Determining the Impacts of Selected Energy Policies on Gauteng's Residential Energy Consumption and the Associated Emissions using LEAP as a tool for Analysis

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Implications for sustainable livelihoods for the poor

By

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Declaration

By submitting this dissertation I declare that this is my own work. I know the meaning of plagiarism, and declare that all the work in this thesis has been conducted by me unless indicated otherwise. This dissertation has not previously been submitted for a degree at the University of Cape Town or any other university.

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Abstract

Energy is a key and substantial factor in economic growth and it is also central to meeting basic socio-economic goals. But the use and production of energy in South Africa is associated with greenhouse (GHGs) gas emissions and pollution problems. In today's energy sector, there is a need for sustainable energy use and production so that sustainable development goals can be realized. Sustainable development is multi-facet concept but there is a general consensus that there are three dimensions to this concept. The three dimensions of sustainable development are social, economic and environmental.

Within the energy sector, the sector where the three dimensions of development can be assessed is the residential sector. Although most of the problems faced by the residential sector in all the provinces in the country are similar, each province has its unique and exceptional energy challenges. Gauteng's residential sector is faced with slowing rate of electrification due to high in-migration rate and high pollution levels in households that use coal to meet their energy needs. The South African government realises that sustainable development can be achieved through effective policies. This study analyses whether the energy policies in Gauteng can help to steer Gauteng's residential sector toward sustainable use of energy by reducing the energy demand and associated GHG and pollutants emissions. Long range Energy Alternative Planning system (LEAP) was used as a tool for analysis.

Of the modelled scenarios, the EE (Energy Efficiency) scenario reduced more energy demand and the associated emissions than other scenarios. If all options in EE are simultaneously implemented, the EE scenario would save 27%, 33% and 22% of energy demand in low, middle income and high income households respectively by 2030 relative to the BASE case. If all the modelled scenarios are implemented, Gauteng's residential sector would reduce 20 000 tonnes, 10 000 tonnes and 3 000 tonnes of carbon monoxide, total suspended particulate emissions and PM10 and sulphur dioxide respectively.

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Abbreviations, Acronyms and Units

ASSA	Actuarial Society of South Africa
BnM	Basa Njengo Magogo
CDM	Clean Development Mechanism
CFL	Compact Fluorescent bulb
COJMM	City of Johannesburg Metropolitan Municipality
CPI	Consumer Price Index
CS2007	Community Survey 2007
CTMM	City of Tswane Metropolitan Municipality
DoE	Department of Energy
DME	Department of Minerals and Energy
DEAT	Department of Environmental Affairs and Tourism
DLR	Domestic Load Research
EE	Energy Efficiency
EI	Energy Intensity
EISD	Energy Indicators for Sustainable development
ENO	Engineering News Online
EMM	Ekurhuleni Metropolitan Municipality
ERC	Energy Research Centre
FBE	Free Basic Electricity
FE	Final Energy
FS	Fuel shares
g	gram
GDP	Gross Domestic Product
GDS	Gauteng and Development Strategy
GEAR	Growth Employment and Redistribution
GHG	Greenhouse gases
GJ	Gigajoule
GIES	Gauteng Integrated Energy Strategy
GMTBPS	Gauteng Medium Term Budget Policy Statement
GPG	Gauteng Provincial Government
GSSD	Gauteng Strategy for Sustainable Development
HDI	Human Development Index

Hhs	Households
HST	Health System Trust
IAEA	International Atomic Energy Agency
JPI	Johannesburg Plan of Implemention
KWh	Kilowatt hour
LEAP	Long range Energy Alternative Planning System
LPG	Liquefied Petroleum Gas
LTMS	Long Term Mitigation Scenarios
MDC	Marcus Dekenah Consulting
MDG	Millennium Development Goals
MEPS	Minimum efficiency performance standards
MET	Metsweding District
MLL	Minimum Living Level
Mono	Using electricity only
Mult	Multiple fuel using
NEP	National Electrification Programme
NIDS	National Income Dynamics Study
PDG	Palmer Development Group
RDP	Reconstruction and Development Programme
RSA	Republic of South Africa
SACN	South African Cities Network
SANS	South African National building Standard
SASOL	South African Coal and Oil Company
SEA	Sustainable Energy Africa
SED	Sedibeng District
SMNRP	Single Maximum National Retail Price
STATSSA	Statistics South Africa
SSN	South South North
SWH	Solar Water Heaters
TED	Technology and Environment Database
TIASA	Thermal Insulation Association of Southern Africa
TSPS	Total Suspended Particulate Solids
UE	Useful Energy
UNDP	United Nations Development Programme

VAT	Value Added Tax
WCED	World Commission on Environment and Development
WR	West Rand District

1. Background

1.1 Introduction

Energy is a key and substantial factor in economic growth and it is also central to meeting basic socio-economic goals (Reddy, 2008, Haw & Hughes, 2007, Winkler, 2005). Improved energy access improves people's quality of life by improving their welfare and increasing their living standards (Gaunt, 2004, Alfstad, 2005, UNDP, 2001).

Despite the benefits of having access to energy, the supply and use of energy is responsible for environmental problems such as climate change and localised environmental pollution (SEA, 2006, Thomas, Liebenberg-Enslin and Walton & Nierop, 2004). The South African Department of Environment and Tourism (2004) has identified extreme air pollution in communities that live close to power stations and oil refineries. The energy sector has been identified as the largest greenhouse gases (GHG) emitting sector in most developing and developed countries alike (SEA, 2006, Winkler, 2009). GHG emissions are identified as the greatest cause of climate change. About 50%-60% of the increased level of GHGs in the atmosphere are said to be from carbon dioxide which is released when burning fossil fuels for energy production and use (SEA, 2006).

Increased emissions (pollutants and GHGs) and limited access to energy undermine the social and environmental spheres of development pursued by nations. Nations try to improve energy access and reduce energy related emissions through energy policies. These policies range from energy supply policies, energy efficiency policies to GHG mitigation policies and so on. The question that one can ask is; do these policies effectively improve energy access and reduce energy related pollution and GHG emissions?

The compromised spheres of development have prompted nations to seek ways of developing a sustainable energy sector. The Energy Efficiency Strategy Review of the Department of Minerals and Energy (DME, 2009: 1) defines a sustainable energy sector as a sector whose energy utilization and production supports the social, environmental and economic aims of sustainable development.

Sustainable development is a multi-facetted term used and defined differently by several academic disciplines (Winkler, 2005, Atkinson, Dubourg, Hamilton, Munasinghe, Pearce & Young, 1997, WCED, 1987, Spalding-Fecher, 2003) however Winkler (2006) found that there is a general consensus in all the definitions of sustainable development. The consensus is that sustainable development is development that promotes economic growth and stability and empowers people so that poverty can be eradicated whilst preserving biodiversity and natural resources (Winkler, 2005).

A Sustainable energy sector is at the heart of sustainable development in South Africa. The Energy Efficiency Strategy of South Africa (DME, 2005) noted that it is essential for every sub-sector within the South African economy to contribute to sustainable energy production and use. The sector where sustainability can be measured in all its dimensions is the residential sector.

Since this study concentrates on the residential sector, it is essential to develop a clear definition of sustainable energy use in the residential sector. In the Gauteng Integrated Energy Strategy (2009), Sustainable Energy Africa (SEA) defines households to be sustainable in their use of energy if clean and affordable energy is used. Winkler (2006) argues that sustainable use of energy in the residential sector is when there is sufficient energy supply to households and the energy that is used improves the life of the people. Based on government's re-iterated aim of providing clean and affordable energy services to households, found in these documents - 1998 Energy White Paper ; 2004 Minister of Energy budget speech: 2006, state of the nation speech; Thabo Mbeki 2006, accompanied with the need for reduced greenhouse gas emissions and energy intensity (ERC, 2008: DME, 2003), the definition for sustainable energy use in Gauteng's residential sector was derived from Winkler's definition and the Gauteng Integrated Energy Strategy (2009) definition, incorporating the government's aim of affordable energy access.

In this study, energy use is considered sustainable if the following three conditions are met. Firstly, the energy should be affordable for low income households, secondly, air pollution should be minimal in low income households and thirdly, GHG emissions that come from the residential sector should also be reduced over a modelling period (2007 - 2030). GHG emissions would be reduced if households become efficient in their use of electricity which will result in reduced energy demand.

The South African Constitution (RSA, 1996) also supports the sustainable use of energy as defined above. The constitution establishes the right to a clean and safe environment for all South Africans. Section 24 (a) of the constitution says:

> *"Everyone has a right to an environment that is not harmful to their health or well-being" (RSA 1996).*

To achieve, sustainable energy use in the residential sector, there is a need for accelerated uptake of renewable energies because these energy sources supply clean energy (energy which has minimal GHG emissions, such as solar energy). But the intermittent nature of these energy sources make the renewable energy technologies unreliable in terms of energy security and the technologies that tap these energy sources are currently expensive (Haw and Hughes, 2007, Winkler, 2005).

1.2 General energy related challenges faced by South Africa

Given the fact that the South Africa's economy relies on fossil fuels (Winkler 2005), the country faces significant challenges in moving the energy sector towards sustainability. Of the primary energy used in the country, 90% comes from coal and crude oil (Winkler, 2006). The reliance of the South African economy on fossil fuels has contributed to making South Africa one of the most carbon emissions intensive countries in the world. Table 1-1 shows South Africa's carbon dioxide (CO_2) emissions intensiveness relative to the world's average.

Table 1-1: Comparison of South Africa CO_2 emissions with the world's average

	tCO_2/capita	$kgCO_2$/GDP
World Average	3.89	0.68
South Africa	6.65	1.65

Source: Winkler (2006)

South Africa ranks among the top 20 CO_2 emitters in the world (Winkler, 2005). Looking at Table 1-1 it can be seen that South Africa produces 2.76 more tCO_2/capita and 2 times more $kgCO_2$ emissions per unit of GDP than the world averages.

But as a signatory of the Kyoto Protocol and the current Copenhagen Accord, South Africa has committed to reduce its energy related greenhouse gas emissions (GHG) although it has no binding emission targets since it is a non-Annex 1 country. In addition to being a signatory of the Kyoto Protocol and Copenhagen Accord, South Africa is also a signatory to other development initiatives such as the Millennium Development Goals (MDGs) and Johannesburg Plan of Implementation (JPI). As a result South Africa has a challenge of meeting a wide range of development goals that need to be met while simultaneously trying to develop a sustainable energy sector.

Generally, the South African development policies tend to be focused on upliftment[1]. Since 1994, the development focus of South Africa has been to redress the injustices of the apartheid system under which the majority of the population was sidelined from service provision based on racial classification. It was after 1994 that energy provision sought to improve the life of the whole population (Mwakasonda & Davidson, 2004, Prasad, 2006, Marquard & Eberhard, 2000). The energy white paper (DME, 1998) stresses the social concern of energy policy in South Africa. Two of the five major objectives in the energy white paper specifically address the social aspect of development - increasing access to affordable energy for the poor and reducing energy-related health effects (DME, 1998). These socially concerned energy policies have highlighted a need to assess the contribution of energy policies to social development. A sector where the contribution of energy policies to social development can be directly assessed is the residential energy sector. Residential sectors of all provinces are faced with challenges such as energy access, pollution, fires, illegal electricity connections in urban areas and so on (SEA, 2006) but the residential sector of Gauteng presents far more dire energy related challenges. Therefore, Gauteng's residential sector was chosen for this study to assess whether the contribution of residential energy policies alleviate the dire energy problems that it currently experiences.

1.3 Energy challenges faced by Gauteng's residential sector

Of the nine provinces in South Africa, Gauteng is responsible for about one third of South Africa's energy consumption and one third of South African carbon dioxide ($CO_{2\text{-equiv}}$) emissions. Gauteng province is specifically burdened with particulate emissions which pose major environmental and health challenges. Gauteng is one of the three provinces (Mpumalanga, Free State and Gauteng) that form the Vaal airshed priority area (an area which has high pollution and needs more air quality monitoring). At global level Johannesburg (one of the metropolitan sector in Gauteng) is rated the fifth highest city in the world in terms of air pollution (GSSD, 2005).

[1]The initial development policy, Reconstruction and Development Programme (RDP) was mainly based on social upliftment The key programmes of the RDP are

- meeting basic needs;
- developing human resources;
- building the economy;
- democratising the state and society;

Within 2 years the government realized the economic bottleneck that resulted after implementation of RDP, (then the new policy - Growth Employment and Redistribution was developed (GEAR)) (Roberts, 2005 and Reddy 2008)

Scorgie, Burger and Annergan (2003) and Mathee (2004) found that Gauteng's pollution largely comes from households that burn coal to meet their energy needs. Scorgie et al (2003) found that 65% of pollution in Gauteng can be contributed to households that use coal. Mathee (2004) found that 48% of quantifiable particulate emissions in Johannesburg came from coal burning households. Terblanche (1992) also found that most of the air pollution in Soweto (a township on the outskirts of Johannesburg) was due to coal burning in households. Scorgie et al (2003) and Mathee's findings are similar to the findings of a previous study by Terblanche (1992) in Soweto, which shows that the problems that existed in the nineties still exist twelve years later.

Fuel burning in households is identified as a significant contributor of indoor air pollutants in Gauteng (GPG, 2004). Indoor air pollution in coal using households causes human health problems which have negative economic implications according to DEAT (2004) and Horen (1994). Horen (1994) argues that health problems caused by indoor pollution can cause a decline in economic production due to the absenteeism of sick employees. Despite the efforts made by the government to increase electrification levels in the province (NERSA, 2005), the continuing problems of air pollution signal that electrification has not helped in reducing the use of dirty fuels[2] which was one of the aims of electrification in the 1998 Energy White Paper Policy document.

Gauteng's residential sector has shown a dramatic increase in energy demand over the past seven years. In 2000, Gauteng's residential sector consumed 5% and 14% of total final energy demand and total electricity demand respectively (Ward and Schäffler, 2008). By 2007, the sector's final energy demand had increased to 16% of total final energy demand consumed within the province (SEA, 2009). 65% of that energy demand was met by electricity (Ward and Schäffler 2008). Gauteng's residential sector had an 11% increases in final energy demand in just seven years. Given the fact that 93% of South African electricity is derived from coal (Winkler, 2009), the increased electricity demand from the residential sector translated into increased GHG emissions.

Increasing GHG and pollutant emissions are not the only problems that Gauteng's residential sector faces. Electrification growth rate is extremely slow in Gauteng relative to other provinces. In 2007, 17% of the households in Gauteng were not electrified, compared to 24% in 1996. Within 11 years (1996 -2007), there was a mere 7% increase in electrification level while other provinces

[2] Fuels that emit pollutants

experienced a massive electrification level increase in the ranges of 10% – 20% (STATSSA, 2007). Low income households that are not electrified tend to use coal and paraffin (Gaunt, 2003, Reddy, 2008, Simmonds & Mammon, 1996, White, Mafokane & Meintjes, 1998, Mapako & Prasad, 2005), and the use of these fuels emit pollutants which exacerbate pollution problems in the province

It is not only the non-electrified households that use coal and paraffin; even the low income electrified households use these fuels. Several studies have shown that low income electrified households continue to use coal and paraffin because they cannot afford electricity (Gaunt, 2003, Reddy, 2008, Simmond & Mammon, 1996, White et al., 1998, Mapako and Prasad, 2005). Energy affordability is a major challenge facing Gauteng's residential sector as it also undermines DME's goal of reducing energy related health impacts because households continue to use dirty fuels when they cannot afford cleaner fuels[3] such as Liquefied Petroleum Gas (LPG) and electricity.

The increase in energy demand was accompanied by high population and households growth rates and a slowing electrification growth rate. The South African City Network (2004), found that the high rate of urbanisation slows electrification growth rates. Gauteng was home to 21% and 25% of South African population and households respectively in 2007 although it is the smallest of all provinces in terms of surface area[4]. Gauteng's state of environment report (2004) reported that 30% of population growth in Gauteng is due to in-migration. (GSSD, 2006) has shown that the annual population growth rate within the province is at 4.1%.

1.4 The aim of the study and the research questions

This thesis has two main objectives. The first objective is to create a deeper understanding of energy use in Gauteng's residential energy sector hence providing data for sustainable energy planning and residential energy policy making. The second objective is to analyse whether residential energy policies can move Gauteng's residential sector towards sustainable energy use.

In trying to achieve the above objectives, the thesis answers the following two main questions;

1) What are the current energy use patterns in Gauteng's residential sector? This question is further divided into:
    a. What types of fuels and appliances are used within different households' categories?

[3] Clean fuels in the residential sector are fuels which do not emit pollution at the point of use.

[4] Gauteng occupies 16 548 km^2 of 1.2-million km^2 in South Africa

b. What are the reasons associated with fuel choice?

c. When do multiple fuel use practices become beneficial?

2) What impacts (both negative and positive) do residential energy policies have on sustainable energy use in Gauteng's residential sector? This question is further divided into two sub-questions as follows:

a. Can the current energy policies help Gauteng households move towards efficient use of energy?

b. Can the current policies and the "what if energy policies[5]" help to reduce GHG emissions and pollutants resulting from energy use?

1.5 Methodology

Energy modelling allows quantification of energy consumption and the associated GHG emissions and pollutants. In order to answer the questions posed in section 1.4, this thesis examined and analysed energy use in Gauteng's residential sector using the Long range Energy Alternatives Planning System (LEAP) model. The households in the sector were disaggregated into three household income categories – high, middle and low income households. The middle and low income households were further split into electrified and non electrified households. The electrified households in both categories were further broken down into households using only one fuel (electricity) and households using multiple fuels. The mobility of households from one income category to the next was included in the model hence reflecting the energy demand of households with respect to their changing income status.

The results from the model were used to assess whether energy policies would steer Gauteng's residential sector towards sustainable energy use. To measure the sustainability of the sector, sustainability indicators that are specific to Gauteng were used. The indicators were derived from the International Atomic Energy Agency (IAEA) report on Methodologies and Guidelines on Energy Indicators for Sustainable Development (IAEA, 2007). With reference to the definition of sustainable energy use given in Section 1.1, the indicators were also split into sector and household levels hence allowing sustainability in the residential sector to be viewed at two levels - the household (micro) level and sectoral (macro) level. At the sectoral level, the modelled energy policies analysed the extent to which GHG emissions and energy demand are reduced through

[5] The policies that were modelled but are not yet implemented by Gauteng province

practicing energy efficiency. At household level the modelled energy policies analysed whether the policies led to reduction of air pollution in low income households and whether the subsidies improved access to affordable energy. The assessment of sustainability compared the value of an indicator between different scenarios in 2030 relative to the Base case. For comparison between the modelled scenarios, the results were normalised and measured on a scale between 0 and 1. Scenarios that gave the indicator a value of 1 highlight that the scenario is the most preferred scenario in terms of achieving sustainable energy use in Gauteng.

1.6 Thesis Outline

This thesis consists of six chapters. Chapter 1 is this background chapter. Chapter 2 gives the methodological approach taken to answer the research questions. It starts by describing the data sources that were used to populate the model, gives a brief overview of the LEAP model and concludes by explaining how sustainable energy use is assessed using sustainable energy indicators. Chapter 3 provides an overview of Gauteng. It starts by giving a spatial distribution of population and households and their energy consumption and it concludes by presenting energy use in Gauteng's residential sector, and the types of appliances used. Chapter 4 describes scenarios and provides detailed ways on how these scenarios were derived from the literature and how they were applied in the LEAP model. Chapter 5 presents the results from the model together with their discussion and interpretation. Chapter 6 assesses whether the modelled energy scenarios contribute to the sustainable use of energy.

2. Data collection, processing and analysis methods

2.1 Introduction

This chapter describes the methodological approach used to explore and analyse the dataset and policies. The chapter starts with a description of the energy consumption data and data sources. After the description of data sources, LEAP is discussed, highlighting how the Gauteng residential LEAP model was constructed. The chapter further explains how the data found in different data sources was manipulated to get the data required by the LEAP model to answer the research questions. The chapter concludes by explaining how the results from the LEAP model were used to assess sustainable energy use.

2.2 Dataset

In energy modelling, a model is only as good as the data that was entered into it (Gaunt, 2003). It is therefore crucial to ensure that the input energy data is reliable. Quantifying energy consumption data by end use for the residential sector is not a straight forward procedure because households consume energy differently depending on factors such as income levels, the type of fuels used, appliances used, household sizes, people's tastes and habits and so on.

The energy data used for this work was collected from a wide range of sources. Data was collected from publicly available resources describing residential energy consumption as well as from the NRS034 Domestic Load Research database housed in the Energy Research Centre (ERC).

Table 2-1 presents the data sources used for this study and the type of data that was available from each source.

Table 2-1: LEAP Model input data requirements

Data Type	**Sources of data**
Number of households	Community Survey 2007
Electricity consumption patterns for households in high income category	NRS034 Domestic Load Research (NRS034 DLR) database
Households income categories by main fuel for cooking, space heating and lighting[6]	Community survey 2007
Sectoral energy demand, end uses performed by different categories of households in Gauteng, fuels used within the households and energy intensities per end use	City of Tswane state of energy report 2006 City of Johannesburg state of energy report, 2007 City of Ekurhuleni state of energy report 2004
Multiple fuel use patterns	White, Mafokane and Meintjes (1998) study.
Appliance efficiencies	Haw and Hughes (2007), Winkler 2005 & Winkler ed , 2006
Emission Factors	Hughes and Haw (2007) & Marquard, Letete and Guma (2008)

The Community Survey 2007, the NRS034 DLR database and multiple fuel use combination patterns found in White, Mafokane and Meintjes (1998) study were used as main sources of data for this study. The other reports were used to come up with energy consumption per end use for different household categories. A short description of the Community Survey 2007, the National Load research database and White et al (1998) study is given below.

[6] The main fuel is the fuel that is used mostly within the household.

2.2.1 2007 Community Survey

The 2007 Community Survey (CS 2007) was a large-scale household survey conducted by Statistics South Africa in 2007 to bridge the gap between the 2001 and 2011 censuses (STATSSA, 2007). During the CS 2007, a sample of 246 618 households was enumerated nationally (STATSSA, 2007). The exact number of households that were surveyed per province was not given; instead the response rate per province was given and Gauteng had a response rate of 91.8%.

The survey reported the main fuels used by households in different income categories for cooking, lighting and space heating. The fuels included were electricity, wood, coal, candles, animal dung and paraffin. The CS 2007 households' classifications were used to classify households into three income[7] categories - low (R0 – R9 600), middle (R9 601 – R153 600) and high (R153 600 and more) income households (refer to Appendix A).

2.2.2 NRS034 Domestic Load Research Database

The NRS034 Domestic Load Research database was developed by Marcus Dekenah Consulting (MDC). The database is a collection of residential electricity consumption surveys that MDC has conducted since 1995. The database contains electricity consumption patterns for households of different socio-economic statuses within South Africa, together with appliance saturation rates of both electrical and non electrical appliances owned by these households.

