumptions in the policy run, as imposed through the model closure, include the sticky real wages with flexible employment in the short-run versus flexible real wages in the long-run that adjust to move employment back to its long-run baseline level. Industry-specific capital stocks are fixed in the first year of the policy shock, and subsequently adjust based on changes in the expected rate of return of investments. In the long run, the model theory dictates that the building of new capital stock through investment expenditure push rates of return across industries back to equilibrium, that is, equal across all industries.

For this chapter, two separate policy shocks are imposed in line with the scenario description. The first shock raises environmental tax revenue collected, via an increase in the underlying tax rate, as a result of the introduction of the carbon tax. This approach is slightly different to some of the earlier literature on carbon taxes previously cited where a direct increase in tax rates were applied. Here, the strategy in Roos et al. (2020) is followed where an increase in the VAT rate was indirectly achieved by increasing VAT revenue collected by the targeted amount. Therefore, in this study, the carbon tax is implemented through an increase in tax revenue collected under the environmental tax category in the model for 2020 by R1.75bn, as per the target amount in the Budget Review (National Treasury, 2020). In subsequent years up to 2030, the carbon tax to be collected is increased in line with the published removal of exemptions in the Carbon Tax Bill (Republic of South Africa, 2019). The model endogenously, and permanently, raises the associated tax rate to an appropriate level.

Further insight is added to this scenario by running two versions of the same carbon tax shock. This first (simulation 1A) assumes that all other tax rates remain unchanged and that government income and the budget deficit is allowed to adjust, that is, no tax recycling occurs. The second (simulation 1B) assumes that the government's budget deficit position remain unchanged relative to the baseline and that all additional tax revenue collected from the carbon tax is recycled back into the economy. The second version (simulation 1B) of the shock aligns closest to National Treasury's intended implementation of the carbon tax and its results for households will be looked at in more detail.

The final shock (simulation 2) considers another PAM – achieving input-saving technical change in the generation of electricity from sources other than coal. The goal of this policy shock is to capture the fall in generation costs of renewable electricity as a result of technological advancements. To implement the technical change in our application, an average 5 percent input-saving technical change improvement on all non-coal electricity generation for each year of the simulation periods up to 2030 is imposed. This cost improvement relative to the baseline is in line with data from various publications tracking the cost of renewable electricity production, including price trends between bid window 1 and 4 of the IPP programme in South Africa (DoE, 2019). The costs in achieving the simulated technical improvement are not considered at this stage.

6.3 Empirical Results

Simulation results are shown in percentage change deviation form for the three scenarios in **Table 22** to **Table 27**.

Scenario 1A shows selected macro results for the carbon tax simulation without tax recycling. Scenario 1B shows results for the carbon tax simulation with tax recycling. Scenario 2 shows the results of the anticipated technical change in non-coal electricity generation as part of the PAMs framework.

Scenarios 1A and 1B

The most striking result when comparing the results of scenarios 1A and 1B is the large contrast in impact between the carbon tax with and without recycling scenarios. This highlights the importance of – as designed by National Treasury and modelled in Van Heerden et al. (2016) – the tax revenue being recycled back into the economy. Without recycling, real GDP and associated macro variables such as household expenditure and employment, fall by around 3 percent relative to the baseline in year t+10 of the policy run, in line with the estimates in Van Heerden et al. (2016). With effective recycling, the negative impact on GDP is reduced to less than 0.04 percent or approximately R2.4 billion in real terms (Refer to **Table 22**)

As indicated in Van Heerden et al. (2016), different recycling strategies may show slightly different results, but on a macroeconomic level, results are broadly comparable. The reason for the slightly larger drop in emissions in the without-recycling scenario is that economic activity is more suppressed relative to the with-recycling scenario. All things equal, less economic activity will result in less emissions. However, the goal of sound policy making is, of course, to achieve the desired drop in carbon emissions with the least possible damage to the economy, and in particular, vulnerable households.