There were five residential areas within Gauteng in the database (see Appendix B). Out of these five areas only two areas – Moreletta Park and Sanctuary Gardens had sufficient[8] data for the purpose of this study. 50, 56 and 58 households were surveyed in Moreletta Park in 2001, 2002 and 2003 respectively. 60 households were surveyed in Santuary Gardens in 2000. Energy consumption characteristics, socio-economic data and appliance saturation rates of households in Moreletta Park and Sanctuary Gardens were taken to be representative of all high income households in Gauteng because the average monthly income for households in these two areas was R 29 000 in 2003. Given that Gauteng had 878 477 high income households in 2007, the sample households

[7] The income was on annual basis.

[8] This is the data that contained enough data on surveyed households. There were number of surveyed households, households characteristics such as income, appliances owned in households,

found in Moreletta Park and Sanctuary Gardens was not a good statistical representation of all high income households. But in the absence of other data, these households were taken as representative of high income households for illustrative purposes.

2.2.3 White, Mofokane and Meintjes's 1998 study

White, Mofokane and Meintjes (1998) undertook surveys in 1995 and 1996 in four townships[9] around Gauteng in order to identify the social determinants of fuels use. The study clearly identified the main and secondary[10] fuels that were used for lighting, cooking, space heating and water heating in the surveyed households. The study was used to derive fuel use combination patterns for middle and low income households. The surveys included electrified and non-electrified townships. Households in electrified and non-electrified townships were considered to be representative of all electrified and non-electrified households. The terms mono and mult will be used in this thesis to reflect households that use electricity only and households that use multiple fuels.

2.3 Deducing multiple fuel use combination patterns

Several studies have proved that the majority of low income households across South Africa practice multiple fuel use (Prasad, 2006, Cowan, 2008, White et al, 1998 and Gaunt, 2003; Simmonds & Mammon, 1996; Louw, Conrad, Howells & Marcus, 2008, Reddy, 2008). Multiple fuel use refers to the practice where households utilise a range of fuels and appliances at the same time, or inter-changeably depending on the fuels' availability and accessibility (PDG, 1998). The 2007 Community Survey reported main fuels used for lighting, cooking and space heating in households. As a result, the Community Survey 2007 did not capture the incidence of multiple fuel use within Gauteng households.

Creating deeper understanding of energy consumption in Gauteng is one of the objectives of this study, so it becomes crucial to capture reality as much as possible in the model. It is therefore important to know how many households practise multiple fuel use as well as the fuel combination patterns that these households follow. The White et al (1998) study was used to deduce multiple

[9] Lusaka City, Powa Park, Mandelaville, Mzimhlope and Mzimhlope backyards

[10] A supplementary fuel

fuel use combination patterns. To find fuel use combination patterns that matched low and middle income households classifications of this study, a series of steps were followed to manipulate the data found in the White et al (1998) study.

The steps are as follows:

1) Inflating 1995 income bands into 2007 income bands

2) Re-classifying the income bands to align them to income bands that define low, middle and high income households in this study to find which townships would be used to represent low and middle income households.

2.3.1 Classification of households found in White et al (1998) into income categories

Table 2-2 shows classifications of households by income as was found in White et al (1998) study in Mzimhlope, Powa Par and Mandelaville.

Table 2-2: Percentage of households by income band

Households Income bands	Mzimhlophe		Powa Park (%)	Mandelaville(%)	Lusaka City (%)
	Formal	Backyard			
Nothing	30.00	20.00	13.33	40.00	46.67
R1 – R250	5.00	0.00	6.67	13.33	0.00
R251 – R500	11.67	26.67	13.33	0.00	6.67
R501 – R1000	18.33	13.33	26.66	6.67	26.67
R1001 – R1500	18.33	20.00	20.00	13.33	20.00
R1501 – R2500	15.00	13.33	20.00	26.67	0.00
R2501 – R3500	1.67	6.67	0.00	0.00	0.00
R3500+	0.00	0.00	0.00	0.00	0.00
Total	100	100	100	100	100

Source: White et al (1998)

The sample size from which Table 2-2 is drawn was 80 households. 30 households were interviewed in Mzimhlophe, 20 in Lusaka City and 15 households were interviewed in both Powa Park and Mandelaville. Although this sample does not give a good statistical representation of middle and low income households in Gauteng, they were used in this study for illustrative purposes since no better data could be found.

The income bands in Table 2-2 were inflated to 2007 Rand value, using Equation [2-1] which resulted into new income bands shown in Table 2-3.

$$AdjIncome = Income\ (\frac{CPI_{thisyear}}{CPI_{collectedyear}}) \qquad [2\text{-}1]$$

AdjIncome is the adjusted income, Consumer price index (CPI) for 1995 was taken as CPI $_{collected\ year}$ and 2007 consumer price index was taken as CPI$_{this\ year}$. The average CPI in 1995 was 45.3 and in 2007 the average CPI was 89.7 (STATSSA, 2010).

Table 2-3: Percentage of households in newly inflated income bands

Monthly (1995)	Inflated Monthly (2007)	Inflated Annual (2007)	Mzimhlope Formal		Powa Park	Mande-laville	Lusaka City
			For-mal	Back-yard			
No income	No income	No income	30.00	20.00	13.33	40.00	46.67
R1- R250	R1.98-R495	R1[11]-R5940	5.00	0.00	6.67	13.33	0.00
R251-R500	R497-R990	R5964-R11881	11.67	26.67	13.33	0.00	6.67
R501-R1000	R992-R1980	R11904- R23762	18.33	13.33	26.66	6.67	26.67
R1001-R1500	R1982- R2970	R23785-R35642	18.33	20.00	20.00	13.33	20.00
R1501-R2500	R2972-R4950	R35666-R59404	15.00	13.33	20.00	26.67	0.00
R2501-R3500	R4952-R6930	R59428-R83166	1.67	6.67	0.00	0.00	0.00
R3500+	R6930+	R83166+	0.00	0.00	0.00	0.00	0.00
Total	-	-	100	100	100	100	100

The income bands in Table 2-3 were re-ordered so that they matched with the definition of low, middle and high income households defined in section in 2.2.1 for this study. Table 2-4 shows the percentage of households that belonged to the low, middle and high income groups.

Table 2-4: Low, middle and high income households in White et al (1998)

		Mzimhlope					
Income Bands	Household categories	Formal	Backyard	Average	Powa Park	Mandelaville	Lusaka City
<R9 600	Low	46	47	47	53	53	53
R9600 to R153 600	Middle	53	67	53	47	47	47
> R153 600	High	0	0	0	0	0	0
Total (%)		100	100	100	100	100	100

[11] The real Rand value is R24. In order to include R1 – R24 in 2007, the income band was assumed to start at R1.

Looking at Table 2-4, it is clear that there were no households in the White et al (1998) study that fell into the high income household category. Households in both Lusaka and Mzimhlophe town-ships were electrified, and as a result they were assumed to be representatives of electrified households in Gauteng. Households in Mzimhlope are assumed to serve as representative of electri-fied middle income households because 60% of households fell in R9 600 to R153 600 income band. Households in Lusaka city are assumed to represent electrified low income households. Since Powa Park and Mandelaville were non electrified settlements at the time of the surveys, households in these two settlements are assumed to represent non electrified middle and low income households.

2.3.2 Multiple fuel use combination patterns

Multiple fuel use combination patterns practiced by households in Mzimhlope, Lusaka City, Powa Park and Mandelaville are shown in Table 2-5, Table 2-6 and Table 2-7.

Table 2-5: Multiple fuel use combination patterns for electrified middle income households

End Use	Fuel Combinations	Number of households	Percentages (%) of households
Cooking Fuel	electricity + coal	6	86
	electricity + paraffin	1	14
Space heating fuel	Coal + electricity	5	83
	Coal	1	13
Water heating fuel	Electricity + coal	5	100

Source: White et al (1998 p.51)

Table 2-5 shows that coal was the primary fuel for space heating in middle income households while electricity was the primary fuel for cooking and water heating.

Table 2-6: Multiple fuel use combination patterns for electrified low income households

End Use	Fuel Combinations	Number of households	Percentage of households (%)
Cooking	Electricity & Paraffin	6	40
	Paraffin	8	53
	Coal	1	7
Space heating	Paraffin	3	27
	Coal	7	64
	Paraffin& coal	1	9

Source: White et al (1998 p.26)

Table 2-6 shows that a high percentage of low income households used coal and paraffin as their primary fuels for space heating whereas for cooking many households used paraffin and electricity as their main primary fuels. Table 2-7 presents space heating fuel combinations for non electrified households

Table 2-7: Mandelaville and Powa Park multiple fuel patterns for Space heating

Fuel combination	Powa Park	Percentage (%)	Mandelaville	Percentage (%)	Average (%)
Paraffin	1	7	5	35	21
Coal	9	60	4	29	45
Coal & Paraffin	2	13	4	29	21
Gas	1	7	0	0	3
No heating	2	13	1	7	10
Total	15	100	14	100	100

Similar to electrified households, Table 2-7 shows that coal is the dominant fuel used for space heating purposes in non-electrified households. It is of great importance to note that the fuel combination patterns shown in Table 2-5, Table 2-6 and Table 2-7 may change over time. For example a household that was using coal and paraffin in 1998 might use different fuel combinations 1 or 2 years later when households' income status, location and tastes change. But for simplicity, the fuel combination patterns were assumed to hold for the entire modelling period (2007 – 2030).

2.4 Mono fuel using households

Despite the fact that White et al (1998) and Simmonds and Mammon (1996) showed that Gauteng households practice multiple fuel use, City of Johannesburg State of Energy Report (2007), City of Ekurhuleni State of Energy Report (2004) and City of Tswane State of Energy Report (2006) reported that some households use electricity only for all their energy needs irrespective of the income category they fall into.

For modelling purposes, the number of households that used electricity for all their energy needs must be calculated. Since the studies in Table 2-1 (where the energy data was taken from) did not explicitly specify which households used electricity only, they had to be estimated. To estimate the number of households that used electricity only, the electricity end use ladder in Figure 2-1 was applied to the data from 2007 Community Survey.

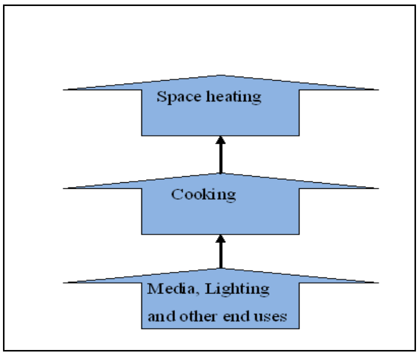

Figure 2-1: Electricity end use ladder for low income households
Source: derived from World Bank (2008:33)

The electricity end use ladder shown in Figure 2-1 simply shows that low income households start to use electricity for media purposes, lighting and some other end uses (such as refrigeration). After some time, electricity is then used for cooking and lastly for space heating when households have acquired suitable electrical appliances. This electricity end use ladder conforms to what South African studies have found regarding the way low income households use electricity (Prasad, 2006, Simmonds & Mammon, 1998, White et al, 1998, White, 1995). So space heating seems to be the last end use which electricity is used for in low income households.

Most residential energy use studies in South Africa target low income households, and as a result, energy use patterns in high and middle income households are not well documented. As a result some studies assume that these households use electricity almost exclusively to achieve their end uses (Winkler et al, 2005). The three states of energy reports for Gauteng's cities and the 2007 Community Survey found that some high and middle income households used other fuels (LPG, Egoli gas, coal and paraffin) for end uses such as cooking and space heating. In the absence of a well documented energy use pattern in high and middle income households, the low income households' electricity end use ladder shown in Figure 2-1 was used across all income categories of this study.

Based on Figure 2-1, all households in the 2007 Community Survey, which used electricity for space heating, were assumed to use electricity only for all their energy needs. The 2007 Community Survey found that 76% of households in Gauteng used electricity for space heating as shown in Figure 2-2.

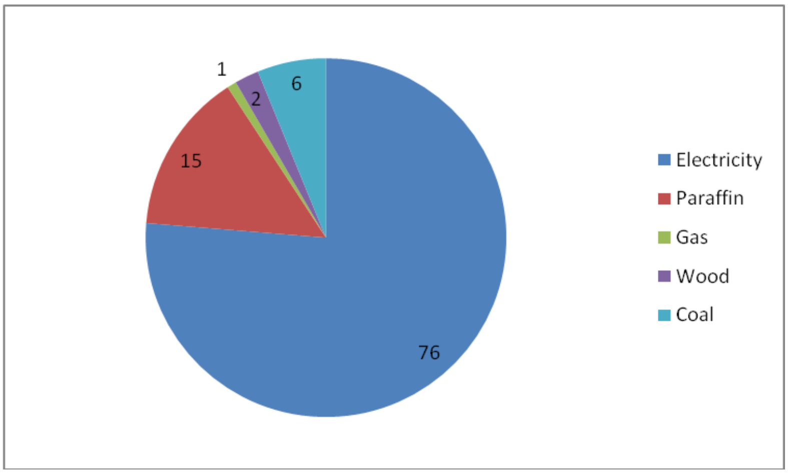

Figure 2-2: Percentage share of fuels used for space heating in Gauteng's residential sector
Source: based on 2007 Community Survey

Therefore, 76% of households in Gauteng were assumed to use electricity only for all their end uses and 24% was assumed to practice multiple fuel use. Figure 2-3 shows the percentage of households that used electricity for space heating within the three household categories.

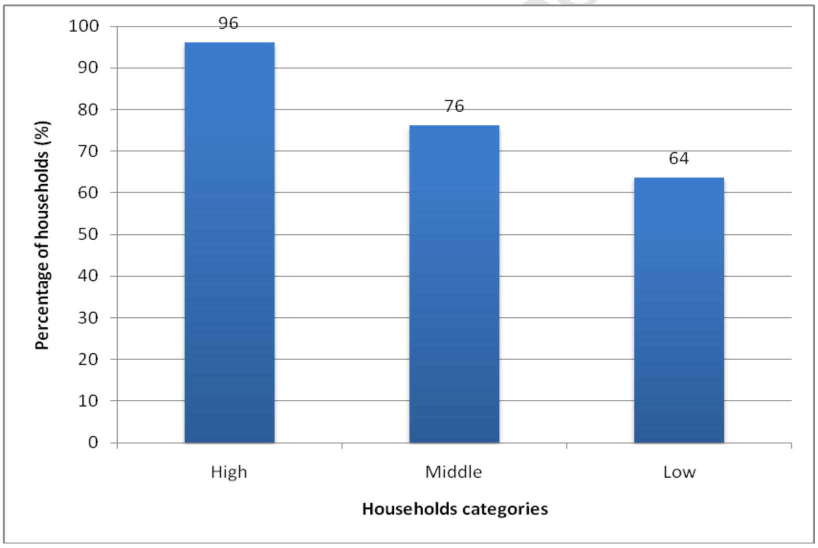

Figure 2-3: Percentage of households that used electricity for space heating
(Based on Community Survey 2007, STATSSA, 2007)

Looking at Figure 2-3, it is evident that the percentage of households that use electricity for space heating increases with income. 96%, 76% and 64% of high, middle and low income households used electricity for space heating respectively in 2007. Therefore it is assumed that 96%, 76% and 64% of high, middle and low income households respectively used electricity only to meet all their energy needs.

By using the following ratios;

High (%) = (96% / (96%+76%+64%)) x 76%

= 41%

Middle (%) = (76% / (96%+76%+64%)) x 76%

= 32%

Low (%) = (64% / (96%+76%+64%)) x 76%

= 27%

it was found that the higher portion of households that use electricity only came from the high income household category. Of the 76% of households that used electricity only to meet all their energy needs, 41%, 32% and 27% came from high, middle and low income households respectively.

2.5 Energy demand in Gauteng's residential sector

2.5.1 Calculation of total energy demand

Section 2.2 highlighted that high level energy consumption data is hard to find for the residential sector since South Africa does not produce provincial energy balances. The only energy balance data that was available was in the states of energy reports produced by Gauteng's three cities in three different years.

The City of Tshwane released its state of energy report in 2006, the City of Ekurhuleni released its state of energy report in 2004 and the City of Johannesburg released its state of energy report in 2007. There were no states of energy reports for the districts (Metsweding, Sedibeng and West Rand). To get Gauteng's residential sector base year (2007) energy data for input into the LEAP model, both aggregate and bottom-up energy calculations were done. Aggregate energy demand is calculated to cross check bottom-up energy demand calculations. To calculate the aggregate energy consumption for the base year (2007), annual household energy intensity for the three cities were calculated. Due to the different years in which the cities states of energy reports were released, calculation of the aggregate energy demand required some adjustment and consolidation.

The annual household energy intensities were 22 GJ/hh for both Ekurhuleni in 2003 and the City of Johannesburg in 2007. The City of Tswane had an energy intensity of 31 GJ/hh in 2004. Due to the huge difference in the household's energy intensities between Ekurhuleni, City of Johannesburg and City of Tswane, the three cities' average energy intensity of 25.2 GJ/hh was used as the household energy intensity in the three districts (Metsweding, Sedibeng and West Rand).

It was assumed that there is no large change in the average household's energy intensity in the cities for the period 2001-2007. Based on the above assumption, the energy intensity for each city and district was multiplied by the number of households in the respective city and district in 2007 to obtain total energy demand for the whole of Gauteng for 2007. The total energy demand for the year 2007 was calculated using Equation [2-2].

$$ET_{2007} = ((EI_{COJMM}*H_{COJMM}) + (EI_{EMM}*H_{EMM}) + (EI_{CTMM}*H_{CTMM}) + (EI_{COJMM}+EI_{EMM}+EI_{CTMM}))/3 * (H_{SED}+H_{WR}+H_{MET})) \quad [2\text{-}2]$$

Where ET_{2007} is the total energy demand in 2007, H is the number of households in each area, EI is the household energy intensity and COJMM, EMM, CTMM, SED, WR, MET represent City of Johannesburg municipality, Ekurhuleni municipality, City of Tswane municipality, Sedibeng, West Rand and Metsweding municipalities respectively. The following section describes the procedure that was followed to calculate bottom-up energy demand which served as input energy data into the model.

2.5.2 Bottom – up energy intensity calculation

The end use energy intensities were taken from many studies (Cowan & Mohlokoane, 2005: Prasad, 2006: CTMM, 2006, COJMM, 2007, EMM, 2004, Qase, Llyod & Van-Zyl, 2001, Shuma-Iwisi & Gibbon, 2008, Simmonds and Mammon, 1996; Winkler, Borchers, Hughes, Heinrich and Visage, 2005) and the end use energy intensity differed greatly between these studies. For example Simmonds and Mammon (1996) found that a typical low income household consumed 96 GJ of coal annually for cooking and space heating whereas Qase et al (2001) found that a household that used coal for cooking and space heating used 14.6 GJ annually per annum. The end use energy intensity data that was used in this study was the value that made sense to the author.

2.5.3 Multiple fuel end use energy intensities

To calculate the energy consumed by multiple fuel using households, the frequency of fuel use should be known for both primary and secondary fuels. The White et al (1998) study was used to deduce multiple fuel use combinations but the study did not explicitly say how many days a month the primary and secondary fuels were used. The frequencies of fuel use for primary and secondary fuels were assumed. It was assumed that households would use the primary fuel for 20 days a month and the secondary fuel for 10 days a month.

Based on the above assumptions of primary and secondary fuels usage frequencies, the amount of energy used by a household using the primary fuel was multiplied by 2/3 and the secondary fuel by 1/3. For example, the amount of electrical energy and paraffin used for cooking was 2.6 GJ/annum and 2.2 GJ/annum for middle income households respectively. If a certain middle income household used both electricity and paraffin for cooking (electricity + paraffin), where electricity is the primary fuel and paraffin the secondary fuel, the energy intensity for cooking in that household would be 2.6 GJ x 2/3 =1.73 GJ/annum for electricity and 0.73 GJ/annum (2.2 GJ*1/3) for paraffin which are added to give 2.46 GJ/annum of total energy consumed. This procedure was followed for all multiple fuel using households.

2.6 LEAP energy system model

LEAP, a scenario-based energy-environment modelling tool is used in this study to aid energy policy analysis to quantify energy consumption, GHG emissions and pollution. The central concept of LEAP is that, it allows end-use-driven scenario analysis (Lazarus, M, Hippel, Hill & Margolis, 1995).

LEAP contains the technology and environment database (TED) module which contains quantitative data on the technology characteristics, costs, and environmental impacts associated with energy use and production. TED includes data on approximately one thousand technologies, referencing reports by dozens of institutions including the Intergovernmental Panel on Climate Change (IPCC), the Department of Energy in the US, and the International Energy Agency (IEA), as well as by institutions (like Energy Research Centre in University of Cape Town) from developing countries. TED can be used as a standalone tool or, as an integral part of LEAP where it can be used to calculate the environmental loadings of energy scenarios. TED's own core database of emission factors can be edited or supplemented by one's own data (Heap, 2004) and for this study, the technologies in TED were edited so that TED contained appliance that were assumed to be used in Gauteng's residential sector. Although deleting other appliances found in TED does not affect the running of my model, they were deleted for ease of navigation when linking appliances with their associated emission factors[12]. The emission factors in TED were also edited to include emission factors specific to South African fuels as shown in Section 4.4 of Chapter 4. The emission factors of

[12] Appliances in TED have emission factors associated with their use. To calculate GHG and pollutants emissions, the appliances in the model are linked to appliances in TED for the calculation.

different pollutants in the TED module are linked to devices to calculate environmental emissions from energy consumption over the forecasting period of 2007 – 2030.

2.7 Useful energy demand analysis methodology

Generally, energy consumption is calculated by multiplying the activity level (number of households) by its energy intensity.

Energy consumption (GJ) = activity level x energy intensity (activity/GJ) [2-3]

When considering useful energy consumption, the energy consumption calculation differs from Equation [2-3] as the appliance efficiencies are multiplied by the variables on the right hand side of Equation [2-3]. There are two ways to enter energy demand data into LEAP, the one is entering final energy intensity and the other is entering useful energy intensity. Useful energy (UE) is the energy required to deliver an energy service such as cooking excluding efficiency losses, while final energy (FE) is the energy delivered to the device (for example, energy in paraffin as it is poured in a primus stove). The useful energy demand analysis was carried out in order to capture appliance efficiency improvements in the scenarios. Appliance efficiency is defined as the ratio of useful energy to final energy demand (UE/FE) when using a particular appliance (Simmonds & Mammon, 1996). Efficacies are generally used for lighting where it is difficult to define the useful energy output of different appliances (Davis & Horvei 1995). The efficacy of a lamp is defined as the ratio of lumen output to the power consumption of the lamp. Equation [2-4] shows how useful energy is calculated.

$$\mathbf{UE = EI x A_{eff} x FS x h_n} \qquad \textbf{[2-4]}$$

Where UE is useful energy, EI is energy intensity, A_{eff} is the appliance efficiency, h_n is the number of households and FS is the fuel share[13]. If one fuel is used, FS = 100%, hence

[13] Fuel share is the amount of energy that is to achieve an end use if more than 2 fuels are used. That is if electricity and wood is used within a household to cook, electricity fuel share would be the amt of electricity that is used by such a household to cook.

$$\mathbf{UE = EI*A_{eff} \; x \; h_n} \qquad \textbf{[2-5]}$$

When conducting a useful energy demand analysis, LEAP allows input of final energy intensity data for each end-use. If the activity level and appliance efficiencies together with the fuel used are known, LEAP can calculate the fuel shares using Equations [2-6] and [2-7].

$$\mathbf{FS_c = (A_c/E_c) \,/\, ((A_c/E_c) + (A_p/E_p))} \qquad \textbf{[2-6]}$$

Where FS_c is fuel share for fuel c, A_c is fuel c activity level (number of households that use fuel c) and E_c is the efficiency of the appliances used when using fuel c. A_p and E_p represent activity level and appliance efficiency associated with fuel p.

$$\mathbf{FS_p = (A_p/E_p) \,/\, ((A_c/E_c) + (A_p/E_p))} \qquad \textbf{[2-7]}$$

Where FS_p is fuel share for fuel p, A_p is fuel p activity level (number of households using fuel p) and E_p is the efficiency of appliances. A_c and E_c are activity level of fuel c and appliance efficiency of fuel c.

Inserting Equations [2-6] and [2-7] in Equation [2-4] the useful energy for using fuel c and p can be calculated using Equation [2-8].

$$\mathbf{UE_{c,p} = EI \; \mathit{x} \; ((E_c \; \mathit{x} \; FS_c) + (E_p \; \mathit{x} \; FS_p))} \qquad \textbf{[2-8]}$$

2.8 Two tier assessment of sustainable energy use

The results from the LEAP model were used to assess the sustainable energy use in Gauteng's residential sector. As mentioned in section 1.5, the assessment is at both sector and household levels which are named macro and micro levels respectively. The assessment was split into two levels because in the last two decades, the governments' efforts had concentrated at macro level energy policies but at household level, the low income household did not benefit as anticipated (DME, 2003, Gaunt, 2004). For example, the National Electrification Programme (NEP) and removal of value added tax (VAT) from illuminating paraffin were both macro development energy strategies/policies.

DME (2003), Gaunt (2003), Prasad (2006) and Mwakasonda and Davidson (2004) have highlighted that NEP succeeded in terms of the number of households that were electrified but poor households did not use electricity as anticipated. In an endeavour to increase access to affordable energy, DME removed value added tax (VAT) from paraffin and introduced the free basic electricity (FBE) in

2003. In its earlier stages FBE was a broad based policy, where every household was given the free basic units. Later in 2007, some municipalities in Gauteng changed their administration of the subsidy which helped in targeting the poor households.

Prasad (2006) pointed out that removing VAT from illuminating paraffin has not benefited the target population (poor households). VAT removal from illuminating paraffin does not benefit low income households because poor households live on the outskirts of Gauteng's cities and as a result poor people still pay high costs for paraffin due to the transportation costs incurred when bringing paraffin closer to them (Prasad, 2006). So, removing VAT from paraffin has not achieved its intended purpose.

In order to facilitate the assessment of the sustainability of energy use in the modelled policies, energy indicators were used. The indicators were drawn from the International Atomic Energy Agency (IAEA) report on Methodologies and Guidelines on Energy Indicators for Sustainable Development (IAEA, 2007). The indicators were selected because they can be quantified with the LEAP model and because they covered the important dimensions of sustainable development. The assessment involved a simple comparison of indicator values in the BASE case with indicator values from other scenarios.

3. Review of current energy use in Gauteng's residential sector

3.1 Introduction

This chapter gives an overview of Gauteng's regional and sectoral energy demand with emphasis on the residential sector. The chapter starts by giving a picture of Gauteng physically and economically. Then, provincial energy and sectoral energy demand is given and lastly residential energy demand together with the devices used in Gauteng's residential sector is presented.

3.2 Background on Gauteng

Gauteng, the smallest province in South Africa, is situated in the north-central part of the country (Landau & Gindrey 2008). Although it is the smallest province, it had a population of approximately 10.5 million people (21% of the country's population) in 2007 (STATSSA, 2007) making it the most populous province in South Africa. The province has three metropolitan areas and three districts as shown in Figure 3-1[14].

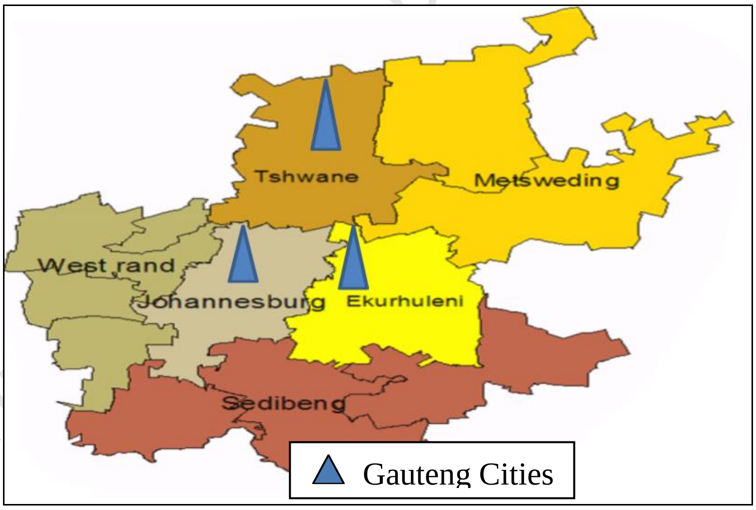

Figure 3-1: Map of Gauteng
Source: Laundau & Gindrey (2008)

3.3 Economy and social development in Gauteng

This section gives a brief overview of the economic situation in Gauteng. The Growth and Development Strategy for the Province of Gauteng (GDS) considered Gauteng as the economic hub of

[14]Areas with triangles are the metropolitan areas and the other ones are the districts.

both South Africa and Africa (GDS, 2005). It is considered so because Gauteng has historically made a significant contribution to GDP in both South Africa and the African region[15]. The contribution of Gauteng's GDP to South Africa's GDP grew from 33.5% in 2000 to 35.1% in 2008 (Ward & Schaffler, 2008; MTBPS, 2009). In 2005, Gauteng's GDP contributed 10% to Sub-Saharan Africa's GDP (GDS, 2005). During the period (2000 – 2007), the economy in Gauteng grew at 4% on average (MTBPS, 2009).

Although Gauteng is performing well economically, the province still experiences high inequality in its society. Figure 3-2 shows that the Gini coefficient[16] has stabilised at 0.65 since 2003. Despite the fact that the Gini coefficient has stabilised, it was still very high, being just 4 points below the South African Gini coefficient of 0.69 (Mabilo, 2009). On the other hand, the quality of life in Gauteng showed a decline between 2006 and 2007. The decline in quality of life is shown by the declining human development index (HDI[17]) depicted in Figure 3-2 below.

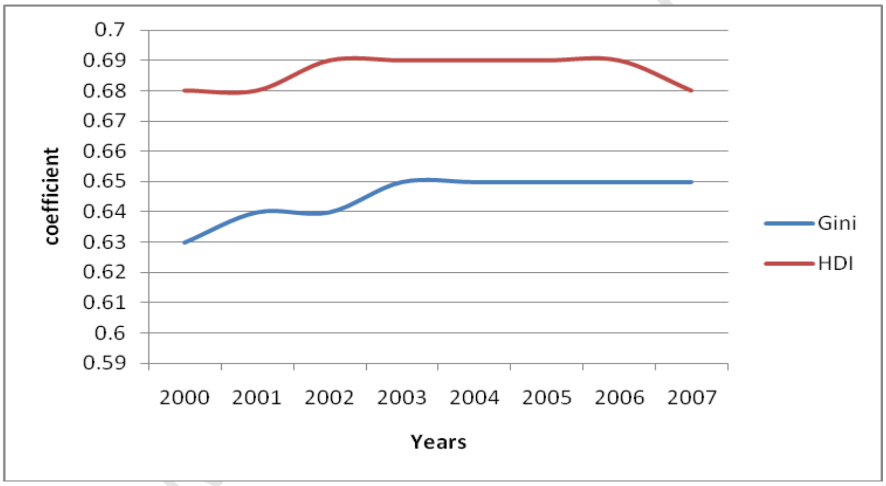

Figure 3-2: Gini coefficient and HDI between 2000 and 2007
(Source: Mabilo, 2009)

[15]It contributes 1/3 (33.5%) GDP to South African economy and 10% to Sub-Saharan GDP

[16]The Gini Coefficient is used widely to measure the distribution of income across a society, ranges from 0 indicating perfect equality where everyone earns the same income to 1 indicating perfect inequality where one person earns all the income (UNDP, 2003).

[17] The HDI is a summary composite index measuring a country's average achievements in three basic aspects of human development: longevity, knowledge, and a decent standard of living. Longevity is measured by life expectancy at birth; knowledge is measured by a combination of the adult literacy rate and the combined primary, secondary, and tertiary gross enrolment ratio; and standard of living by GDP per capita (PPP US$) (UNDP, 2008). The HDI value of 1 shows high level of human development, hence improved standard of living and 0 shows the opposite, hence the quality of life is compromised.

According to Bhorat, Landman, Van-Aardt and Van Der Berg (2003), the Gini coefficient and poverty are two different phenomenons. The argument they raised is that, the Gini coefficient deals with differences in income levels within a society while poverty deals with little or no income within a society. A well-off society can still have high Gini coefficient (which measures inequality).

After realising that the Gini coefficient does not tell everything about development at household level, minimum level of living (MLL) was used to see poverty levels in Gauteng's residential sector. According to Martins and Maritz (2001), the Minimum Living Level (MLL) denotes the minimum financial requirements for members of a household to maintain an acceptable standard of living. Different researchers have proposed different methodologies for calculating the value of MLL because of their differing definitions of acceptable standard of living (Martins, 2003, Nel and Dawson, 1988, Shelburne, 1999). Although the conditions on which the value should be calculated based on, is highly controversial, in 2004, the presidential office defined the official value of urban MLL as R1398 per household per month.

Figure 3-3 shows that the number of households that earned income below minimum level of living (MLL[18]) decreased as the economy was growing.

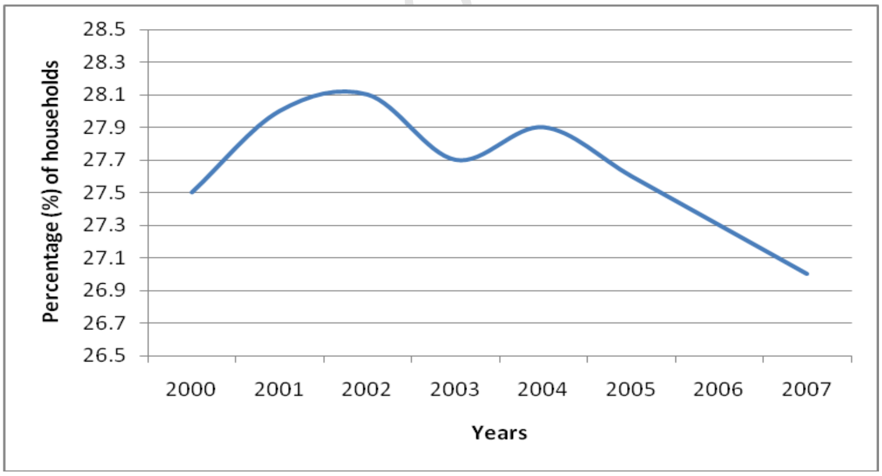

Figure 3-3: Percentage of households earning below MLL
Source: Mabilo, 2009

Figure 3-3 shows that 27 % of the population in Gauteng was living below the minimum level of living. It can therefore be concluded that the percentage of poor households in Gauteng are reducing, hence Gauteng is moving towards its goal of reducing poverty.

[18] MLL varies in accordance with household size – the larger the household, the larger the income required to keep its members out of poverty. In 2004, the presidency office http://www.thepresidency.gov.za/docs/pcsa/planning/nsdp/part2.pdf found urban MLL to be R1398.

Although Figure 3-2 and Figure 3-3 show a stabilised Gini coefficient and HDI and reduced percentage of people living below MLL respectively, Gauteng was still a highly unequal society, like the rest of South Africa, since its Gini coefficient has been above 0.60 throughout the period 2000 – 2007.

3.4 Background on energy consumption in Gauteng

3.4.1 Primary energy demand

There are four primary energy sources consumed in Gauteng: namely coal, natural gas, crude oil and wood. Coal is used mainly in industry for heat and electricity production although a small percentage is used in the residential sector. Natural gas is also used mainly in industry with very low usage in the residential sector. Wood is used in households at very low levels since it is a scarce resource in the province (COJMM, 2007). Crude oil is consumed mainly in the transport sector in the form of petrol, diesel, lubricants, power paraffin, illuminating paraffin; Liquefied Petroleum Gas (LPG) etc. Illuminating paraffin and LPG are also used in residential sector and there are very low levels of petrol and diesel use in households. Petrol and diesel are used to run generators in non electrified households (White et al,1998).

3.4.2 Energy consumption by carrier

Figure 3-4 presents percentage shares between energy carriers in 2000 and 2007.

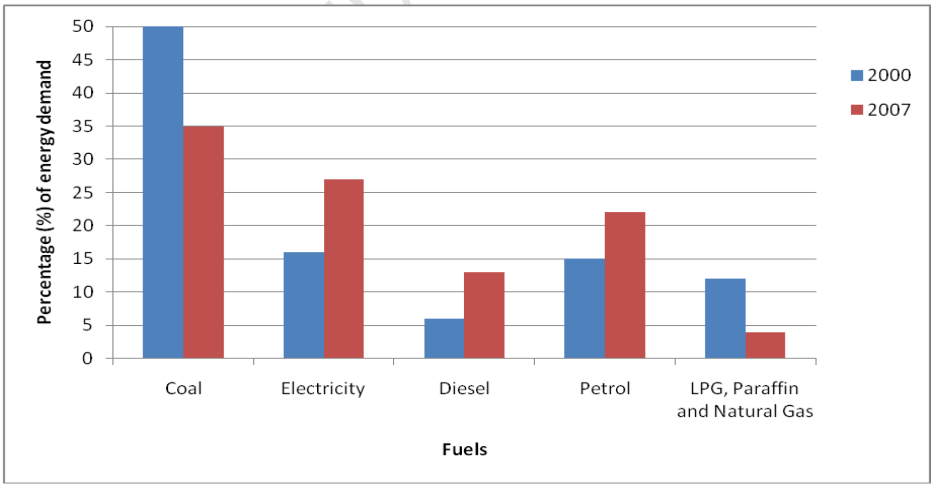

Figure 3-4: Percentage of Gauteng's energy consumption by energy carrier in 2000 and 2007
Source (Sarah Ward and Jason Schaffler, 2008; Gauteng Integrated Energy Strategy, 2010)

Figure 3-4, shows that coal was a dominant fuel in Gauteng in both 2000 and 2007, although the contribution has been decreasing. The demand for diesel, petrol and electricity increased between the two periods. Electricity has the highest growth rate among all the fuels. Electricity is becoming a significant fuel within Gauteng's economy.

According to GIES (2010), Gauteng's electrical energy demand was 169.2 PJ in 2007. 28% of that demand was consumed in the residential sector, 35% in industry and 38% was consumed in the commercial, transport and agricultural sectors. The industrial and residential sectors are the two largest electricity consuming sectors in Gauteng. Figure 3-5 shows sectoral electricity demand share.

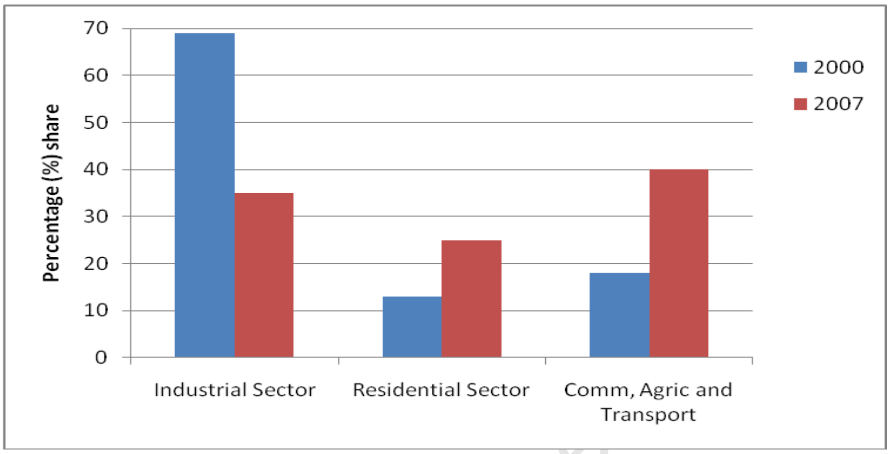

Figure 3-5: Electrical energy demand share in Gauteng's sector 2000 and 2007
Source (Sarah Ward and Jason Schaffler, 2008; Gauteng Integrated Energy Strategy, 2010)

Figure 3-5 shows that both the residential and the combined commercial, agriculture and transport sectors increased their electricity demand share while the industrial sector experienced a decreased electricity demand share.

3.4.3 Final energy demand by sector

Gauteng consumed 783 PJ in 2000 (Ward, 2008) and 655.4 PJ in 2007 (GIES, 2010). The industrial and transport sectors consumed more energy than other sectors in both 2000 and 2007.

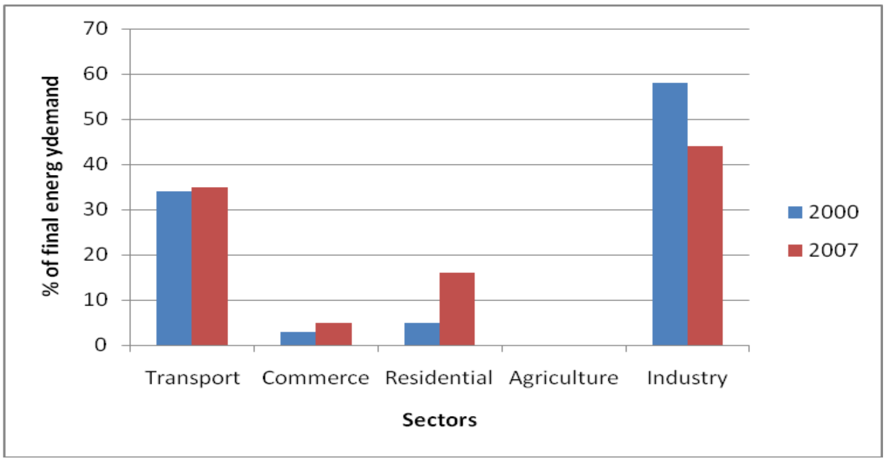

Figure 3-6: Gauteng's sectoral energy demand share 2000 and 2007
Source (Sarah Ward & Jason Schaffler, 2008; Gauteng Integrated Energy Strategy, 2010)

Figure 3-6 shows that the industrial sector consumed 58% and 44% of final energy demand in 2000 and 2007 respectively. The transport sector consumed 34% and 35% of final energy demand in 2000 and 2007 respectively. The residential sector consumed 5% and 16% of Gauteng energy demand in 2000 and 2007 respectively.

Although the residential sector is the third largest consumer in terms of the energy demand share, it had the highest energy demand growth rate. The residential sector energy demand share grew by 11% between 2000 and 2007 while the industrial sector energy demand share decreased by 14% in the same period. The energy demand shares for the transport and commercial sectors increased by 1% and 2% respectively between 2000 and 2007.

3.4.4 An economy undergoing transition

The change in electricity demand share among sectors and the reduction of total energy demand signals that Gauteng's economy is undergoing a transition from a primary based economy to a service based economy. Figure 3-7 shows that energy intensity was decreasing while the economic output was growing.

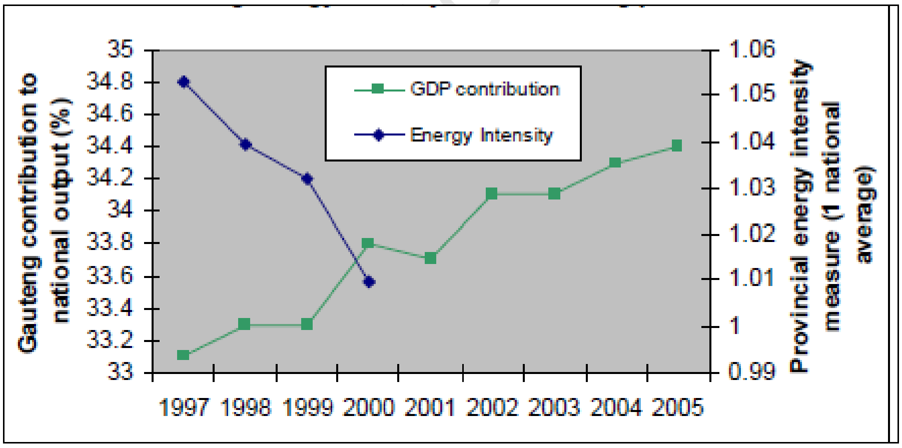

Figure 3-7: Gauteng's economic production vs energy intensity:
Source (Sarah Ward and Jason Schäffler, 2008)

The Gauteng Provincial Government Medium Term Budget Policy Statement 2009 (2009:1) noted that indeed Gauteng is undergoing economic structural change and that the contribution of the primary sector to economic output was decreasing.

> *"The decline in the contribution of the primary sector is illustrated by a drop from 3.4 per cent in 2001 to 2.1 per cent in 2008. As Gauteng moves closer to an economic configuration typical of advanced economies, the composition of production moves away from the re-source-based primary sector and toward the more skill-intensive tertiary sector" GPG 2009.*

If the economic transition in Gauteng continues, the residential and the commercial sectors would be the greatest energy consuming sectors in the future. In order to move towards sustainable energy use these sectors need to be energy efficient and increase renewable energy uptake.

3.5 Demographic Dynamics

According to Landau and Gindrey (2008), the population within the province was concentrated in the metropolitan areas. The three metropolitan areas held 86% of the provincial population, leaving only 14% residing in the districts. The population is unevenly distributed between the metropolitan areas. Figure 3-8 shows how population was distributed across the metropolitan areas and districts of Gauteng.