Scenario 1A is largely of academic importance since the carbon tax is not designed or implemented like this in practice. Its purpose is merely to reiterate the impact of tax revenue recycling and it impacts households in particular. Scenario 1B is therefore a more realistic, version of the carbon tax simulation. The results for simulation 1B in **Table 23** show a much smaller impact on key economic variables. The first-round impact of the shock is to increase the price of commodities directly affected by the carbon tax including coal, gas and petroleum products. This occurs through the shock to environmental tax revenue in the model that raises the associated tax rates and ultimately the final purchasers' price of these goods. The new tax revenue that is collected is subsequently recycled back into the economy, mitigating the tax's macroeconomic impact to a large extent. On an industry level, winners and losers are more apparent. Output of heavy carbon emitting industries that are now taxed, fall significantly more relative to the baseline than other goods and services. Further mitigation is facilitated by the model's ability to distinguish between different types of electricity generators and a partial substitution towards the now relatively cheaper non-coal generators. The price increase in other goods, such as *iron & steel manufacturing* or *refined petroleum products*, has a more direct impact on local production given the model's Leontief structure in the top nest (see **Figure 16**).

Table 23 shows the impact of the carbon tax as modelled in Scenario 1B on overall GDP and output of selected industries. The selected industries shown are of importance because they are either directly affected by the tax or are important components in the consumption basket of households (e.g. *food production* and *transport services*).

The initial increase, albeit very small, in GDP in year t, can be explained by the increased spending by government relative to the baseline as a result of the increased tax revenue collection stemming from the newly introduced carbon tax. This offsets the negative impact on virtually other key macroeconomic variables. Beyond year t+1 with only moderate increases in the carbon tax, overall real GDP falls relative to the baseline. It should be noted that no change in investor confidence or preferences is assumed, that is, the required rate of return by investors is not affected by the tax. This assumption is in line with a post Paris agreement world where relative rate of return between countries who impose climate change mitigating policies do not change significantly.

The second-round impact of the shock sees various supply and demand dynamics generate general equilibrium effects in accordance with the model's theoretical specification. Given the focus on households in this study, the impact on household expenditure on both an aggregate an individual income group level is of great importance. A-priori expectation indicate that poorer household groups (P1-P5) will be slightly more affected than richer household groups due to the fact that poorer groups spend a relatively larger share of their income on energy related goods and services, as indicated by household expenditure data from the Social Accounting Matrix (SAM) incorporated in the model's database. Higher indirect tax rates on goods and services, such as environmental taxes, are, at least partially, passed on to final consumers who face higher prices. At any given income level, this reduces the real spending power of households. The smaller share of supernumerary spending to total spending for poorer household groups, reflected in the model's Frisch parameter, further contributes to the harsher impact of these more vulnerable household groups.

Table 24 shows the impact of the carbon tax as modelled in Scenario 1B on both aggregate households and individual income groups. It should be noted that the impacts in percentage change form are very small. The reasons for this include the initially conservative implementation of the carbon tax that includes various exemptions and ultimately lower than published effective carbon tax rates. The impacts become more noticeable after year t+5 when most exemptions have expired, however greater mitigation in the form of substitution towards cleaner sources of energy that are not taxed (or to a lesser extent) serves as a mitigating factor in the long run. Regardless of the nominal size of the impacts, for the purposes of this study and to better understand the impact of environmental taxes such as the carbon tax on households, the relative impacts between households, as well as the overall impact on household expenditure relative to GDP is of greater importance.

With this in mind, the impact on households should be regarded as important and worth careful study. Most notable is that overall household expenditure falls by more than double compared to GDP (0.075 v. 0.036). The importance of the relatively large drop in overall household expenditure flows through to analysis on an income group level. As seen in **Table 24**, poorer households (P1-P5) are indeed worse off relative to richer households. Whilst the richest households' expenditure is hardly affected by the introduction of a carbon tax, poorer households with limited room for substitution are much worse off. As noted earlier, this is mainly a function of the fact that poorer households spend a relatively larger fraction of their income on energy/electricity than richer households, as per the model database and as described in previous chapters.