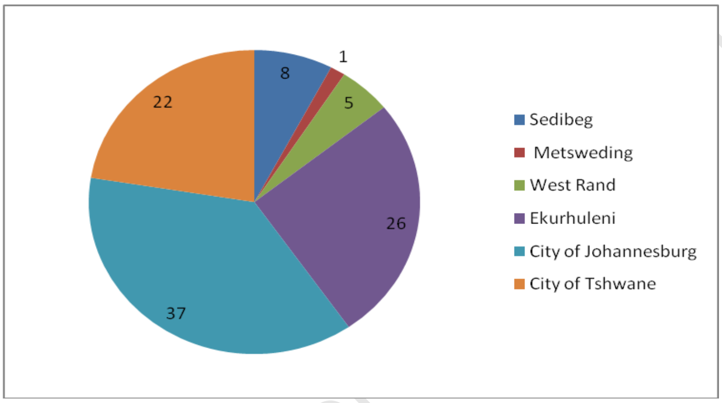

Figure 3-8: Population distribution across Gauteng province
(Based on Community Survey 2007, STATSSA, 2007)

Figure 3-8, shows that City of Johannesburg contained 37% of Gauteng's population, City of Ekurhuleni 26% and City of Tswane 22%. Sedibeng, Metsweding and West Rand housed 8%, 1% and 5% of the population respectively. Figure 3-9 shows the share of households across districts and metropolitan areas in Gauteng.

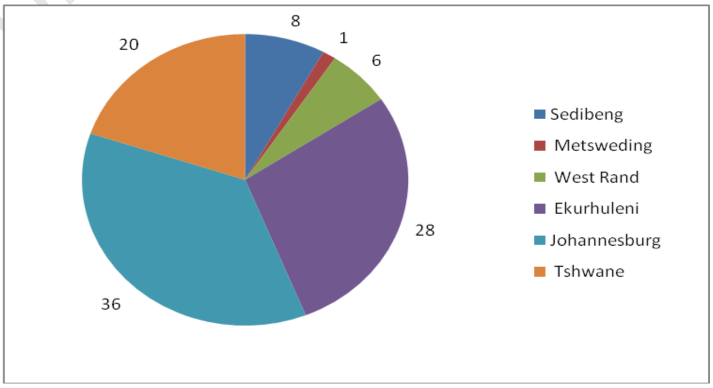

Figure 3-9: Percentage of households living in Districts and Metros
(Based on Community Survey 2007, STATSSA, 2007)

Of the 3.18 million households in Gauteng in 2007, 36% were situated in the City of Johannesburg (COJMM), 28% in the City of Ekurhuleni (EMM) and 20% in the City of Tswane (CTMM). The three districts collectively contained 15% of the households in Gauteng (STATSSA, 2007). Like all

South African cities most low income households in Gauteng live on the outskirts of cities and are isolated from urban opportunities and services (Mafukidze & Fazeela Hoosen, 2008).

3.6 Household distribution by area and income categories

Figure 3-10 shows the distribution of households within Gauteng by income bands.

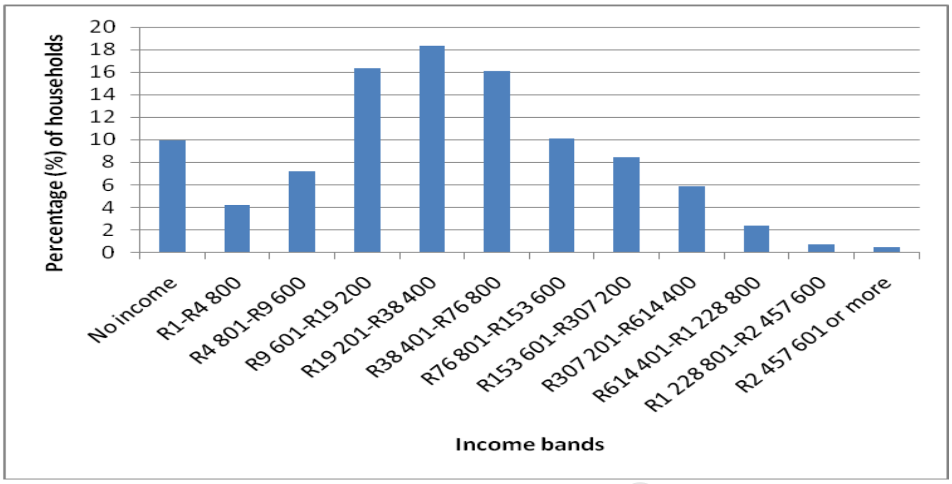

Figure 3-10: Households distribution across income bands
(Source: Derived from STATTSA, 2007)

Figure 3-10 shows that most households within Gauteng fall within the R19 201 – R38 400 income band. And based on the definitions of low, middle and high income households as presented in Section 2.3, most households in Gauteng are middle income households. Figure 3-11 shows the distribution of households by area per income group.

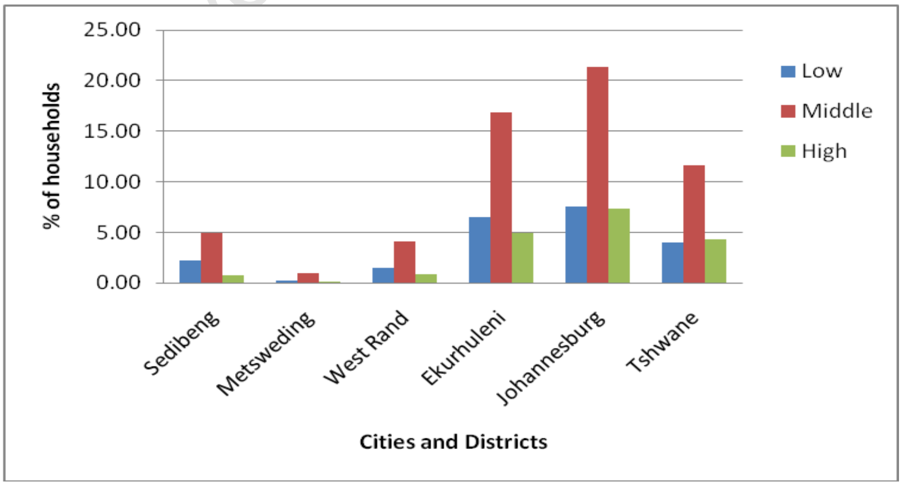

Figure 3-11: Households distribution across Gauteng per income category
(Based on Community Survey 2007, STATSSA, 2007)

Looking at Figure 3-11, it can be seen that both the districts and metros have a high percentage of households in the middle income category. Most high income households reside in the cities with Metsweding having a mere 0.15% of high income households. The City of Tswane is the only area where the percentage of high income households exceeds low income households. This disparity of household income distribution within the cities explains why the City of Tswane has the highest energy intensity per household. High income households are known to have a higher energy intensity than low income households. In the City of Johannesburg, the percentage of low income households is similar to the percentage of high income households.

3.7 Electrification status in Gauteng

In terms of basic services such as tapped water and flush toilets, Gauteng is one of the provinces with a high percentage of households that have such services. However when it comes to electrification, Gauteng has the slowest electrification growth rate. Gauteng had an electrification of 79% in 1996 and ten years later, the electrification was only 83.4% (STATSSA, 2007). Figure 3-12 shows provincial electrification levels from 1996 – 2007.

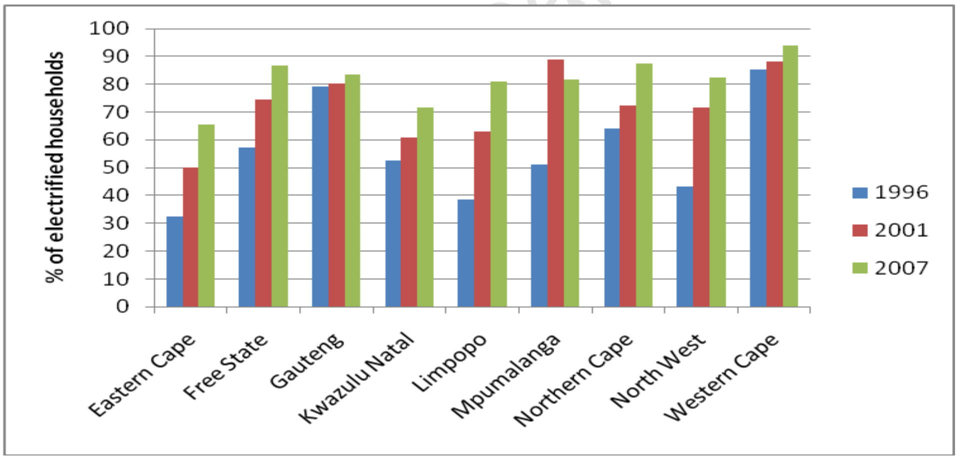

Figure 3-12: Provincial electrification rates in 1996, 2001 and 2007.
(Source: STATSSA Community Survey 2007)

In 1996, Gauteng had the second highest province with electrification level after the Western Cape but in 2007 it was in the fourth position. The stagnant growth in electrification is due to an escalating in-migration into the province (see Chapter 1). In 2008, Cowan[19] identified that urbanization in South African cities has led to several problems one of them being inability to develop the required infrastructure (such as extending grid electricity) and it seems that Gauteng is no exception (ERC,

[19] When undertaking a study in Imzamo Yethu

2008). The metropolitan areas have a high percentage of electrified households relative to the districts in Gauteng. Figure 3-13 shows electrification density within Gauteng.

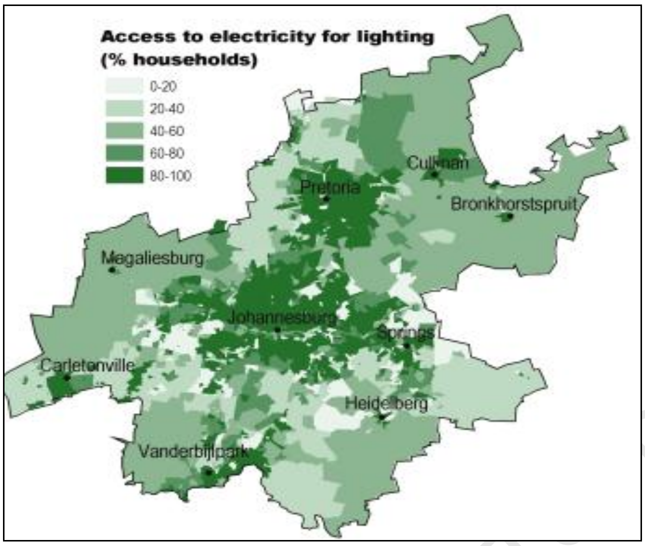

Figure 3-13: Areas with Access to electricity in Gauteng
(Source: Gauteng State of Environment report 2004)

Figure 3-13 shows that Johannesburg, Pretoria and Springs (which is a town in Ekurhuleni metropolitan area) had high electrification levels in the range of 80% to 100% electrification. But on the outskirts of the province, electrification levels were as low as 0% to 20%. Figure 3-14 presents electrification classified by income and area in Gauteng.

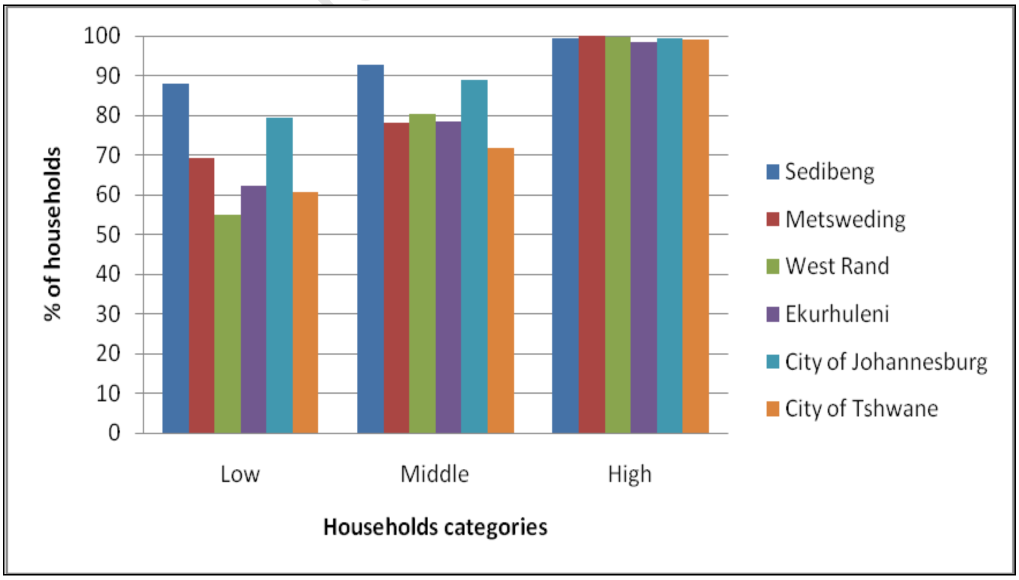

Figure 3-14: Electrification levels of households categories by area
(Based on STATSSA, 2007)

Figure 3-14 shows that in both the districts and cities' high income households have a high electrification level ranging from 98% to 100%. It is clear that high income households have access to electricity irrespective of where they live within Gauteng. Sedibeng has a higher percentage of electrified households in all households' categories and is followed by the City of Johannesburg. West Rand has the lowest percentage of electrified low income households. The City of Tswane has the lowest percentage of electrified households in both the low and middle income categories.

3.8 Determinants of fuel use in households

The disposable income (budget) of the household is a major determinant of fuel use within households (Dzioubinski and Chipman, 1999; White et al, 1998; Akese, 1996, Hunt, Judge and Ninomiya, 2002 and Prasad, 2006). Louw, Conrad, Howells and Dekenah (2008), represents the household's budget by the utility function in [3-1]

$$\mathbf{U = U\,(ES\,(E, A, F), G, S, z)} \text{ subject to}$$

$$\mathbf{I = p_1 \mathit{x}_1 + p_2 \mathit{x}_2 + \ldots + p_n x_n} \qquad \textbf{[3-1]}$$

Where, ES refers to the energy services, E to electricity, A to appliances that households own, F to other fuels consumed in the household, G and S are the non energy goods and services, z is the household's preferences. I is household's disposable income, p_1-p_n are the prices for x_1- x_n goods. According to econometric theory, the utility function simply states that a household consumes goods and services that they can afford to pay for. Applying this to energy, it is obvious that a households would consume energy, together with the other goods that are needed within a households based on what they can pay for.

Prasad (2005) identified that fuel prices, transport and distribution chain determine what type of fuels low income households use. The transport and the long fuel distribution chains are indirect fuel determinants because they increase the mark-up prices of the fuels, hence going back to the fact that income and fuel prices determine fuels used within households.

The price of the fuel directly determines what fuel a household can use based on their disposable income. For example Malzbender and Kamato (2005) found that municipal electricity is more expensive than Eskom electricity. The electricity distribution chain is longer for households that get their electricity from the municipalities. Eskom sells electricity to municipalities, who in turn sell the electricity to households hence lengthening the distribution chain. Households in two different townships (Ivory Park and Tembisa[20]) in Gauteng paid different electricity tariffs.

Households that bought their electricity from the municipality were paying 9% - 15% more for a kilowatt-hour of electricity than the households that got their electricity from Eskom. Secondly if a fuel is transported over a long distance, its price goes up. For example in Cape Town paraffin use is more prevalent in households than coal because coal is expensive at the coastal areas (Mehlwane & Cowan, 2004). Again paraffin use is lower in Gauteng relative to Cape Town because the paraffin price in Gauteng differs from coastal paraffin prices (DME, 2010). The reason for the difference is that, there is an added cost associated with transporting crude oil from the coastline to Natref[21] in Sasolburg or transporting paraffin from the coast to Gauteng.

Although fuel prices and household's income play a significant role in fuel choices, they are not always the sole determinants of fuel use; there are some non income based determinants. Dzioubinski and Chipman (1999) identified that factors such as households' preference, availability of fuels and appliances, determine what fuels households use.

Afrane-Akese (1996) and Hunt et al (2002)'s found weather to be the main determinant of the type of fuel used within households. This study argues this is not always the case, as in most cases weather determines how much fuel can be used, not what type of fuel is used. However, the argument does not rule out that, weather can determine what type of fuel is used in certain circumstances. An example of such a circumstance can be when a household that uses either wood or paraffin to meet their energy needs prefer paraffin when the wood is wet or when it is raining and wood is difficult to collect. In the above example, the weather determined what fuel to use; hence weather can be termed a conditional determinant of fuel use.

White et al (1998) identified that the way a house is built (built from corrugated irons or bricks) and the fuel supply infrastructure are the main determinants of fuel use. Generally the way a house is

[20]Ivory Park and Tembisa are said to be in the same area and are divided by a road and Ivory Park fall under City of Johannesburg and Tembisa falls under City of Ekurhuleni. Ivory Park households bought their electricity from Eskom and Tembisa households bought their electricity from Ekurhuleni municipality

[21]An inland refinery, 63.6% owned by SASOL and 36.4% owned by Total South Africa

built determines how much energy a household uses. Van Es and Winkler (2007) found that a house with brick walls and a corrugated iron roof lost up to 60% of energy through the roof only. Therefore, it can be concluded that a shack (a house built entirely with corrugated iron) can lose more than 60% of energy through the walls and the roof. A household living in a shack would technically require more energy to maintain warmth than a household living in a brick walled house. In the above example, the material used to construct the house determined how much fuel is consumed not the type of a fuel used.

But, White et al (1998) found that the way a house is built can determine what fuels a household uses based on perceived social identity that appliances are assumed to communicate. White et al (1998) found that formal households (houses with brick walls) were not using mbawula (coal brazier) in their households because the society saw that as an unacceptable practice. A household living in a formal housing unit would only use mbawula when they are so destitute that they no longer cared about their image. By discovering that mbawula usage was associated with shacks, it can be concluded that the type of durable assets that households own can to some extend determine the types of fuels used within households.

The consensus from the above discussion is that fuel choices are determined mainly by household income, although the contribution of other determinants cannot be ignored. Having explored what determines fuel usage in households, the following section gives detailed energy consumption within Gauteng's residential sector.

3.9 Overview of energy access and fuel consumption trends

In Gauteng a high percentage of households use electricity as their main fuel for cooking, space heating and lighting. According to the Community Survey 2007 and census 2001, the number of households that used electricity as the main fuel for these three end-uses has increased between 2001 and 2007. Figure 3-15, shows that the percentage of households that used electricity as the main fuel for lighting increased from 80% in 2001 to 83% in 2007.

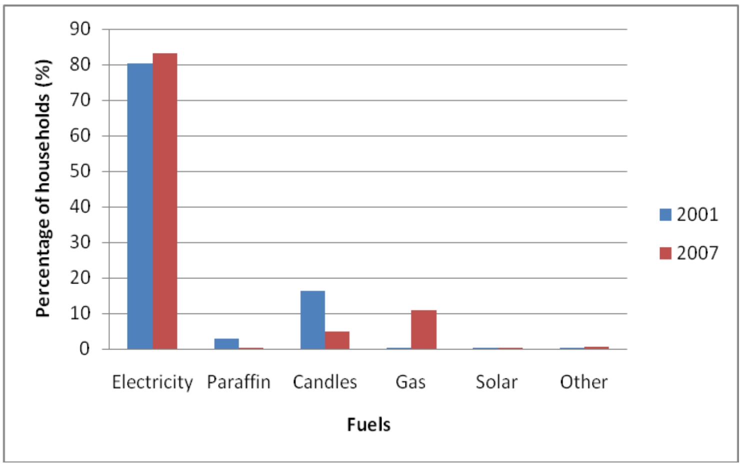

Figure 3-15: Fuels used for Lighting in 2001 and 2007
(Based on Community Survey 2007 and Census 2001)

There was a significant reduction in the percentage of households that used candles and paraffin as the main fuels for lighting, while the number of households using Liquefied Petroleum Gas (LPG) for lighting increased. The decrease in the number of households that used candles and paraffin for lighting may be as a result of households being connected to the electric grid. The Free basic electricity (FBE) could also have played a part in increasing the percentage of households that use electricity for lighting. For example, households that could not afford electricity for lighting in 2001, before FBE was introduced, could have abandoned other fuels for electricity.

Figure 3-16 , shows a trend similar to the one in Figure 3-15 for cooking.

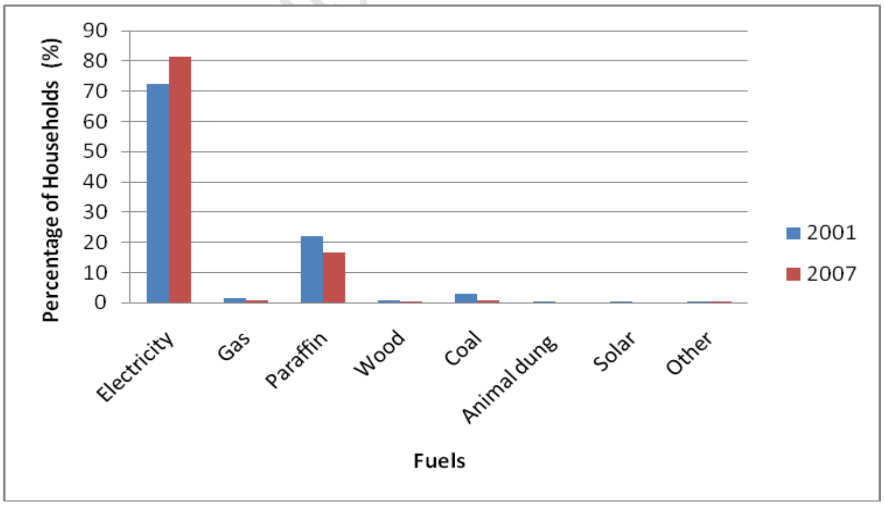

Figure 3-16 : Fuels used for cooking in 2001 and 2007
Based on Community Survey 2007 and Census 2001)

A high percentage of households used electricity as the main fuel for cooking in 2001 and in 2007 relative to other fuels. The percentage of households that used electricity as the main fuel for cooking increased from 72% to 81% between 2001 and 2007. The increase in electricity use was accompanied by a decrease in paraffin, LPG, wood and coal usage. Figure 3-17 shows the main fuels used for space heating in Gauteng households.

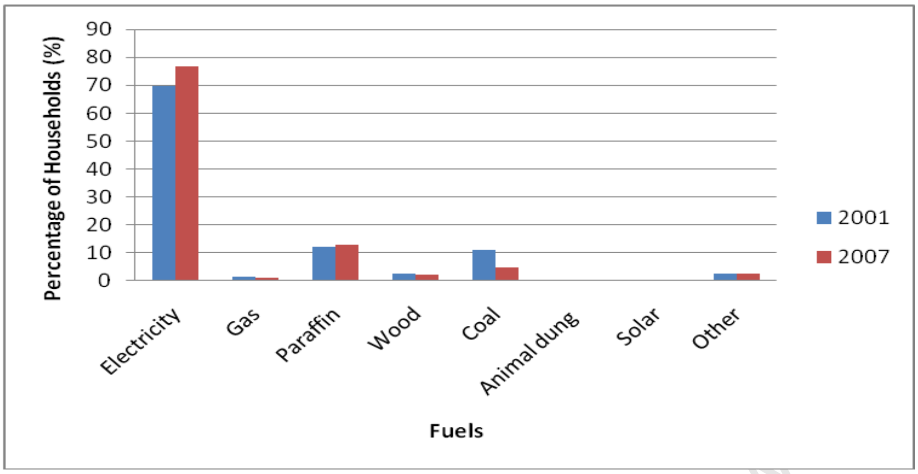

Figure 3-17 : Fuels used for space heating in 2001 and 2007
(Based on Community Survey 2007 and Census 2001)

The percentage of households that used electricity as the main fuel for space heating increased from 70% to 76% between 2001 and 2007. The percentage of households that used paraffin for space heating remained almost constant in the two periods - at 12% in 2001 and 12.8% in 2007. There was a reduction in the percentage of households that used coal as the main fuel for space heating while wood usage was constant in both periods. The following section gives an overview of how fuel is used by households in the three income categories for cooking, space heating and lighting.