Table 22 Macro Comparison Between Carbon Tax with and Without Revenue Recycling

Macros	Year t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Real GDP without recycling	-0.16	-0.37	-0.63	-0.94	-1.27	-1.61	-1.97	-2.34	-2.71	-3.10	-3.49
Real GDP with recycling	0.00	0.00	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.04
Emissions without	-1.17	-2.67	-4.36	-6.20	-8.18	-10.22	-12.27	-14.34	-16.46	-18.63	-20.82
Emissions with	-0.97	-2.23	-3.61	-5.14	-6.78	-8.48	-10.19	-11.94	-13.74	-15.60	-17.50

Table 23 Carbon Tax with Revenue Recycling: Macro and Industry Output Effects

Output	Year t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Real GDP	0.002	-0.004	-0.009	-0.013	-0.016	-0.020	-0.023	-0.026	-0.030	-0.033	-0.036
Refined Petroleum Products	-0.058	-0.115	-0.162	-0.204	-0.242	-0.278	-0.313	-0.347	-0.380	-0.412	-0.444
Coal Mining	-0.064	-0.074	-0.082	-0.090	-0.097	-0.104	-0.110	-0.116	-0.121	-0.125	-0.129
Iron & Steel Manufacturing	-0.063	-0.083	-0.101	-0.117	-0.132	-0.146	-0.160	-0.172	-0.184	-0.195	-0.204
Electricity	-0.052	-0.084	-0.108	-0.128	-0.147	-0.164	-0.180	-0.196	-0.211	-0.225	-0.238
Food Production	-0.004	-0.007	-0.010	-0.013	-0.016	-0.019	-0.022	-0.025	-0.028	-0.030	-0.033
Transport Services	-0.015	-0.024	-0.033	-0.041	-0.050	-0.059	-0.067	-0.076	-0.084	-0.092	-0.100

Table 24 Carbon Tax with Revenue Recycling: Household Expenditure Effects

Households	Year t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Aggregate Household Expenditure	-0.008	-0.016	-0.024	-0.031	-0.037	-0.044	-0.050	-0.057	-0.063	-0.069	-0.075
P1	-0.011	-0.020	-0.027	-0.034	-0.041	-0.047	-0.054	-0.060	-0.066	-0.072	-0.078
P2	-0.015	-0.025	-0.034	-0.042	-0.049	-0.057	-0.064	-0.071	-0.077	-0.084	-0.090
P3	-0.017	-0.028	-0.037	-0.045	-0.053	-0.061	-0.068	-0.076	-0.083	-0.089	-0.096
P4	-0.018	-0.029	-0.038	-0.047	-0.055	-0.063	-0.071	-0.078	-0.085	-0.092	-0.099
P5	-0.016	-0.027	-0.036	-0.044	-0.052	-0.060	-0.067	-0.074	-0.082	-0.088	-0.095
P6	-0.013	-0.023	-0.031	-0.039	-0.046	-0.053	-0.060	-0.067	-0.074	-0.081	-0.087
P7	-0.009	-0.018	-0.025	-0.033	-0.039	-0.046	-0.052	-0.059	-0.065	-0.071	-0.077
P8	-0.006	-0.014	-0.021	-0.028	-0.034	-0.040	-0.046	-0.053	-0.059	-0.064	-0.070
P9	-0.003	-0.011	-0.018	-0.024	-0.030	-0.036	-0.042	-0.048	-0.053	-0.059	-0.065
P10	-0.002	-0.009	-0.016	-0.022	-0.028	-0.034	-0.039	-0.045	-0.051	-0.057	-0.063
P11	-0.003	-0.011	-0.017	-0.024	-0.030	-0.036	-0.042	-0.048	-0.054	-0.060	-0.066
P12	-0.001	-0.006	-0.012	-0.018	-0.024	-0.030	-0.036	-0.042	-0.048	-0.055	-0.061

Where P1=poorest and P12=richest

Scenario 2

The results for scenario 2 are very important to the broader understanding of PAMs in the South African economy. Whilst the scenario and simulation design details are based on a reduction in non-coal electricity generation costs due to input-saving technical change, the simulation may serve as a proxy for many related PAMs that seek to incentivise more efficient energy supply and use methods. As is clear from the rapid fall in renewable energy prices between bid window 1 and bid window 4 of the IPP programme, input-saving technical change and scale benefits can easily be achieved given sufficient incentives. Wind power fell from over 150c/kWh in round 1 to an average bid price of 68c/kWh in round 4. Likewise, solar PV bid prices fell from over 320c/kWh in round 1 to an average of 82c/kWh in round 4 (DoE, 2019). The important issue to note here is not necessarily how competitive these prices are with fossil-fuel based competitors, but the rapid rate of change. Whilst the rate at which renewable prices fall will no doubt slow in coming years in order to maintain a reasonable rate of return, the various incentives given to the industry in its infancy, combined with consumer preference shifts, have made renewable energy a most viable alternative to fossil fuels before even considering the associated externality costs of fossil fuel energy.

The key results for simulation 2 shown in **Table 25**, **Table 26** and **Table 27** below, should also be considered alongside the results for simulation 1B. In simulation 1B, the partial shift to non-coal electricity generation in the model due to the imposition of the carbon tax on coal-fired generation, harms the economy because the cost-saving associated with non-coal sources has not been included in the baseline. As shown in **Table 25**, all important macroeconomic variables benefit from the technical improvement. Real GDP, household expenditure and investment all rise between 0.7 and 0.9 percent relative to the baseline by year t+10. With nominal GDP expected to approach R10trillion in 2030, a one percentage point deviation in GDP will be worth R100billion.

An interesting result when analysing the impact of scenario 2 on household income groups, is that richer households tend to benefit slightly more than poorer households. Rich households spend a greater share of their income on other goods and services such as real estate and additional electricity to support luxury household items. These goods benefits from improved technology and cheaper electricity, allowing richer households to purchase more. Nonetheless, poorer households benefit nearly as much. It is clear that targeting improved technology that leads to cost reductions in the economy is a worthwhile investment to support households (Refer to **Table 26**).

Relative to the increase in GDP, the drop in coal output is explained by the impact of the policy that improves cost-saving technology in only the non-coal generating sectors. This causes a shift away from coal-fired generation in favour of now relatively cheaper non-coal sources such as wind and solar. *Electricity* output overall rises on the back of much lower electricity prices (due to the technical change shock) and a subsequent increase in demand. Other important industries such as *food production, transport services and real estate* also see moderate output gains, relative to the baseline (Refer to **Table 27**)

Table 25 Input-Saving Technical Change in the Energy Sector: Macro Effects

Macros	Year t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Real GDP	0.08	0.15	0.23	0.29	0.36	0.42	0.48	0.54	0.60	0.65	0.70
Household Expenditure	0.08	0.17	0.26	0.34	0.43	0.51	0.59	0.67	0.74	0.82	0.89
Investment	0.14	0.25	0.34	0.42	0.49	0.55	0.60	0.65	0.69	0.73	0.77

Table 26 Input-Saving Technical Change in the Energy Sector: Household Expenditure Effects

Households	Year t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Household Expenditure	0.08	0.17	0.26	0.34	0.43	0.51	0.59	0.67	0.74	0.82	0.89
P1	0.06	0.12	0.18	0.23	0.28	0.33	0.38	0.43	0.47	0.52	0.56
P2	0.07	0.14	0.20	0.26	0.32	0.38	0.44	0.49	0.55	0.60	0.65
P3	0.08	0.15	0.22	0.29	0.36	0.43	0.49	0.56	0.62	0.67	0.73
P4	0.08	0.16	0.24	0.32	0.39	0.47	0.54	0.61	0.67	0.74	0.80
P5	0.09	0.17	0.26	0.34	0.42	0.50	0.57	0.64	0.71	0.78	0.85
P6	0.09	0.18	0.27	0.35	0.44	0.52	0.60	0.68	0.75	0.82	0.89
P7	0.09	0.18	0.28	0.37	0.46	0.54	0.63	0.71	0.79	0.87	0.94
P8	0.09	0.19	0.28	0.38	0.47	0.56	0.65	0.73	0.81	0.89	0.97
P9	0.09	0.19	0.29	0.39	0.48	0.57	0.66	0.75	0.84	0.92	1.00
P10	0.10	0.20	0.30	0.41	0.51	0.60	0.70	0.79	0.88	0.97	1.06
P11	0.10	0.21	0.32	0.43	0.53	0.64	0.74	0.84	0.94	1.03	1.12
P12	0.06	0.13	0.20	0.28	0.35	0.43	0.51	0.58	0.66	0.73	0.80