3.10 Fuel use by households in three income categories

Energy use differs across different household income categories. A high percentage of high income households use electricity for lighting, cooking and space heating. Figure 3-18, Figure 3-19 and Figure 3-20 show fuel use among low, middle and high income households.

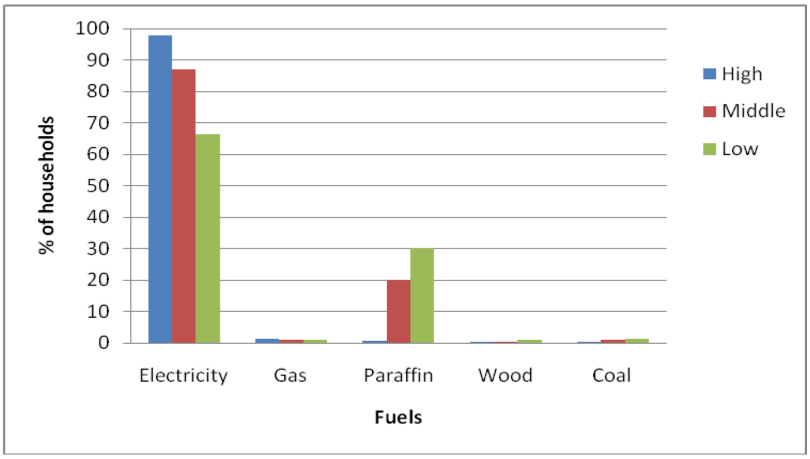

Figure 3-18: Fuels used for cooking within three households categories
Source: based on STATSSA community survey 2007

Figure 3-18 shows that as income decreased, the percentage of households that use electricity as their main fuel decreased but the percentage of households that use paraffin, coal and wood as their main fuels increased with decreasing income. 98%, 87% and 67% of high, middle and low income households used electricity as the main fuel for cooking respectively. The percentage of households that used LPG for cooking was almost 1% throughout all households' income groups. 1%, 20% and 30% of high, middle and low households used paraffin as the main fuel for cooking respectively.

1% of low and middle income households used coal as their main fuel for cooking and no high income households used coal for cooking. There were no high and middle income households that used wood for cooking as their main fuel and only 1% of low income households used wood as the main fuel for cooking.

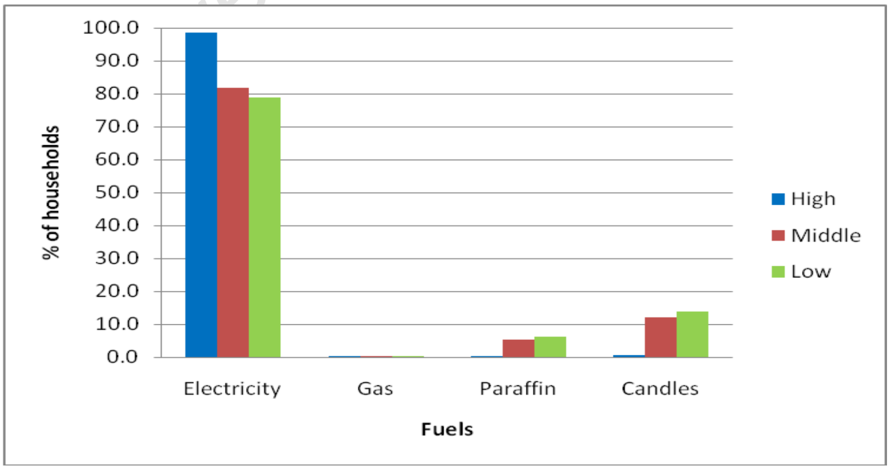

Figure 3-19: Fuels used for lighting within three households categories
Source: based on STATSSA community survey 2007

Figure 3-19, shows that 99% of households in the high income category used electricity as the main fuel for lighting and a mere 1% used candles. 82% and 79% of middle and low income households used electricity as the main fuel for lighting. The percentage of households using candles and paraffin increased with decreasing income. 12% of middle income households used candles as the main fuel for lighting and 14% of low income households used candles as the main fuel for lighting. 5.4% of middle income households and 6.3% of low income households used paraffin as their main fuel for lighting.

LPG use for lighting is very low across all households. A mere 0.2% of both middle and low income households and 0.5% of high income households used LPG as their main fuel for lighting.

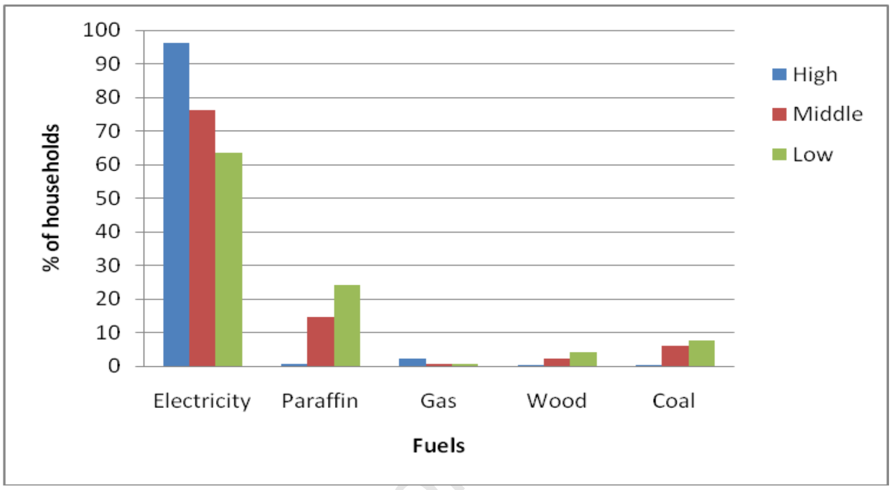

Figure 3-20: Fuels used for space heating within three households' categories
Source: own calculation based on STATSSA community survey 2007

Figure 3-20 shows a similar electricity usage trend for space heating to that seen in Figure 3-19. As income increases, a larger percentage of households use electricity as their main fuel for space heating. 96% of high income households used electricity for space heating. 76% of middle income households used electricity for space heating. 64% of low income households used electricity for space heating.

A very low percentage of households used LPG for space heating across all income groups, but the percentage decreased with decreasing income. 3% of high income households used LPG as their main fuel for space heating. 1% of both middle and low income households used LPG as their main fuel for space heating. The percentage of households using paraffin, coal and wood increased with decreasing income. 1%, 14% and 24% of high, middle and low income households used paraffin as their main fuel for space heating respectively. 1%, 6% and 8% of high, middle and low income households used coal as their main fuel for space heating respectively. 2% and 4% of middle and low income households used wood as their main fuel for space heating respectively. There were no high income household that used wood for space heating.

Figure 3-18, Figure 3-19 and Figure 3-20 all show a similar trend, where the percentage of households that use electricity increased with increasing income and the percentage of households that used paraffin, coal and wood increased with decreasing income. It can also be seen that paraffin, coal and candles are used mainly by low income households. This indeed confirms that income is a main determinant of the type of fuel used by households in Gauteng. The movement of a household from a lower to a higher income group will have an impact on fuels used by the household. Having given a picture of how fuels are used in the three household categories, the next section gives the end use energy intensities in households.

3.11 Household's end uses energy intensity and the associated appliances

There are five primary energy end-uses in the residential sector (Afrane-Akese, 1996; Winkler 2005). These primary end-uses are cooking, space heating, water heating, lighting and refrigeration. Households use different fuels to achieve these end uses. Electricity is the main fuel used for refrigeration in most households. Some households use paraffin and LPG fuelled fridges but their use is not wide spread and not well documented. Electricity is also the main fuel used for water heating in middle and high income households whereas in low income households fuels used for cooking are also used for water heating.

3.11.1 Appliances used across Gauteng residential sector

Table 3-1 shows a list of fuels and the end use for which they are used together with the associated appliances and appliances efficiencies.

Table 3-1: Fuels and the associated appliances used by Gauteng households

Fuel	Energy End Use	Associated appliances	Appliance Efficiencies
LPG	Cooking	Ring Stove	65% 65%
	Lighting	Gas lamp	1 lumens/watt
	Water heating	Ring Stove	65% 65%
	Space Heating	Gas Heater	70%

Table 3-1: Fuels and the associated appliances used Gauteng households (continued from previous page)

Fuel	Energy End Use	Associated appliances	Appliance Efficiencies
Paraffin	Lighting	Pressure lamp Wick Lamp	1.2 lumens/watt 0.3 lumens/watt
	Cooking	Wick Stove Primus Stove	30% 40%
	Space heating	Heater	73%
	Water Heating	Wick Stove Primus Stove	30% 40%
Coal	Cooking	Coal Stove Mbawula BNM Mbawula	25% 8% 11%
	Space heating	Coal Stove Mbawula BNM Mbawula	40% 59% 79%
	Water heating	Coal Stove Mbawula BNM Mbawula	40% 8% 11%
Electricity	Lighting	60W Incandescent lamp 100W Incandescent lamp 40W CFL lamp	11 lumens/watt 18 lumens/watt 75 lumens/watt
	Cooking	4 plate stove Hot plate	65% 65%
	Space heating	Radiant / fan heater	100%
	Refrigeration	Fridge Freezer	70% * 60% *
	Water heating	Kettle Geyser Geyser blankets Solar water heater	100% 70% 80% 100%
Wood	Cooking	Stove	25%
	Space heating	Stove	40%
	Water heating	Stove	25%

Source: efficiencies and appliances were taken from (Simmonds and Mammon, 1996, Winkler 2006 and Haw and Hughes 2007)

From Table 3-1, it can be seen that electrical appliances are the most efficient appliances. Although coal appliances are said to be energy inefficient, the mbawula has a higher energy efficiency than paraffin or LPG heater if it is lit using the Basa Njengo Magogo (BNM) method. Sub-sections 3.11.1.1 and 3.11.1.2 gives appliance penetration levels in different household categories.

3.11.1.1 Appliance penetration levels for households that use electricity only

Not all households perform the five primary end uses mentioned in section 3.11. Table 3-2 presents the assumptions regarding households' participation in the five primary end uses.

Table 3-2 : Assumed percentage of households that are involved in households' end uses

Households	Cooking	Water heating	Space heating	Refrigeration	Lighting	"Other" end uses
High Income	100%	100%	100%	100%	100%	100%
Middle Income	100%	100%	100%	100%	100%	100%
Low Income	100%	95%	90%	60%	100%	100%

White et al (1998) and Simmonds and Mammon (1996) showed that not all low income households use refrigerators, space heat their houses and heat water for bathing. Since the 2007 Community Survey did not give any information regarding which households do not perform certain end uses, White et al (1998)'s findings were assumed for this study. Table 3-2 shows that 5%, 10% and 40% of low income households do not undertake space heating, water heating and refrigeration as was found by White et al (1998). It was assumed that middle and high income households carry out all the five primary end uses.

The "other" end uses in Table 3-2 include end uses that use diverse electrical appliances. These appliances include electric fans, television sets, HiFis and radios, computers and many other electrical appliances that are used within households. To ease the complication of modelling the "other" end uses, a particular set of appliances used in low, middle and high income households was defined. Appliances that are commonly used in low income households were found in Shuma-Iwisi and Gibbon (2008). Appliances that are used in middle and high income households were found in NRS034 Domestic Load Research Database (for explanation, refer to Chapter 2, section 2.1 and for appliance saturation rates refer to Appendix B). The usage patterns found in Shuma-Iwisi and

Gibbon (2008) together with findings from other studies were used to calculate the amount of energy used by these appliances.

Table 3-3 shows a list of appliances that fall under the "other" end use used in low, middle and high income households.

Table 3-3 : Appliances used to perform other end use in Gauteng households

Household Classification	Appliances	Appliance saturation (%)
High Income households	Computers, Cell phones, TV sets, Laundry Machines, HiFis, Fans, Kettle, irons, DVD decoder, swimming pool heaters and toaster	100%
Middle Income households	Cell phones, TV sets, HiFi, irons, DVD decoder , kettles and toaster and Laundry machines	100%
Low income households	TV, Hi-Fi, cell phones and iron	100%

All electrified households in each household category (low, middle and high) were assumed to have electrical appliances shown in Table 3-3. Table 3-4 gives appliance saturation rates for the high income households.

Table 3-4: High income households' electrical appliance saturation rates

End Use	Appliance	Appliance saturation (%)
Cooking	4 Plate stove	98%
Space Heating	Heater	45%
Refrigeration	Fridge	100%
Water Heating	Geyser Geyser blanket Solar water heaters	100% 0%*[22] 0%*
Lighting	Incandescent lamps CFLs	98%* 2%*

[22]A star (*) means that the percentage was assumed for this study since the studies in which appliance saturation rates were taken, those penetration rates were not clearly specified. For example in the NLR database all households had lamps but is was not specified how many households had either incandescent lamps or CFL lamps.

Compact Fluorescent lamps (CFLs) and solar water heater (SWH) saturation rates could not be found in the literature, as a result the saturation rates for CFLs and SWHs shown in Table 3-4 were assumed. Table 3-5 shows electrical appliance saturation in middle income households.

Table 3-5: Appliance saturation rates for middle income that use electricity only

End Use	Appliance	Appliance saturation (%)
Cooking	4 Plate stove 2 Plate stove	70% 30%
Space Heating	Heater	100%
Refrigeration	Fridge	100%
Water Heating	Geyser Geyser blanket Solar water heaters Kettle	70% 0%* 0%* 30%
Lighting	Incandescent lamps CFLs	98%* 2%*

Table 3-5 shows that middle income households used kettles and geysers for heating their water. Table 3-6 shows appliance saturation for low income households that use electricity only for all their energy needs.

Table 3-6: Appliance penetration rates for low income households that use electricity only

End Use	Appliance	Appliance saturation (%)
Cooking	2 Plate stove	100%
Space Heating	Heater	100%
Refrigeration	Fridge Deep Freezers	60% 40%
Water Heating	Solar water heaters Kettle	0%* 100%
Lighting	Incandescent lamps CFLs	98%* 2%*

Table 3-6 shows that low income households do not use geysers for water heating. There are low income households that have solar water heaters, but this study assumed that no low income households used geysers in 2007.

3.11.1.2 Appliance penetration rates in multiple fuel using households

A range of non electrical appliances are used by middle and low income households that practice multiple fuel use. Table 3-7 shows saturation rates for non electrical appliance used in middle and low income households that practice multiple fuel use.

Table 3-7 : Non electrified middle and low income households' appliance saturation rates

Appliance	Saturation levels (%)	End use
Coal Stove[23]	20	Cooking, water heating and space heating
Mbawula	13	Cooking, water heating and space heating
Paraffin Wick Stove	43	Cooking and water heating
Paraffin Primus Stove	3	Cooking and water heating
LPG ring or Stove	3	Cooking and space heating
Paraffin heater	7	Space heating

Table 3-7 shows that one appliance can achieve up to three end uses. Coal stoves are mostly used for cooking, space heating and water heating (Mathews and Van Wyk, 1996; White et al, 1998; Alfastad, 2005). Coal stoves achieve these end uses simultaneously because the times in which cooking and space heating are needed overlap in the evenings. Balmer (2007) found that coal stoves are used most frequently for space heating and cooking as in most cases the stoves are lit in the evenings coinciding with South African households cooking times[24]. The appliance saturation rates shown in Table 3-7 are used in both electrified and non-electrified middle and low income households that practice multiple fuel use. The following sub-section presents the end use energy intensities in low, middle and high income households.

3.11.2 Household end use energy intensities

3.11.2.1 Electrified households end use energy intensities

Table 3-8, Table 3-9 and Table 3-10 presents end use energy intensities in different household categories.

[23]White et al (1998)' study did not specify whether the stove was a home made coal stove or coal stove that is bought from shops. Balmer (2007) noted that most households that use coal stove, the stoves are homemade type of stoves.

[24] Water heating is classified as a morning end use (both adults and children need water for bathing in the morning when they go to work and school respectively

Table 3-8: Low income households electricity intensity per end use

End-uses	Fuel type	Energy-intensity (GJ/annum)	Percentage (%) of total energy demand	Percentage (%) total energy demand with no refrigeration
Lighting	Electricity	0.97	16.20	19.80
Cooking	Electricity	1.08	18.40	22.00
Refrigeration	Electricity	2.41	22.20	-
Water Heating	Kettle	0.88	14.70	18.00
Space Heating	Electricity	1.37	18.40	28.00
Other	Electricity	0.60	10.00	12.20
Total		7.31	100.00	100.00

Source: (COJMM (2007), CTMM (2006), EMM (2004), Simmonds and Mammon (1996), Winkler, 2005)

Table 3-8 shows electrical energy intensity in low income households. Table 3-8 shows that refrigeration consumes the highest electrical energy demand in low income households, followed by space heating, cooking, lighting, water heating and finally the "other" end use. Afrane-Okese (1998) discovered that low income households use fridges with efficiencies that are lower than fridge efficiencies found in higher income households.

Table 3-9 shows the energy intensity for each end use in middle income households.

Table 3-9: Electrical energy intensity per end use in middle income households

End-uses	Fuel type	Energy-intensity (GJ/annum)	Percentage (%) of total energy demand
Lighting	Electricity	1.4	9.2
Cooking	Electricity	2.6	17.1
Refrigeration	Electricity	2.1	13.9
Water Heating	Kettle	1.4	9.1
	geyser -electric	3.8	24.9
Space Heating	Electricity	2.8	18.4
Other	Electricity	1.1	7.2
Total		15.2	100.00

Source: (COJMM (2007), CTMM (2006), EMM (2004), Simmonds and Mammon (1996), Winkler, 2005)

Table 3-9 shows that water and space heating consume more energy in a middle income household. Cooking and refrigeration are also significant energy consuming end uses. There might be different reasons for this high consumption of energy by these end uses. In the case of water heating, it is known from available literature that electric geyser consumes the greatest share of energy demand in households that use it. From Table 3-9, it is evident that water heating has a significant share of energy in households that use geysers instead of electric kettles to heat water. In the case of space heating, the level of income of the household might contribute to higher consumption because they can afford electricity. For example, a heater can be put on for longer periods to achieve the required level of comfort, whereas in a low income household, limited income can limit the prolonged period of heating even if the required comfort is not attained. Table 3-10 shows energy end use intensity for high income households.

Table 3-10 : Electrical energy intensity per end use in high income households

End-uses	Fuel type	Energy-intensity (GJ/annum)	Percentage (%) of energy intensity
Lighting	Electricity	4.68	12.70
Cooking	Electricity	6.40	17.37
Refrigeration	Electricity	2.00	6.54
Water Heating	Electricity	16.40	44.52
Space Heating	Electricity	1.75	4.75
Other	Electricity	5.20	14.12

Source: (COJMM (2007), CTMM (2006), EMM (2004), Winkler, 2005)

Table 3-10 shows that high income households generally have high end use energy intensity. Even within these households there are some end uses that are more energy intensive than others. Table 3-10, shows that energy consumed to heat water is almost half of the household's energy demand, followed by cooking, other electrical end uses and lighting.

3.11.2.2 End use energy intensity middle and low income multiple fuel using households

Table 3-11 shows end use energy intensities for electrified middle income households that practice multiple fuel use.

Table 3-11 : Energy intensity per end use in electrified middle income households that practice multiple fuel use

End Use	Fuel	Energy Intensity (GJ/annum)	Percentage of households (%)
Lighting	Electricity	1.40	100.00
Cooking	Electricity & coal	8.15	40.00
	Paraffin& electricity	3.53	3.00
	Electricity	2.60	53.00
	LPG	2.33	4.00
Space heating	Coal	30.18	19.00
	Paraffin	2.33	2.00
	Electricity & coal	20.58	38.00
	Electricity	2.80	41.00
Refrigeration	Electricity	2.63	88.00
Water heating	Electricity and coal	2.87	33.00
	Electricity	1.39	67.00
Other	Electricity	1.10	100.00

Table 3-11 shows that majority of middle income households that practice multiple fuel use, mostly use a single fuel for most end uses. Households use multiple fuels for cooking, space heating and water heating. Electricity is mostly the primary fuel, where there is a combination of fuels. The common fuel combination patterns are electricity & coal and electricity & paraffin (White et al, 1998). Table 3-12 shows end use energy intensities for non electrified middle income households.

Table 3-12: End use energy intensities for non electrified middle income households

End Use	Fuel	Energy Intensity (GG/annum)	Percentage of households (%)
Lighting	Paraffin	2.22	29.00
	Candles	1.41	71.00
Cooking	Paraffin	4.00	72.00
	Paraffin & Coal	10.44	24.00
	LPG	2.34	4.00

Table 3-12: End use energy intensities for non electrified middle income households (continued from previous page)

Space heating	Paraffin	2.33	12.00
End Use	Fuel	Energy Intensity (GG/annum)	Percentage of households (%)
	Coal	30.18	60.00
	Coal and Paraffin	20.90	28.00
Water heating	Paraffin	2.66	65.00
	Coal	5.83	35.00

Table 3-12 reflects that non electrified middle income households sometimes use a combination of two fuels – paraffin and coal for cooking and coal & paraffin for space heating. Since the first fuel is assumed to be the primary fuel for this study, coal seems to be the preferred fuel for space heating in middle income households while paraffin seems to be the preferred fuel for cooking. Table 3-13 and

Table 3-14 respectively show end use energy intensities for electrified low income households that practice multiple fuel use and for non electrified low income households.

Table 3-13: End use energy intensity for electrified low income households that practice multiple fuel use

End Use	Fuel	Energy Intensity (GJ/annum)	Percentage (%) of households
Lighting	Electricity	0.97	100.00
Cooking	Paraffin	1.47	40.00
	Paraffin & electricity	1.21	53.00
	LPG	1.00	7.00
Space heating	Coal	24.06	65.00
	Paraffin	2.33	15.00
Refrigeration	Electricity	2.12	55.00
Water heating	Electricity and coal	5.83	100.00
Other	Electricity	0.60	100.00

Table 3-13 shows that the common fuel combinations in low income households that practice multiple fuel use were electricity & coal for space heating and paraffin & electricity for cooking. Paraffin is the preferred fuel for cooking. There were no fuel combinations for space heating, households either space heat with paraffin or with coal in the low income electrified households category. Looking at

Table 3-14 it is evident that the most frequent fuel combinations were paraffin & coal for cooking and coal & paraffin for space heating.