Where P1=poorest and P12=richest

Table 27 Input-Saving Technical Change in the Energy Sector: Macro and Industry Output Effects

Output	Year t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Real GDP	0.08	0.15	0.23	0.29	0.36	0.42	0.48	0.54	0.60	0.65	0.70
Coal Mining	-0.01	-0.02	-0.03	-0.05	-0.06	-0.08	-0.10	-0.11	-0.13	-0.14	-0.15
Food Production	0.03	0.05	0.08	0.11	0.14	0.16	0.19	0.21	0.24	0.26	0.28
Electricity	0.15	0.36	0.61	0.89	1.19	1.51	1.83	2.16	2.49	2.82	3.15
Transport Services	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.07	0.08	0.09	0.10
Real Estate	0.01	0.03	0.06	0.10	0.15	0.20	0.25	0.31	0.36	0.42	0.48

6.4 Conclusion and Policy Recommendations

This chapter evaluated the economy-wide and household specific effects of the carbon tax and energy efficiency gains in the non-coal electricity sector – two of the PAMs that South Africa is adopting as part of its effort to mitigate GHG emissions.

A dynamic CGE model of the South African economy was implemented to evaluate the policies at hand. The CGE model employed in this chapter included features such as: detailed household disaggregation per different income levels; updated elasticities with regards to households' response to changes in income and electricity prices; it is linked to an updated emissions database; and it has detailed tax information that facilitated the in-depth analysis of different policies designed to reduce GHG emissions.

The contribution to the literature of the research conducted in this chapter is two-fold. Firstly, the impact of the recently introduced carbon tax was evaluated not only at an economy-wide level, but at a household level, that is, it included in-depth analysis on different household groups in South Africa. The recent availability of revenue collection estimates for the carbon tax by National Treasury (2020), allowed for the design of policy scenarios in line with the modelling strategy in Roos et al. (2020) with regards to the implementation of the policy shock. Secondly, this chapter further investigates the role technology and cost-saving in non-coal electricity generation could have on the macroeconomy and household groups.

The carbon tax impact was evaluated in two different simulations. Simulation 1A assumed that the revenue collected from the carbon tax is not recycled back into the economy; therefore, government income and the budget deficit were allowed to adjust. Simulation 1B assumed that the government's budget deficit position remains unchanged relative to the baseline and that all additional tax revenue collected from the carbon tax is recycled back into the economy. Results for simulation 1A showed that without recycling, real GDP and associated macro variables such as household expenditure and employment, fall by around 3 percent relative to the baseline in year t+10 of the policy run, in line with the estimates in Van Heerden et al. (2016). For simulation 1B, results showed that with effective recycling, the negative impact on GDP is reduced to less than 0.04 percent. At the household level results from simulation 1B showed that whilst the richest households' expenditure is hardly affected by the introduction of a carbon tax, poorer households with limited room for substitution are much worse off.

Simulation 2 focused on achieving input-saving technical change in the generation of electricity from sources other than coal. This was simulated by applying an average 5 percent input-saving technical change improvement on all non-coal electricity generation. Results from simulation 2 suggest that all important macroeconomic variables benefit from the technical improvement. Interestingly, results showed that richer household tend to benefit from the policy slightly more than poorer households.