Table 3-14 : Fuel combinations in low income non electrified households

End Use	Fuel	Energy Intensity (GG/annum)	Percentage of households (%)
Lighting	Paraffin	2.22	20
	Candles	0.46	80
Cooking	Paraffin	1.47	74
	Paraffin & Coal	8.75	24
	LPG	1.00	4
Space heating	Paraffin	2.33	25
	Coal	24.06	34
	Coal and Paraffin	16.82	41
Water heating	Paraffin	1.33	80
	Coal	5.83	20

This highlights that paraffin is the preferred fuel for cooking while coal is the preferred fuel for space heating. It should be noted that households that use coal, do so extensively in winter. In summer, coal consumption tends to decreases (Balmer, 2007). As a result, households can have different fuel combination patterns for cooking and water heating in winter and summer. For the purpose of this study, fuel combinations shown in Table 3-14 were assumed to hold in both summer and winter.

3.12 Fuel Consumption in different households categories

Section 3.10 showed that electricity usage is high in low, middle and high income households. Figure 3-21 shows the percentage of energy demand that is met by each of the fuels used by the residential sector in Gauteng.

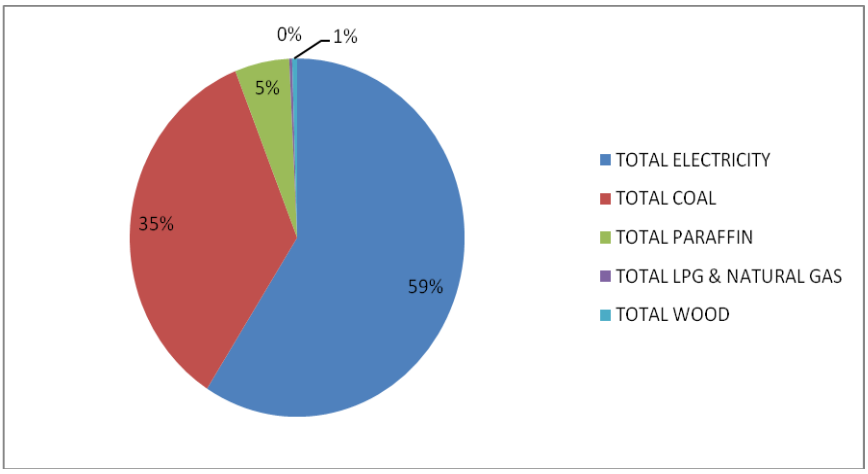

Figure 3-21: Energy demand by carrier (based on 2007 base year data)

Figure 3-21, it is clear that electricity and coal met 94% of Gauteng's residential sector energy demand in 2007, 5% was met by paraffin and 1% by wood. LPG and natural gas usage was very low relative to the other fuels. Section 3.11.1 showed that electricity is used by many households in Gauteng across all income groups. Based on the end use energy intensities given in Section 3.11.2 and following the bottom-up end use energy intensity methodology shown in sub-section 2.5.2 of chapter 2, the overall fuel demand was calculated and the results are shown in Table 3-15.

Table 3-15: Base Year Fuel Demand by Households categories in 2007

Household Category	Electricity (TJ)	Paraffin	Coal	Wood
High	34 907	0	0	0
Middle	8548	2225	12283	0
Low	3117	1924	15264	380
Total	46572	4149	27547	380

Table 3-15, shows that 75% of electricity consumed in Gauteng's residential sector was used by high income households, 19% by middle income households and the remaining 6% by low income households. 54% of paraffin was used by middle income households and 46% was used by low income households. With regard to coal, 55% of the fuel was consumed by the low income households and the remaining 45% was consumed by middle income households. Although Chapter 6 has shown that coal is the most expensive fuel to cook and space heat with in energy terms, the greatest share of energy demand for coal came from the low income households. Through analysis, this study concludes that coal is preferable in low income households because there are no financial requirements needed to acquire mbawulas, as the tin that a household possesses can be used to make the appliance and coal can be bought in smaller quantities, hence making it affordable for low income households. Money is required only to buy the fuel itself, and in some instances the coal is collected freely from nearby mines (White et al, 1998, Balmer, 2007).

In addition to the widely used fuels - LPG, coal, paraffin, wood and electricity, households in the City of Johannesburg use Egoli gas. Egoli gas is sold to households and other customers in Johannesburg by a gas company called Egoli Gas. Egoli Gas used to buy hydrogen rich gas from SASOL plant in Sasolburg however since April 2004, it has been buying and supplying natural gas (DME, 2008). Egoli Gas buys almost 2 Million GJ per annum of natural gas from a SASOL (DMEb, 2005). Table 3-16 shows the amount of Egoli gas that was consumed by households in Johannesburg in 2006/2007.

Table 3-16: Egoli Gas Consumption in Johannesburg households in 2006/2007

End User	Energy, GJ/annum
Single Households	97,000
Multiple Dwellings	142,000
Total	**239,000**

Source: City of Johannesburg State of Energy report 2007

Table 3-16 shows that 60% of Egoli gas was used by households living in multiple dwellings[25].

[25] Multiple dwelling are houses such as hostels, block of flats, etc where many households live in the same building.

4. Gauteng's residential sector energy demand model and scenarios

4.1 Introduction

When forecasting energy demand, it is crucial to establish drivers of energy demand and understand how these drivers evolve over time. The chapter starts with a description of the energy demand drivers and how these drivers evolve over the 2007 – 2030 modelling period. The chapter then provides a description of the scenarios that were modelled in LEAP and the assumptions used to construct those scenarios.

4.2 General assumptions and drivers of future trends

Energy demand in the residential sector is driven by population, the number of households and gross domestic product (GDP). Population and household growths are linked because the one is a function of the other. If GDP grows and more people are employed, households become wealthier and their demand for energy increases. In order to forecast energy demand in the residential sector; it is crucial to also forecast population growth, GDP growth and households growth. Sub-sections **Error! Reference source not found.**, 4.2.1 and 4.2.2 describe detailed GDP, population and household growth projections respectively.

4.2.1 Population growth and household growth

The HIV/AIDS pandemic has been argued to have a large impact on population dynamics in South Africa (Winkler, 2005). One would expect the population in Gauteng (which was characterized by high HIV/AIDS prevalence rate of 10.3% in 2008) to grow slowly (at 1% annual growth rate) as was suggested by Professor Dorrington's 2003 ASSA [26] model. But Laundau and Gindrey (2008) argue that despite mortality (brought by diseases such as HIV/AIDS and TB); the population within Gauteng has the potential to increase dramatically.

Laundau and Gindrey (2008) argue that besides HIV/AIDS impact on population, population

[26] Actuarial Society of South Africa (ASSA) models are South African population projection models that incorporated the influence of HIV/AIDS. They were models developed by Professor Dorrington of Commerce Faculty for Actuarial Society of South Africa.

increase in Gauteng also occurs as a result of both inter-provincial and international migration into Gauteng. Almost 217 000 additional people were gained in Gauteng per annum between 2001 and 2007. Laundau and Gindrey (2008) found that 74% of the 217 000 was due to natural growth[27], the remaining 26% was found to be a result of net[28] migration. In 2007, 87% of the in-migrants in Gauteng were South Africans from other provinces of the country and 13% were from other countries (Laundau & Gindrey 2008).

The trend of inter-provincial migration cannot be restricted as it is the right of every citizen to live where they choose. Section 21.3 of South African's bill of rights states that:

"*Every citizen has the right to enter, to remain in and to reside anywhere in, the Republic*".

Even if international migration policies could limit the number of people that enter South Africa, the population of Gauteng will continue growing given the small percentage (3.38%[29]) that international migration contributes to the overall population growth in the province.

Due to the many, inter-related, variables that contribute to population growth in Gauteng (e.g. political instability in neighbouring countries, HIV/AIDS prevalence, international and internal migration, unequal spatial development), Laundau and Gindrey (2008) argue that it is not advisable to have a single population growth projection. He developed three scenarios - Low*[30], Medium** and High*** to project Gauteng's future population growth.

These scenarios (low*, medium** and high***) incorporated the three primary determinants of population growth: fertility, mortality and migration. The low* scenario assumed that the present fertility rate[31] of 2.29% in Gauteng would decrease to 2.00% and the internal to international migration ratio would remain at 0.87: 0.13 if the net migration gain remains at 26%.

The Medium** growth scenario also assumed a decrease in fertility rate from 2.29% to 2.10%, but the improved HIV/AIDS treatment results in reduced HIV/AIDs related mortality rates. The internal

[27] All births that occurred in Gauteng irrespective of the parents' nationality, according to South African Citizenship Act (Act 88 of 1995), a person can be a citizen of South Africa if they are born within the borders of South Africa.

[28] Net migration is the difference between the number of people that moved in and out of a region.

[29] In-migration contributes 26% of Gauteng population. The ratio of local and international migration is 0.87:0.13. Hence international migration only contributes 3.38% (0.13*26%) to the 26% contributed by migration.

[30] The stars are there to differentiate these population projections from low, middle and high income households categories.

[31] Average number of births per woman

to international migration ratio remains unchanged at 0.87: 0.13 while the net migration gain remains at 26%. The High*** scenario, assumes internal migration remains unchanged at 2% growth every five years, international migration growth grows from 0.2% every five years to 0.5% every five years (as political unrest in neighbouring countries grows) such that the ratio of internal to international migration becomes 0.6:0.4 while the mortality rate decreases by 3% every 5 years.

Figure 4-1, shows the 2003 Gauteng population growth derived from the 2003 ASSA model and the three population growth trajectories derived by Laundau and Gindrey (2008).

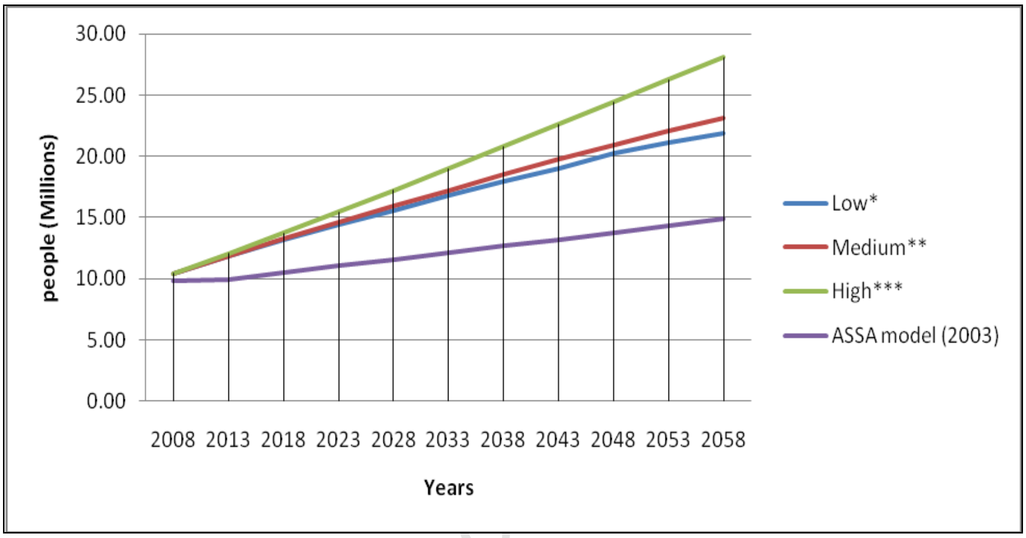

Figure 4-1: Population Projection by ASSA models and Landau
Source (based on ASSA model 2003 (www.assa.org.za) and Landau & Gindrey, 2008)

Laundau and Gindrey's Medium** growth scenario was chosen for this study to forecast population growth for Gauteng. The Medium ** growth scenario was chosen because it shows Gauteng's improved HIV/AIDS treatment (HST, 2003) which has lowered the mortality rate to below that of the ASSA model and Low* growth scenarios.

The Medium** growth scenario has an average annual population growth rate of 1.6%. The internal to international migration ratio remain unchanged at 0.87:0.13. The high*** growth scenario was not chosen because, it has very high population growth, which can be accommodated well in Gauteng only if the physical boundary of the province changes. Figure 4-2 shows that Gauteng already had the highest average population density in the country in 2001. In 2008, it was estimated that the population density was 631 people per square kilometer (Landau & Gindrey, 2008).

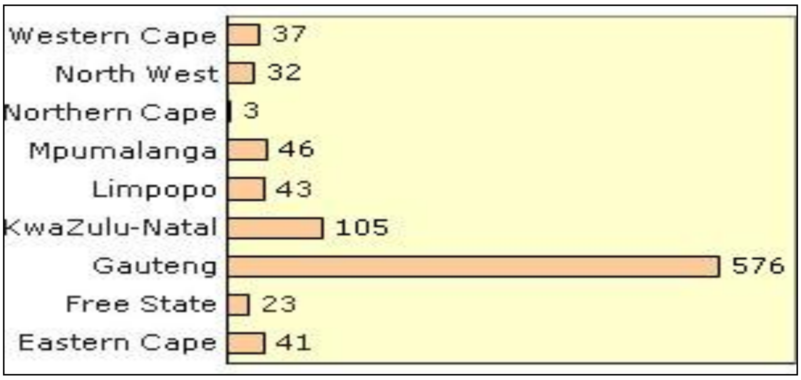

Figure 4-2: Population density (Number of people per square kilometre) by province

The high*** scenario could result in a population increase of 20 million by 2030, and that will result to 1250 people per square kilometres. Considering the land (space) problems that the province already has for residential development in places such as Dieploof and Alexandra (Mafukidze & Hoosen, 2008), 1250 people per square kilometre would aggravate the problem.

4.2.2 Future number of households

The 2007 Community Survey estimated that there were 3.175 million households in Gauteng in 2007 while the 2001census reported that there were 2.74 million households in 2001. Based on these two values, the number of households has been growing at a rate of 2.3% per annum (STATSSA, 2007). Also, the household size has decreased from 3.9 in 2001 to 3.3 in 2007. This study assumes that household size in Gauteng would not fall below 3 any time in the future. If household size does not fall below 3 and the population grows as proposed in section 4.2.1, household growth rate is estimated to be 2.30% per annum during the modelling period (2007- 2030).

4.2.2.1 Household mobility across income categories

Since households are classified by income categories, to undertake energy demand modelling, it is crucial to know households mobility between these income categories. The most difficult assumption one can make concerns estimates of future household's income. The movement of households from one income band to another is highly random and bi-directional (up the income ladder or down the income ladder). These movements are complex and occur as a result of employment, education, training, long term macro-economic policies and labour market absorption rates.

Household income mobility is a topic of much debate in many income related studies (Fields, 2009; Meth, 2008; Raut, 1996). Researchers propose different methodologies for undertaking such studies and it has been identified that household mobility can best be estimated from panel data[32] (Fields, 2009). South African income mobility studies that concentrate on panel data are in their infancy. The National Income Dynamics Study (NIDS) undertaken by the Southern Africa Labour and Development Research Unit (SALDRU) of the University of Cape Town looks at households' income mobility using panel data. The NIDS is still in its first wave [33] (which started in 2008), hence concrete conclusions regarding household income mobility cannot be taken from the NIDS study at present. Due to the lack of income panel data in South Africa and a harmonized methodological approach to forecast household income mobility, the household income data from the censuses 1996 and 2001 was used forecast household income mobility.

Hair, Babin, Money and Samouel (2005) and Field (2009) suggest that it is important to verify that households have moved from one income band to another before applying any mobility concepts on the data. As a result households' income data from the 1996 and 2001 censuses and the 2007 Community Survey was used to verify if there was any household income mobility between the three years. The mobility was verified by observing the middle income band in the three years (1996, 2001 and 2007). In skewed distributions such as income distributions, Hair et al (2005) identified that a good measure of central tendency is the median because the mean can be biased.

The 1996 and 2001 censuses and the 2007 Community Survey reported household income bands, which grouped data in statistical terms. Statistically, the procedure for calculating the median of the grouped data starts by identifying the middle group (which is the middle income band for this study). Cumulative frequency was used identify the middle income band. Households in the 2001 census and the 2007 Community Survey were classified by the same income bands, although the value of the Rand differed in real terms due to inflation. The households in the 1996 census were classified into income bands that were different from the income band classifications of the 2001 census and the 2007 Community Survey (See Appendix D).

[32] Panel data is a form of data where same households are followed year to year so that a trend can be established.

[33] Wave 1 means the first 5 years in which same households would be studied. Wave 2 would be the next 5 years that follow the first 5 years.

Figure 4-3 shows the median income bands from both the 2001 census and the 2007 Community Survey income data.

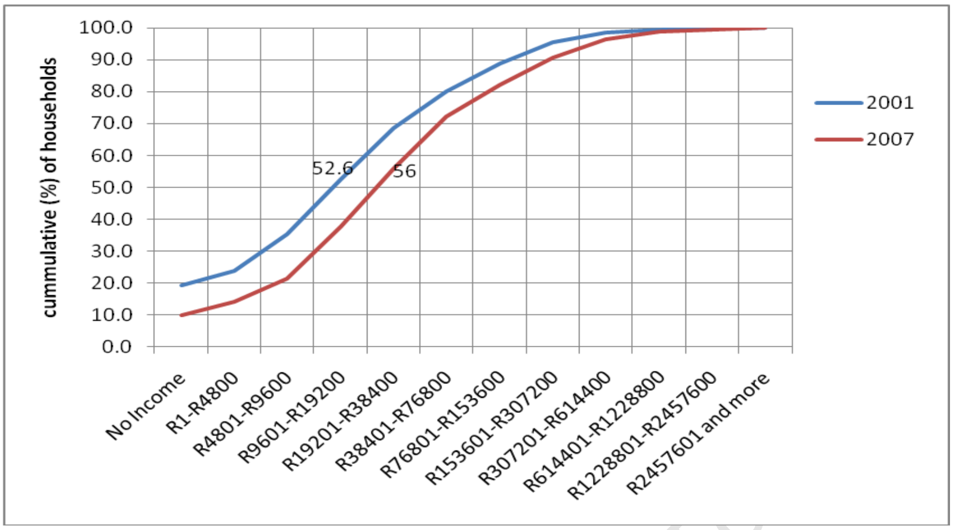

Figure 4-3: Locations of middle income bands in Census 2001 and CS2007
Source (Own calculations based on Community Survey, 2007 and Census 2001)

Figure 4-3 shows that the middle income band was R9601 – R19 200 and R19 201 – R38 400 in 2001 and 2007 respectively. Figure 4-4 shows median income band for households in the 1996 census.

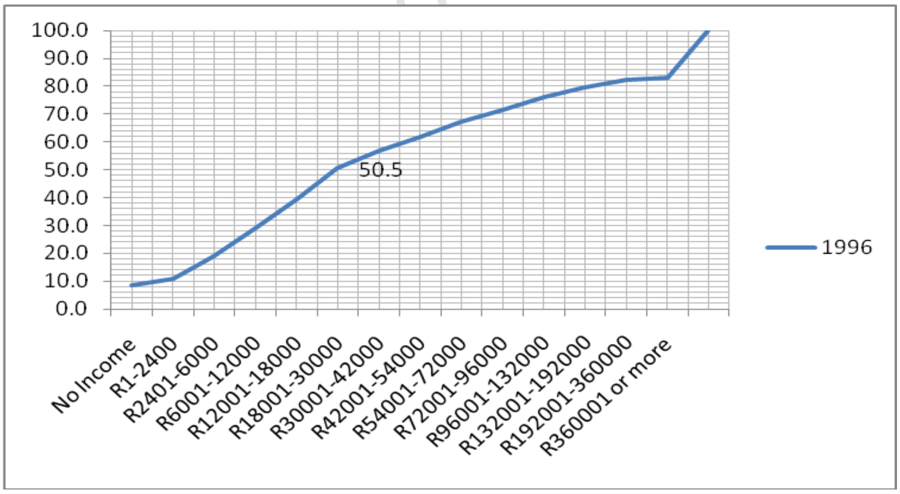

Figure 4-4: Location of middle income band for Gauteng households in 1996 census
Source: (Own Calculation based on Census 1996)

Figure 4-4 shows that the R18 001 – R30 000 income band, is the middle income band for the 1996 census. Equation [4-1] was used to calculate the median incomes within the identified middle income bands of the 1996 and 2001censuses and 2007 Community Survey given the location of median income bands.

$$\textbf{Median} = l + ((n/2 - cf)/f) \times h \qquad [4\text{-}1]$$

where l is the lower limit of the middle income band, n is the number of observations (for this study, these observations are the number of income bands in the 1996 and 2001census and the 2007 Community Survey this study), cf is the cumulative frequency of the income band preceding the middle income band, f is the frequency of the middle income band and h is the number of households found in the middle income band. Table 4-1 shows the calculated median incomes for the 1996 and 2001censuses and the 2007 Community Survey.

Table 4-1: Median Incomes in 1996, 2001 and 2007 in their respective years and in 2007 rand value

Year	Median Band	Median calculated using Equation [4-1]	Median in 2007[34] Rand value
1996	R18 001-R30 000	R12 993	R23 981
2001	R9 601-R19 200	R9 960	R13 516
2007	R19 201-R38 400	R19 862	R19 862

Table 4-1 shows that, the 1996 median income was higher than the median income in 2007. Table 4-1 shows that, the median incomes for households in Gauteng were R23 981, R13 516 and R19 862 in 1996, 2001 and 2007 respectively. This shows that 50% of households moved into lower income bands between 1996 and 2001 and during 2001 – 2007 period 50% of households moved into higher income bands. The information contained in the median income highlights the movement of the middle income point, and it does not say everything about the mobility of households across all income bands. To capture the mobility of households within different income bands, linear extrapolation was done on the 1996 and 2001censuses to align income bands in those two years to income bands as found in the 2007 Community Survey. The 1996 and 2001 income bands were aligned to the 2007 income bands because 2007 was chosen as the base year of this study.

To apply the linear extrapolation, it was assumed that households were evenly distributed within the respective income bands in both the 1996 and 2001 censuses. Besides the differing income bands (see Figure 4-3 and Figure 4-4) in the three years, income cut-off points of each income band was

[34] The calculated medians were given in 2007 rand value because the base year for this study is 2007.

different in real terms due to inflation. Therefore, before extrapolating the income bands, the income cut-off points in the 1996 and 2001 censuses data were inflated to the 2007 Rand value using consumer price index (CPI). After inflating the income bands to 2007 Rand value, linear extrapolation was applied to both the 1996 and 2001censuses income bands to align them to the 2007 income bands to enable comparison of the income bands in the three different years.

Figure 4-5 shows visualisation of how linear extrapolation was applied on the households.