The results in Chapter 6 confirm that policymakers need to be careful in introducing new taxes on goods that form a large part of the consumption bundle of vulnerable households, such as energy and transport. Poorer household groups are shown to be most exposed to rising energy costs as a result of the carbon tax. Despite its design challenges, the socio-economic and environmental considerations of the carbon tax make it a necessary intervention to correct for the unaccounted negative externalities of the current fossil-fuel dominated status quo. However, mitigating policies such as additional PAMs and further relieve for vulnerable households in the form of energy subsidies should be considered.

Chapter 7: Conclusion and Discussion

7.1 Overview of the Study

This study focussed on evaluating the impact of two different polices designed at reducing GHG emissions on South African households at different income levels: the carbon tax and energy efficiency gains in the form of technology and cost-saving in non-coal electricity generation. The main contribution of this study is provided in the evaluation of South African households at a disaggregated income level, appreciating the fact that households at different levels are impacted differently by the implementation of policies at national level.

Given the country's weak economic performance in recent years, high unemployment and elevated levels of inequality, the impact of proposed policies on low-income households and vulnerable industry groups are of particular concern. In order to evaluate how policies aimed at reducing GHG emissions affect households, this study conducted three different tasks. Firstly, a thorough analysis of how households have been consuming energy over time was conducted. This was achieved by profiling energy consumption in the South African residential sector by households at different income levels. This task included: i) a review of the different policies targeting energy provision and consumption that are in place in South Africa; ii) an analysis of the different types of energy used by both electrified and non-electrified households; iii) analysing the different sources of energy used by different households to satisfy their basic energy needs for cooking, heating and lighting; and iv) an analysis of the status quo of the South African energy consumption by households which included an international comparison with other neighbouring, developing and developed countries. Additionally, the energy and electricity consumption related questions in the National Income Dynamics Study (NIDS) by the Southern Africa Labour and Development Research Unit (SALDRU) were studied in order to evaluate the state of households' access to electricity, the type of energy used by households and households' expenditure on electricity and energy in South Africa based on the NIDS dataset findings.

Secondly, the determinants of residential electricity demand in South Africa per household income bracket were evaluated. This task involved: i) the identification of the determinants of residential electricity demand in South Africa at both aggregate and disaggregated (by low, middle and high) income levels; ii) the analysis of income and expenditure patterns of South African households at both aggregate and disaggregate income levels in order to identify other goods and services that might be consider complements or substitutes to electricity by South African households; and iii) the estimation of short and long-run price and income elasticities of residential demand for electricity at both aggregate and disaggregated income levels – an Auto Regressive Distributed Lag (ARDL) econometric model was implemented to achieve this task.

Thirdly, the economy-wide and household specific impact of the carbon tax and energy efficiency gains in the non-coal electricity generation was measured using a CGE model of the South African economy. Another contribution of this study was the updating and improvement of the CGE model by adding the latest elasticities estimated regarding household's response to changes in income and electricity prices; linking it to an updated emissions database; splitting households into different income categories; and adding detailed tax information that facilitated the in-depth analysis of different policies designed to reduce GHG emissions.

7.2 Synthesis of Results

Given the significance of the residential sector in terms of energy consumption, a comprehensive understanding of households' energy consumption patterns and choices is imperative. Chapter 4 focussed on profiling the South African residential sector's energy characteristics considering their energy-use profile, and understanding other characteristics such as their geographical distribution and demographic characteristics. The findings showed that despite poorer households who are connected to the national grid receiving 50 kW/h of free electricity per month to help them cover their basic energy needs, South African households – particularly low-income households – still use various sources of energy including wood and paraffin to satisfy their basic energy requirements. Solid fuels are predominantly used in rural areas where around 75 percent of non-electrified households rely on solid fuels for cooking, heating and lighting. Low-income South African households consume between 5-10 percent of their total energy in lighting; space heating and cooking account for the remainder 85-90 percent of their total energy consumption.