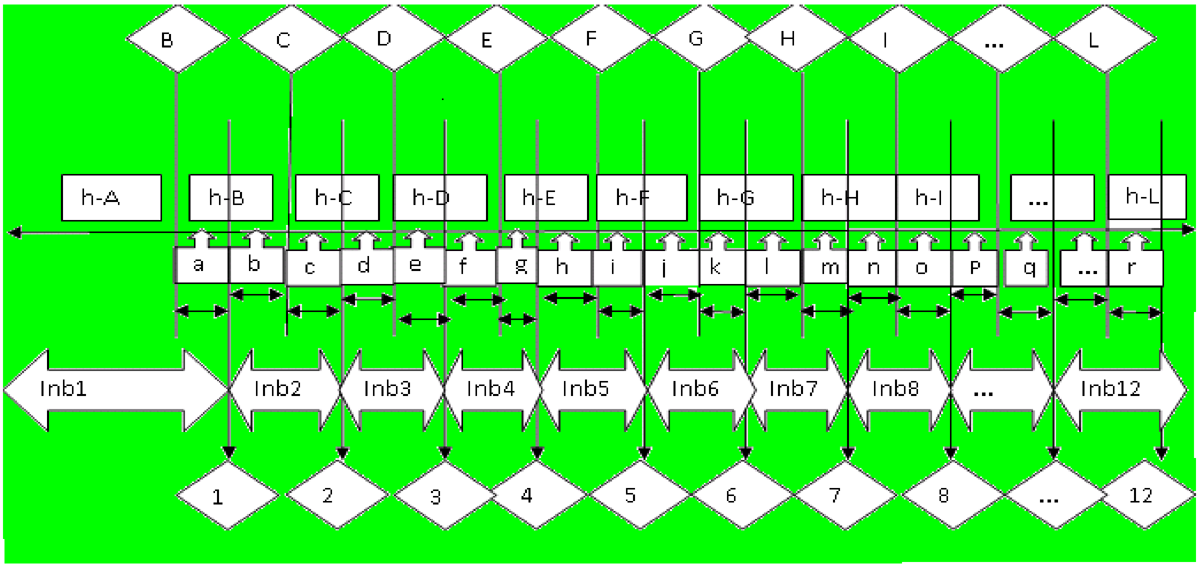

Figure 4-5: Graphical visualisation of linear extrapolation

The newly formed income bands were classified as Inb1, Inb2 …Inb12 shown in Figure 4-5. The numbers 1, 2, 3 to 12, marked income cut-off points for the 2007 Community Survey[35] which defined the upper limit on the newly formed income bands. These newly formed income bands correspond with the income bands of the 2007 Community Survey. For example, Inb1 corresponds to No Income band of the 2007 Community Survey, Inb2 to R1 – R4800, Inb3 to R4801 – R9600 and so on. The number of households in the income bands of the 1996 and 2001 censuses are represented by h-A, h-B … h-L with A, B, C …L corresponding to income cut-off points associated with those households. a, b, c… r represents the number of households in each income band once the income bands are aligned.

The following Equations were used to calculate the number of households represented by a, b …r.

$$a = h\text{-}B\,(1-A)/(C-B) \quad [4\text{-}2]$$

$$b = h\text{-}B\,(C-1)/(C-B) \quad [4\text{-}3]$$

[35] The cut-off point is highest value in the income band range. For example, if the income band was R1 – R4800, the cut-off point is taken as R4800.

c= h-C (2-C) / (D-C) **[4-4]**

.

.

.

r= h-L (12-l) / (L-K) **[4-12]**

The number of households in each income band after alignment is shown in Figure 4-6.

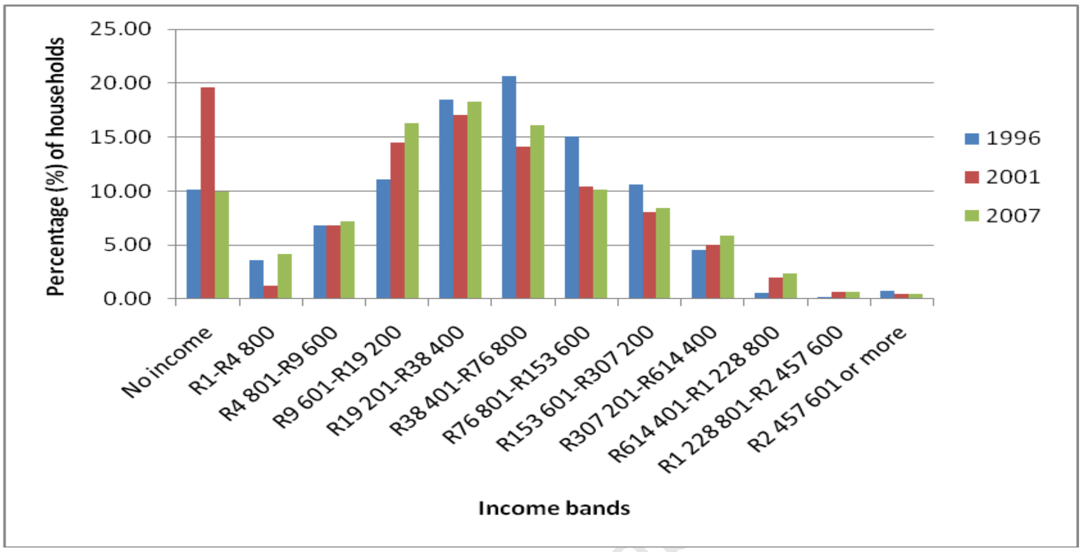

Figure 4-6: Households' distribution in 1996, 2001 and 2007 after extrapolation

Figure 4-6 shows that there were more households in the R19 200 - R34 800, R38 401 – R76 800 and R76 800 – R153 600 income bands in 1996 than in any other income band. In 2001, the picture changed, as more households were found in the *No Income* and R19 201 – R38 400 income bands. In 2007, most households were found in the R9 601 – R19 200, R19 201 – R38 400 and R38 401 – R76 800 income bands. In order to clearly see the positional change in the three years – 1996, 2001 and 2007, household income distributions in Figure 4-6 are represented in continuous form in Figure 4-7.

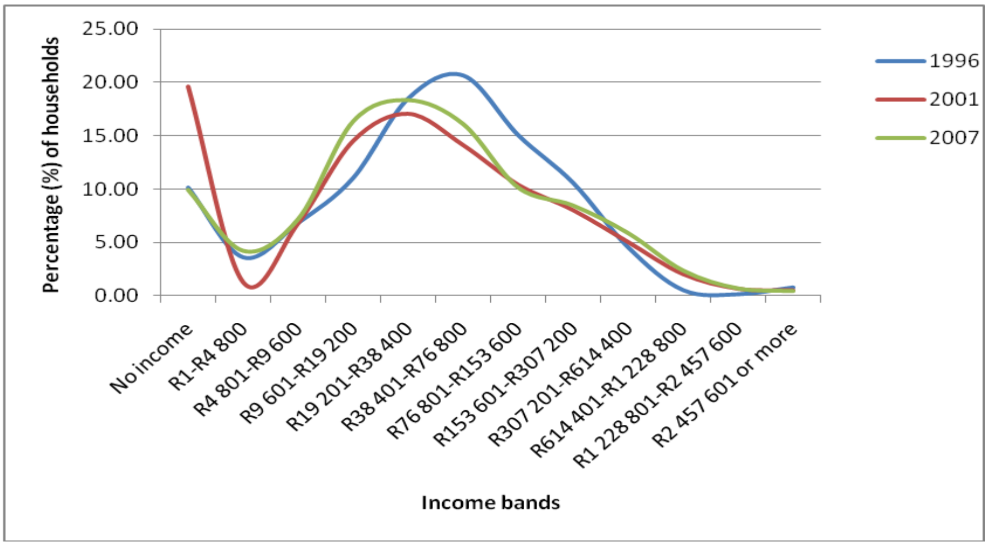

Figure 4-7: Households income frequency distributions in 1996, 2001 and 2007

Figure 4-7 clearly shows a position change in household distribution across income bands in 1996, 2001 and 2007. A higher percentage of households in both 2001 and 2007 shifted to lower income bands relative to 1996. This means that Gauteng had a higher percentage of households in the high income household category in 1996 than in both 2001 and 2007. The results shown in Figure 4-7 substantiate the findings regarding the median income as presented in Table 4-1. There was no major shift to lower income bands between 2001 and 2007, although there were more households in the *No Income* - income band in 2001 than in 2007.

Results from the re-distributed income bands of 1996, 2001 and 2007 were used to establish household mobility trends. Figure 4-8 shows the mobility of low, middle and high income households in 1996, 2001 and 2007.

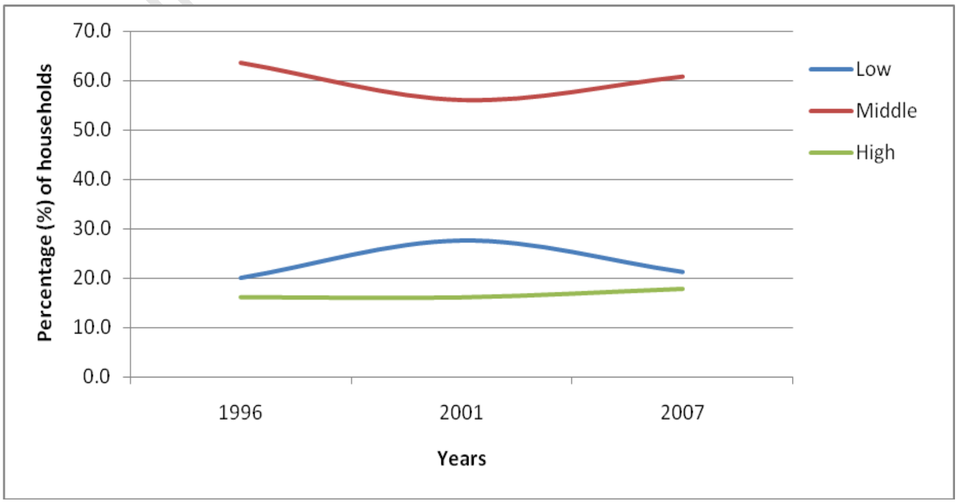

Figure 4-8: Share of households in 1996, 2001 and 2007

Since there are only three data points, a linear trendline was applied to the three points to forecast future share of low, middle and high income households in Gauteng. The result is shown in Figure 4-9.

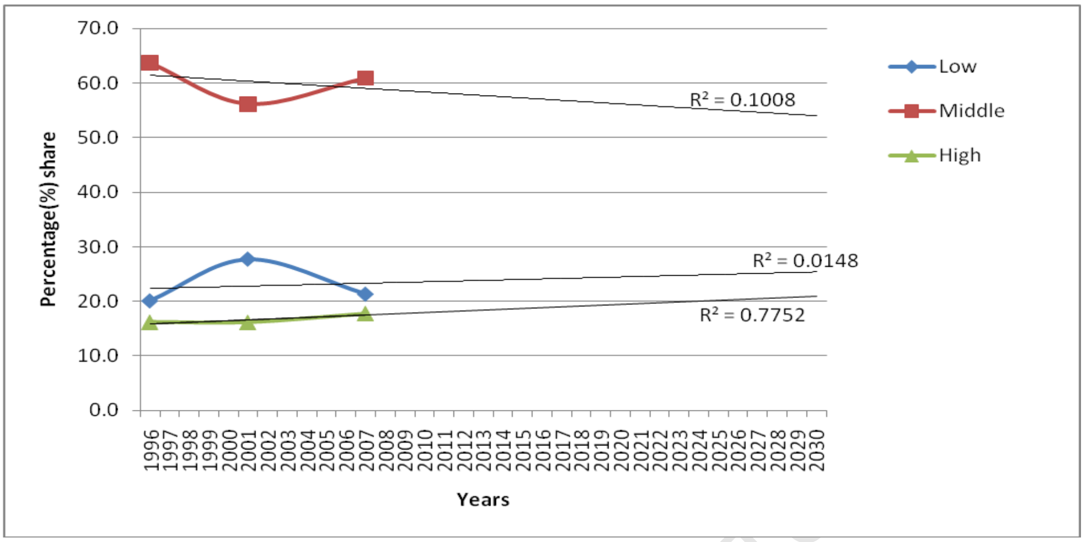

Figure 4-9: Future share of low, middle and high income households in Gauteng

Figure 4-9 shows that the percentages of both low and high income households increased over time while that of middle income households decreased. The R-values in Figure 4-9 show that, the reliability of the forecast was only satisfactory for high income households. The reliability of both the middle and low income forecasts is very low. The reliability is compromised because there are very few data points. In the absence of any better data, it was decided to use the forecasts as they are. It is recognised that this could introduce some biases into the LEAP model. Using linear trending forecast, the share of low, middle and high income households becomes 24.2%, 55.6% and 21.8% respectively by 2030.

4.3 Electrification growth

By assuming that households that use electricity for lighting represent the electrified households, 83% of households in Gauteng were electrified in 2007 (STATTSA, 2007). It is assumed that the rate at which households are electrified will affect the way energy will be used in the future, hence it is also essential to estimate how electrification will evolve. It was assumed that Gauteng's current annual electrification rate of 0.56% (NERSA, 2005) will continue, resulting in 96% electrification in Gauteng by 2030.

Figure 4-10 shows electrification levels in Gauteng between 1996 and 2007 together with the forecast electrification level.

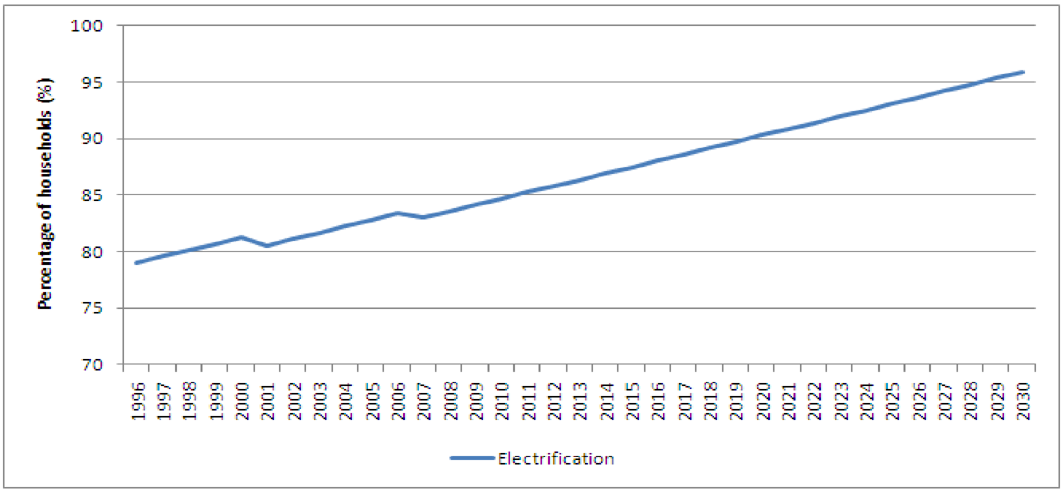

Figure 4-10: Percentage of electrified households (1996 – 2030)
Source: (Own calculation, from NERSA electricity sales reports, 1998, 1999, 2000, 2002, 2003, 2005)

The result shown in Figure 4-10 clearly shows that the government's goal of 100% electrification by 2012 (DME, 2005) is faced with some challenges. Although Gauteng electrifies more households each year than any other province (DME, 2005), the high household growth rate in the province undermines such an effort.

4.4 Emissions factors

Sustainable energy use in the residential sector requires the reduction of pollutants and GHG emissions from fuels used by households. To quantify GHG and pollutant emissions, emission factors are used to relate energy consumption to emissions. The emissions that impact negatively on sustainability are: carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and oxides of nitrogen (NO_x) and PM_{10} and total suspended particulate emissions (TSPs). TSPs are classified air particles that are less than 10 micron (PM_{10}). These emissions were chosen because of the negative impacts they bring to the environment (both global warming and local effects) and their associated human health impacts. PM_{10}, NOx, CO and SO_2 and CO_2 are elevated in the Vaal priority area (the Vaal priority area is formed by parts of Mpumalanga, Gauteng and Free State) (Scorgie et al, 2003) and are considered to cause respiratory problems in the region (Terbalenche, 1993).

Life cycle emission factor for electricity generated by Eskom is 1.015 kg $CO_{2\text{-equiv}}$/KWh (Marquard et al, 2007). This emission factor was used to find electricity related CO_{2equiv} emissions. The appliances in the technology and environment database (TED) in LEAP were linked to appliances found within the Gauteng LEAP model. This link was done to calculate the emissions (GHGs and pollutants) from the different fuels used in Gauteng's residential sector. The default emission factor for coal (25.5 ton CO_2/GJ) from the Intergovernmental Panel on Climate Change (IPCC) was replaced with Winkler (2006)'s emission factor of 26.5 ton CO_2/GJ. Winkler' emission factor corresponds to South African coal. Where applicable, the TED emission factors were replaced with emission factors specific to South African situation. The other emission factors that were edited in TED are shown in Table 4-2.

Table 4-2: Emissions factors for paraffin and coal

Fuels	Emission Factors		
	SO_2 (g/kg)	NO (g/kg)	PM_{10} (g/kg)
Coal	11.6	4.0	12
Paraffin	0.1	1.5	0.2

Source: Thomas et al (2004)

Table 4-2 shows the emission factors for SO_2, NO and PM_{10} from paraffin and coal. Local air pollutants such as total suspended particulate emissions (TSPs) and fine particulate matter (PM_{10}) were modelled for households using paraffin and coal. The IPCC default emission factor for TSPs was used to calculate TSPs. Section 4.5 presents the LEAP model that was developed to analyse residential energy demand and emissions in Gauteng.

4.5 Gauteng LEAP model structure

The LEAP model allows the user to develop a unique structure to represent the energy system that is modelled. With regard to the residential sector, most residential energy demand models that are developed include the activities performed by the households. Figure 4-11 shows the structure of the LEAP energy demand model developed for the residential sector of Gauteng.

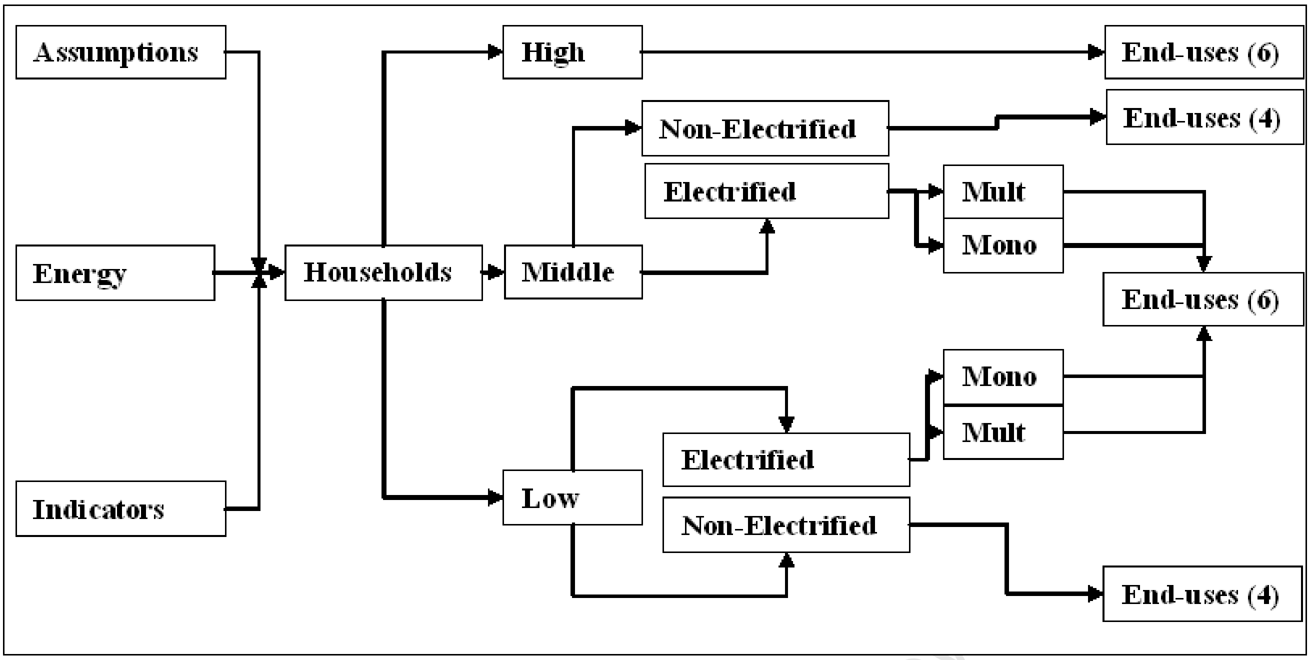

Figure 4-11: The designed Gauteng residential sector LEAP

The LEAP model structure shown in Figure 4-11 was developed in a hierarchical tree structure with five levels. The primary level is the residential sector which is represented by households, followed by the second level of three household categories - high, middle and low income households. The third level is represented by the split of middle and low income households into electrified and non-electrified households and the fourth level is represented by the split of electrified middle and low income households into mono (Mono households are households that use electricity only to meet their energy needs) and multiple (multiple households are households that use more than one fuel for their energy needs) fuel using households. The last level in the hierarchical tree is the end-use level (e.g cooking, lighting etc). All non-electrified households were assumed to use multiple fuels.

4.6 Modeling energy policies as scenarios

"*A scenario is a story that describes a possible future*" (Shell, 2003). In energy terms, energy scenarios refer to a "set of illustrative energy pathways" that indicate how "the future may unfold" (Ghanadan and Koomey 2005). To determine possible impacts of energy policies, energy scenarios are constructed from the policies.

Scenarios were constructed based on the reviewed South African energy policies that are relevant to the residential sector and from possible energy efficiency interventions. The reviewed energy policies and energy efficiency interventions were found in Winkler (2006), the Energy Efficiency

Strategy 2005, the States of Energy Reports from Gauteng's three metropolitan areas and the Gauteng Integrated Energy Strategy (GIES, 2010). The policies and energy efficiency interventions found in those documents were used to construct five scenarios for this study. The scenarios are base case scenario, energy efficiency scenario, thermal design scenario, minimum efficiency performance standards (MEPS) and Gas scenarios. Although, the thermal design scenario is an energy efficiency measure, it is included as a stand-alone scenario due to the way it is implemented.

4.6.1 The BASE CASE scenario

The base case scenario reflects the future under 'business-as-usual'. It assumes that the current energy consumption trend of Gauteng's residential sector continues into the future. The base case in LEAP represents a case without new policy interventions. In other words, it is a projection of what would happen in the absence of new energy policies or strategic energy interventions.

The base case scenario assumes that Basa Njengo Magogo[36] (see section 4.6.2.2) would be used by 3% of households that use coal in 2015. The scenario also assumes that 30% of households that would use coal in 2030 would be using BNM (ERC, 2007). The scenario also assumes lower levels of CFL usage. It is assumed that 2% of all households in each household category were using CFLs in 2007 and in 2030, 30% of households in each household category are assumed to use CFLs. With regard to solar water heaters, it was assumed that, by 2030, 30% of households would be using SWH in each household category. Besides the assumptions made about SWH, BnM and CFL usage, there were no other appliance efficiency improvements that were assumed in the base case scenario.