After evaluating the relevant data regarding households' access to electricity, the type of energy used by households and households' expenditure on electricity and energy in South Africa from the NIDS dataset; it was concluded, that electricity access is reasonably high across South African households. Additionally, an increasing trend can be observed in their total expenditure on electricity. However, approximately 70 percent of households still spend on other energy sources to satisfy their basic energy needs.

The international comparison of electricity consumption analysis shows that access to electricity in South Africa compares favourably to developing countries but, as expected, is still lagging behind compared to developed countries. Residential electricity consumption in South Africa is well below the average of both the G-7 countries and BRICS. Access to electricity and residential electricity consumption in South Africa are both higher than the average in SADC.

Chapter 5 estimated the determinants of electricity demand at both the aggregate and at disaggregated income levels by applying an Auto Regressive Distributed Lag (ARDL) econometric model (a bounds testing approach to testing cointegration methodology as used by Narayan and Smyth (2005) and Ziramba (2008)). The residential demand for electricity was estimated 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 electricity price restructuring. This chapter contributes to the South Africa literature by evaluating the period 1975-2016 – a longer time frame than previously studied in the South African literature – which accounts for the electricity price restructuring (increases in electricity prices) that happened in South Africa from 2007. The period of rapid electricity price increases that followed is believed to have affected consumer's behaviour towards electricity consumption, and to our knowledge, has not been studied in the South African context. Additionally, by providing a thorough analysis of the income and expenditure patterns of South African households at both aggregate and disaggregate income levels, this research contributes to the South African literature by determining whether South African households consider electricity and food as complementary or substitute goods, and whether this relationship differs amongst different income groups. The empirical results from Chapter 5 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. With regards to the complementarity or substitutability between electricity and food by South African households, Chapter 5 concluded that at both aggregate and disaggregate income levels food and electricity are substitute goods for all South African households.

Chapter 6 evaluated two of the main policies to reduce GHG emissions in South Africa – the carbon tax and energy efficiency incentives in the non-coal electricity sector. The impacts of these policies are evaluated across different households, including low-income households who are said to be least responsible for climate change. A dynamic CGE model of the South African economy, which is linked to an emissions database and includes detailed tax information that allows for accurate measurement of the effects of both the carbon tax and energy efficiency gains in the electricity sector, was used to conduct the modelling simulations. Results show that the effects of the carbon tax on economic growth are minimised when the revenue collected from the carbon tax is recycled back into the economy. Additionally, low-income households are shown to be more affected by the implementation of the carbon tax compared to high-income households. With regards to the effects of energy efficiency gains in the non-coal electricity sector, results showed that all important macroeconomic variables benefit from the technical improvement and that even though all households benefit from the imposed policy, high-income households see slightly better outcomes than low-income ones. The results from Chapter 6 confirm that policymakers need to be careful in introducing new taxes on goods that form a large part of the consumption bundle of vulnerable households, such as energy and transport. Poorer household groups are shown the be most exposed to rising energy costs as a result of the carbon tax.

7.3 Policy Recommendations

This study sheds light on the economy-wide effects of energy and environmental policies in South Africa. One of the key findings is that policies should consider being targeted along different income groups. 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 sheds light into how low-income South African households spend a large proportion of their income on electricity. This indicates that there is room for re-evaluating and adapting the FBE policy, maybe by providing more than 50 kW/h of free electricity per month to low-income households. That way these households will have more money to spend on other essential 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 Chapter 4, can be detrimental to both health and productivity.

A novelty of this study was its ability to present the determinants of electricity demand for South African households as a whole and also in a disaggregated manner per income level. This research will be important in informing future policies that aim at reducing electricity consumption in the residential sector in order to help mitigate CO_2 emissions. Given the results obtained with regards to the effects of residential electricity prices on residential electricity consumption – coefficients were negative and significant for all the models. It can therefore be concluded that future pricing policies aimed at reducing residential electricity consumption and hence GHG emissions are bound to be successful in South Africa.

From a policy perspective, the results obtained with regards to the price elasticity of demand for South African households are key. The results show that electricity prices do influence electricity demand for South African households post-2008. This indicates that there is room to have policies designed around pricing to reduce electricity consumption, and ultimately, GHG emissions in South Africa.

When considering policies to mitigate GHG emissions, policymakers should account for both the socio-economic and environmental considerations of the carbon tax and other PAMs as a necessary intervention to correct for the unaccounted negative externalities of the current fossil-fuel dominated status quo. However, mitigating policies such as additional PAMs and further relief for vulnerable households in the form of energy subsidies, should be considered. As the results in Chapter 6 show, policymakers must carefully design any energy policy interventions with the impact on poorer households in mind given its direct impact on key commodities such as electricity and transport that form a large part of the consumption bundles of poorer households.

7.4 Future Research

Assuming the South African electricity sector continues its trend towards using more renewable energy, electricity consumption patterns by South African households are bound to change. Therefore, future research may use the information gathered in Chapter 4 to inform and propose policies that will aim at changing consumer behaviour and the way new electricity connections are planned in South Africa. Additionally, reducing energy consumption in the residential sector and planning most future connections to be based on renewable energy sources has been identified as one of the many policies and measures that South Africa can implement to reduce GHG emissions and comply with different climate change agreements such as the Paris Agreement. In the ever-evolving world of energy, technology and environmental impacts, future research on these topics will undoubtably be an ongoing effort.

The South African Integrated National Electrification Programme aims at improving access to electricity and having universal access to electricity in South Africa by 2025 – which is important for households' standard of living and for the provision of basic human rights. It aims to achieve universal access to electricity in a cleaner way, implying technological efficiency improvements. Against this backdrop, an interesting policy to model with regards to the different PAMs designed to reduce GHG emissions, would involve a combination of policies including the increase in electrification using energy efficiency methods. This will offer insight into what will be the economy-wide and household level effects of a policy that is aimed at i) increasing electricity access in South Africa (which will exogenously increase electricity consumption in the residential sector) and; ii) incentivising consumers to consume electricity in a more efficient way (greener buildings and more efficient household appliances).

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Appendix: Glossary

Access to electricity: the percentage of population with access to electricity. Electrification data are collected from industry, national surveys and international sources.

Electricity demand: total gross electricity generated, less own use in generation, plus net trade (imports less exports), less transmission and distribution losses (IEA, 2016).

Energy consumption in the residential sector: all energy consumed by households excluding transportation uses (EIA, 2016).

Energy Poverty: lack of access to modern sources of energy, and a reliance on biomass for cooking and heating (IEA, 2010). The preferred definition of energy poverty by the Department of Energy and by Statistics South Africa is based on the expenditure-based approach, which defines energy poverty as a household that spends more than 10% of their net income on energy (DoE, 2013a).

Free Basic Electricity: refers to the amount of energy which is deemed sufficient to provide basic electricity services to poor households (Statistics South Africa, 2013).

Household: a group of persons who live together and provide themselves jointly with food and/or other essentials for living, or a single person who lives alone (Statistics South Africa, 2013).

Load shedding: Load shedding or load reduction is the South African term for electricity rationing.

Mains Electricity: is defined as the general-purpose alternating-current (AC) electric power that is supplied to households (Statistics South Africa, 2013).

Quantile: a quantile is one-fifth (20%) of a given number. The monetary cut values for income quantile are as follows: (Statistics South Africa, 2013).

Quantile 1: R0 – R390

Quantile 2: R391 – R764

Quantile 3: R765 – R1499

Quantile 4: R1500 – R3997

Quantile 5: Larger than R3997

Rural: farms and traditional areas characterised by low population densities, low levels of economic activity and low levels of infrastructure (Statistics South Africa, 2013).

Rural Formal: farms and traditional areas that are characterised by low population densities, low levels of economic activity and low levels of infrastructure (Statistics South Africa, 2013).

Urban: cities and towns that are usually characterised by higher population densities, high levels of economic activities and high levels of infrastructure (Statistics South Africa, 2013).

Urban Informal: settlements or 'squatter camps' that are usually located in urban areas (Statistics South Africa, 2013).