4.6.2 Energy Efficiency Scenario

This scenario is a combination of 4 sub-scenarios which are explained in detail in sections 4.6.2.1, 4.6.2.2, 4.6.2.3 and 4.6.2.4. These sub-scenarios include replacing the existing incandescent lamps with CFLs, installing ceilings, installing roof insulation, replacing electrical geysers with solar water heaters and also insulating the electric geysers and the hot pipes.

[36] This is a lighting technology where coal is lit from above when it is used in coal braziers.

4.6.2.1 CFL penetration rates

Energy efficiency interventions in the cities States of Energy Reports include the introduction of an efficient lighting (CFL) target. The City of Tshwane, City of Ekurhuleni and City of Johannesburg States of Energy Reports suggested a 50% and 100% CFL usage levels in all their households in 2015 and 2025 respectively. These targets were used for this study. 100% penetration of CFLs has not been realised in any country worldwide. Even in countries such as Denmark and Australia that have among the highest CFL penetration levels in the world, 100% penetration levels have not occurred (Winkler, 2009). Denmark and Australia had 46% and 56% CFLs penetration respectively (Winkler, 2009). These ambitious penetration levels of CFLs, as found in the cities' States of Energy Reports were assumed to be possible if mandatory minimum appliance efficiency specifications are implemented as soon as 2015 in South Africa.

4.6.2.2 Basa Njengo Magogo (BnM) usage

Practicing Basa Njengo Magogo (BnM), was found to halve the amount of coal used per month by households in pilot studies that were carried out in Mpumalanga and Gauteng (DME, 2006). Basa Njengo Magogo is a coal lighting and stacking method. It improves the coal brazier's efficiency. Basa Njengo Magogo involves stacking coal and lighting the coal in the brazier from above hence more air is allowed into the coal fire within the mbawula which improves coal combustion. Figure 4-12 demonstrates how coal and other materials are stacked in the mbawula.

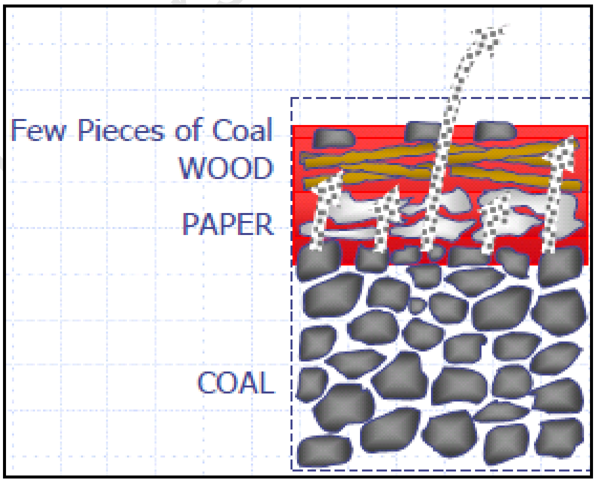

Figure 4-12: BnM fire preparation demonstration
Source: Department of Energy (2009)

To stack the BnM fire shown in Figure 4-12, a large amount of coal is added to the brazier, then cardboard or thick paper is added and finally wood is added together with an extra coal. The stacked materials are lit from above (CSIR, 2005). The BnM achieves different efficiencies for different end uses (Haw & Hughes, 2007). When it is used for space heating the coal braziers efficiency increases from 59% to 79% and when it is used for cooking and water heating, the efficiency increases by 3% (8% to 11%).

The small increase in efficiency for cooking and water heating happens because some heat is lost during the coal combustion waiting period. In order to cook and heat water on a fire lit the traditional way in the brazier, normally one requires a wait of up to 30 minutes after making the fire because poor coal combustion in the brazier results in smoke with a high soot content (CSIR, 2005). When lighting the fire using the BnM method, the waiting period is 5 minutes (CSIR, 2005) due to improved combustion that lowers the smoke emission period. The efficiency improves when it is used for space heating. Once the fire is lit, heat from the fire is dissipated, increasing the efficiency of the coal brazier.

It is assumed that by 2015, the awareness campaign (conducted by DME) to promote the use of this coal lighting and combustion method will have reached 50% of coal users in the province and that by 2030 it will have reached 100% of coal users. BnM penetration levels are higher than the national targets that were assumed by the LTMS (ERC, 2007) because the awareness campaigns have already reached many coal using communities (Akanani-Mitiya 2005; DME, 2006).

4.6.2.3 Retrofits (Ceiling, solar water heaters and roof insulation) sub-scenario

Ceilings and roof insulation are currently not installed as part of low cost housing delivery in South Africa (SSN, 2004). Most high and middle income households in South Africa have ceilings but insulation is not often present. This might be due to a lack of information concerning the benefits that can accrue from insulating a ceiling (Winkler, 2006). This sub-scenario assumes that low income and middle income households install ceiling and roof insulation. As it is assumed that individual households would fund this investment, a low penetration level is assumed for low income households. It was assumed that 70% of high and middle income households would have installed ceilings and insulated their houses by 2030, while in low income households only 20% were assumed to have installed ceilings and roof insulation by 2030.

An earlier study by Winkler, Spalding-Fecher, Tyani & Matibe (2002), estimated that if a 30 square metre RDP house was fitted with a ceiling the electricity saving would be 1 345 kWh/annum. This represents an average annual saving of 20% of the energy that would have been used for space heating. The study did not specify the type of ceiling material required for the saving. The retrofit scenario assumes that households invest in insulation and ceilings and it also assumes that low income households buy the least cost materials. Isotherm[37] 40 mm with an R-value of 0.88 m^2K/W costs R14/m^2 (Gauteng Integrated Energy Strategy draft, 2009). The Thermal Insulation Association of South Africa (TIASA) (2001) estimated that an R-value of 0.88 m^2K/W allows a heat loss of 18W per square meter at low temperatures when the room temperature is 25°C. A very small amount of energy is saved by installing this material.

For this study it was assumed that low income households could achieve a maximum energy saving of 40% for space heating if 40 mm isotherm is used. All middle and high income households were assumed to retrofit with the TIASA's recommended insulation material which has a minimum R-Value of 3.7 m2K/W. The heat loss of a material with an R-value of 3.7 m2K/W is 4.2W per square meter. Adding insulation with a higher R-value improves the thermal performance of the house hence it is assumed that 90% of the energy used for space heating can be saved in middle and high income households.

4.6.2.4 The solar water heating sub-scenario

Solar water heaters (SWHs) provide an alternative to supplying hot water with electric geysers. 70% of high income households were assumed to have solar water heaters by 2030 and the remaining 30% are assumed to have insulated their geysers and hot water pipes improving their geyser efficiency to 80% from 70% (Hughes, 2007). It is assumed that 100% of middle income households that use electricity only to meet all their energy needs used electric geysers to heat their water by 2030. 23% of multiple fuel using middle income households were assumed to use electric geysers to heat their water, the remaining 77% was assumed to use electric kettles.

By 2030, it was assumed that 30% of middle income households have would have replaced their electric geysers with solar water heaters while the remaining 70% were assumed to have insulated their electric geysers and pipes. Low income households that use electricity to heat their water are assumed to use electric kettles. By 2030, it was assumed that only 20% of low income households would have solar water heaters. Since low income households do not have the buying capacity of high income households, it was assumed that they would be provided with SWHs through initiatives

[37] An Isotherm is a type of insulation and ceiling material

similar to the Kuyasa CDM project.

4.6.3 The Thermal Design Scenario

This scenario assumes that all the new houses that are built, particularly RDP houses will be built according to the new SANS 204 building code which is still under review. This code includes, orienting houses to improve their thermal performance by reducing heat in summer and gaining heat in winter.

White et al (1998) suggested that windows and doors of the house should face 15° north or south, in order to maximize thermal performance all year round. In winter, a thermally efficient house allows more sunlight into the house so that the house needs less energy from other sources to heat it. In summer, the orientation reduces the amount of sunlight getting into the house hence reducing the need for cooling. In addition to house design, ceilings and insulation (wall and roof) are assumed to be installed when the house is built. If the insulation material suggested by TIASA is installed, Mathews and Van Wyk (1996) showed that a thermally designed house can save up to 90% of the energy used for space heating. This scenario assumes that RDP houses that are built from 2011 onwards would have incorporated SANS 204.

In 2007, 30% of all low income households in Gauteng were classified as informal dwellings. Due to the limited data of how many households live in collective buildings in the province, it was assumed that each house was occupied by one household. Therefore the thermal design scenario can be applied to 30% of low income households. Using the findings of Mathews and Van Wyk (1996), it was assumed that thermally designed houses would save 90% of the energy required for space heating. This is similar to the findings of Sustainable Energy Africa (2008), which found that 85% of space heating energy could be saved by good thermal design.

4.6.4 Standards and Appliance labelling Scenario

Introduction into appliance labelling and standards

Appliance labelling is a system which allows consumers to compare the energy efficiency of the products they wish to purchase (Wilkenfeld, 1996). Energy labelling provides buyers with information that is consistent and reliable, but does not force manufactures to produce energy efficient appliances or to remove less efficient ones from the market. Consumers can still buy inefficient appliance based on their preferences. Labelling is effective as an energy saving intervention if it influences consumer appliance choice.

In the United States and UK, Waide, Pett and Ramsay (2003) and Wilkenfeld (1997) found that voluntary labelling alone did not achieve significant energy savings. Substantial energy savings were only realised when appliances that meets minimum energy efficient requirements are sold. The policies and regulations that require appliances to meet specific minimum energy efficiency requirements are called minimum energy performance standards (MEPS) (Wilkenfeld, 1997, Nadel, 2002).

When MEPS is implemented, manufactures can produce appliances of any design as long as the energy efficiency requirements are met or exceeded. Inefficient appliances are removed from the market, allowing a high penetration of efficient appliances into the market. Unlike labelling, standards can impact on product energy efficiency even if consumers are unaware that the program exists. Although standards are cost-effective energy saving measures, Nadel (2002) argues that they are not appropriate for all products and situations hence countries such as the United States of America (USA) run MEPS in parallel with labelling.

In counties such as the USA, Australia and the United Kingdom (UK), MEPS started in the early 1990s (Wilkenfeld, 1997). Figure 4-13 shows the percentage change in energy savings that resulted from a MEPS program in freezers in Australia between 1993 and 2005.

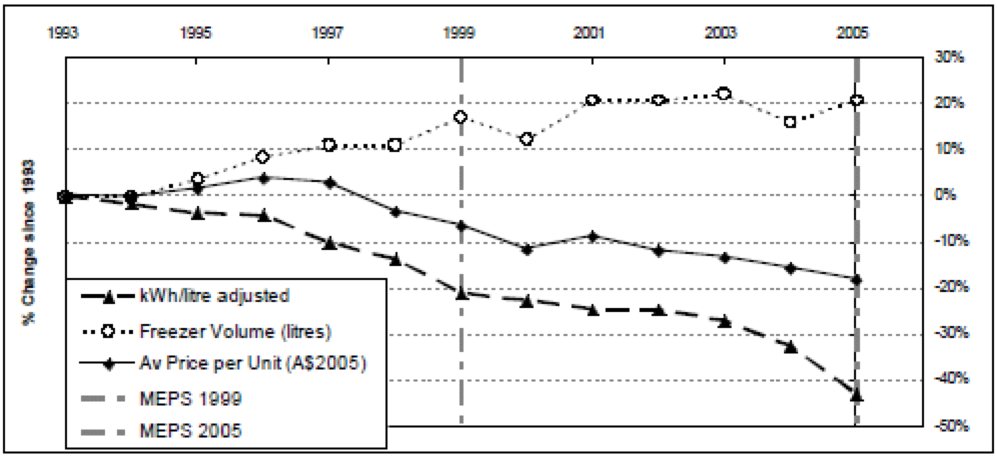

Figure 4-13: Australian freezers performance under MEPS
Source: Nadel (2005)

The volume of the freezers was increasing and energy savings were taking place at the same time. Although this study does not propose such a high percentage change in energy savings, shown in Figure 4-13, Figure 4-13 is used to illustrate the potential for energy savings.

For this study, it is assumed that MEPS and labelling would run in parallel in the country. The South African government proposed that the Energy Efficiency Strategy of 2005 be reviewed every three years. In 2008, the 2005 Energy Efficiency Strategy was reviewed and the reviewed strategy highlighted that the minister of energy can make energy efficiency standards mandatory under the new Energy Act (2008). Since appliance energy efficiency standards were not made mandatory in the 2008 strategy review, it seems reasonable to assume that the next review (that will possibly be in 2012-2013) would make MEPS mandatory. This study assumes 2015 to be a reasonable year in which MEPS become mandatory. If MEPS become a regulation as early as 2015, the earliest time that electrical appliances which conform to the MEPS could have gained a reasonable market share is 2025, because the life span of most electrical appliances is 10 years (Winkler, 2006, Thorne, 1996). The assumptions on appliance penetration rates are shown in Figure 4-14 and Figure 4-15.

One of the main criteria for determining priorities for labelling and MEPS is the contribution of each end use and appliance type to the total electricity or energy used by different households. Refrigerators and the appliances used for the "other" end uses are considered to fall under the MEPS program. Given the amount of energy that these end uses consume in all the three household categories (see Table 3-8, Table 3-9 and Table 3-10 in Chapter 3), it becomes crucial to include them under this scenario.

South Africa has begun voluntary appliance labelling (DME, 2010) and the Department of Energy (DoE) has identified fridges as the first appliances to be labelled under the labelling program but labelling is not restricted to fridges, other appliances can be labelled as well. This scenario assumes that most of the appliances that fall under the "other" end uses together with refrigeration would fall within the MEPS program. For refrigeration, all households are assumed to use A+ rated fridges which have an improved efficiency of 95%[38]. Since the efficiencies of fridges used in low income households was around 60%, MEPS would result into significant energy demand reduction. For the

[38] An A+ rated fridge from one of the companies in South Africa consumed 0.975KWh/day (http://www.ardo.co.za/fr29all.htm). This translates into 0.96GJ annually. A typical high income household used 2.00 GJ of energy for refrigeration. That can result in a 52% energy saving.

"other" end use, it is assumed that all households would use A+ rated appliance. Waide et al (2003) found that efficiency improvements from a range of appliances (the appliances included washing machines, dish washers, tumble driers etc) resulted into 5% - 20% energy savings in European Union countries. For this study, it is assumed that the overall appliance efficiency improvement in appliances that achieve other end uses would be 20%, 10% and 5%, in high, middle and low income households respectively. Table 4-3 shows fridges efficiency improvements and other end uses appliance improvements.

Table 4-3: Energy Efficiency improvements

Appliances		Efficiency in 2007	Efficiency improvement	Efficiency in 2030
A+ Fridges	High	90%	5%	95%
	Middle	80%	15%	95%
	Low	60%	35%	95%
Other end uses	Low	80%	5%	85%
	Middle	80%	10%	90%
	High	80%	20%	100%

With regards to paraffin appliances, it is assumed that by 2020 all households using paraffin would be using primus stoves only. Figure 4-14 and Figure 4-15 show the penetration of fridges and other appliances for low, middle and high income households with efficiency improvements shown in Table 4-3.

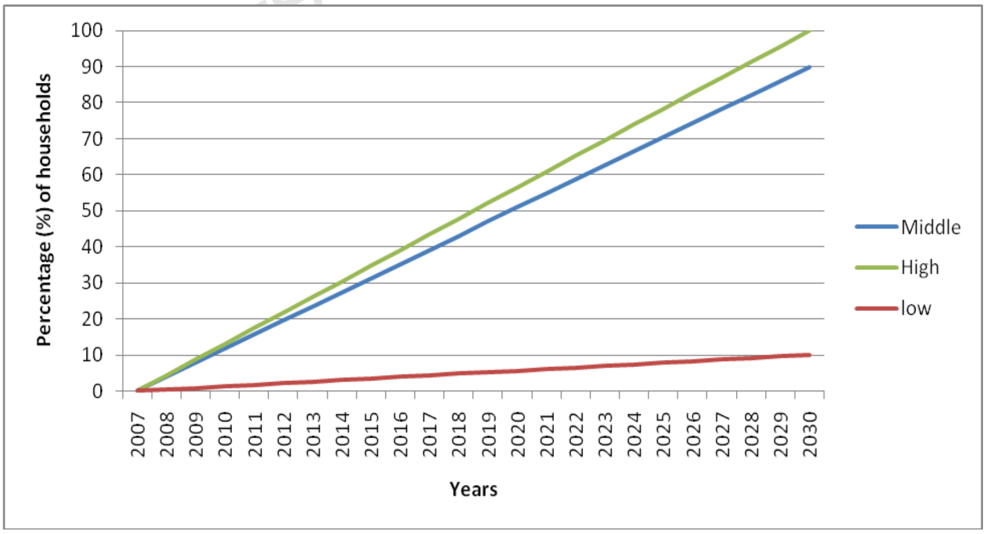

Figure 4-14 : Fridges penetration rates in all income categories from 2007 - 2030

The percentage of high and middle income households that would use efficient fridges in 2030 were assumed to be 100% and 90% respectively. Only 10% of low income households were assumed to use efficient fridges by 2030. Figure 4-15 shows the assumed penetration levels for a group of electrical appliances that are used to achieve "other" end uses in all household categories.

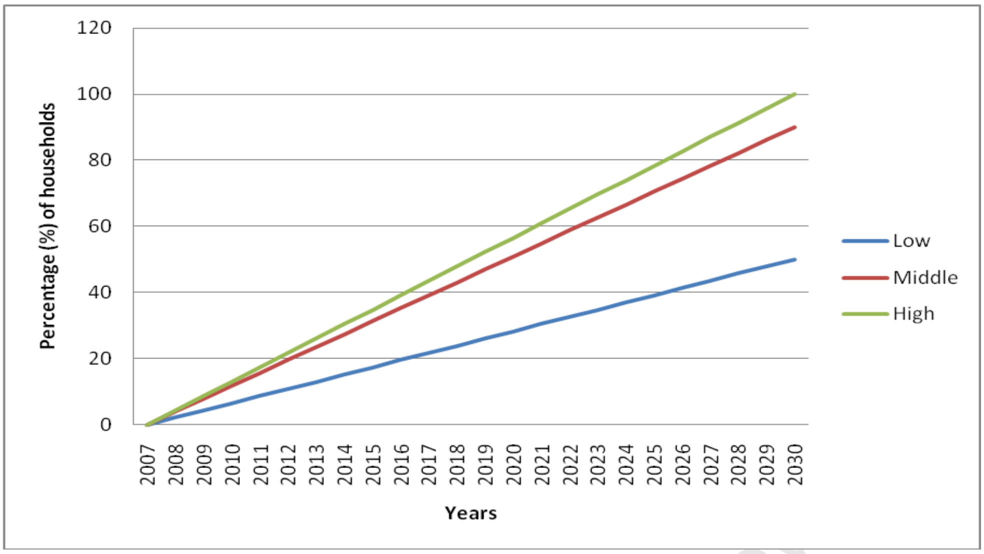

Figure 4-15: Other electric appliance penetration rates per household category

The "other" efficient appliance penetration would be 100% and 90% for high and middle income household categories. Only 50% of low income households are assumed to have efficient appliances that are used for the "other" end use in 2030. The appliance penetration rates shown in Figure 4-14 and Figure 4-15 are applied in households that use electricity only for all their energy needs.

4.6.5 Gas scenario

Background on LPG and Egoli gas usage in Gauteng

In Gauteng's residential sector, two types of gases are used – Egoli gas and LPG. Egoli gas is used only in Johannesburg while LPG is used all over the province. Simmonds and Mammon (1996) found that LPG usage was very low in Gauteng in comparison to other provinces such as Durban and the Western Cape. Egoli gas (refer to Chapter 3, Section 3.12) is used in 13 000 households in Johannesburg. Egoli Gas' 1200 km pipeline network currently covers 25% of Johannesburg and due to geological reasons; the network cannot extend beyond Johannesburg (Engineering News Online, 2008).

Currently, Egoli gas is used mainly by multiple housing units like hostels in Johannesburg's residential sector for cooking, space and water heating (Engineering News Online, 2008, DME[39], 2009).

[39]This is the Gas infrastructure plan document

But Parker (2008) reported that some high income households living in single housing units also use Egoli gas for cooking and space heating. The exact number of households living in multiple housing units in the low, middle and high income household categories as defined in this study is not known. For simplicity in the LEAP model, it was assumed that 3% and 15% of high income households used Egoli gas for cooking and space heating respectively in 2007. This study assumes that a carbon tax would be introduced between 2010 and 2030 and as a result, household would be interested in Egoli gas and invest in it. The penetration rates for both cooking and space heating were assumed to be 20% by 2030 (see Figure 4-16).

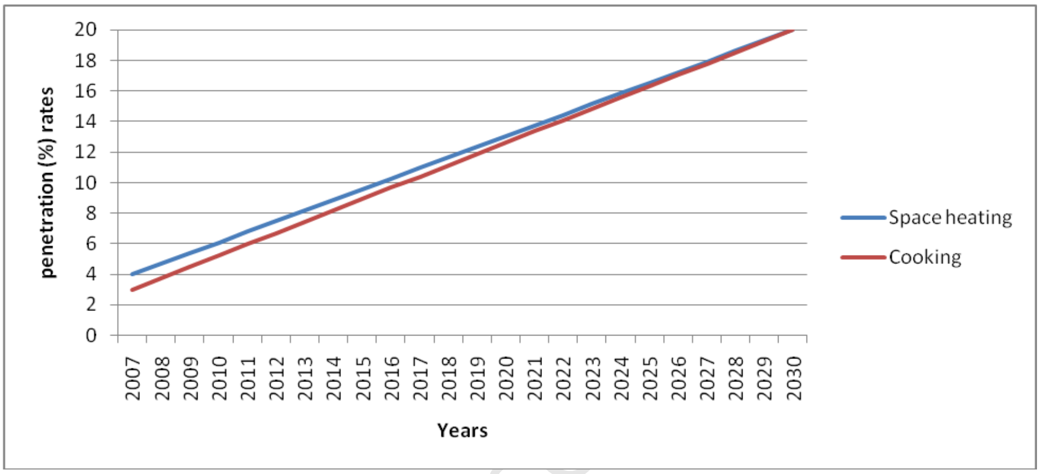

Figure 4-16: Egoli Gas cooking and space heating penetration rates

This scenario also assumes that all non electrified low and middle income households use LPG for cooking and water heating by 2030. On top of these assumptions, the scenario further assumes that LPG will be used for cooking by all electrified households which practice multiple fuel usage.

5. Results, Interpretation and discussion

5.1 Introduction

This chapter presents and interprets the results. It starts by presenting the sectoral and household energy demand together with the associated GHG emission resulting from the BASE scenario. The chapter progresses to present energy demand and greenhouse gas emissions resulting from the other scenarios relative to the Base case scenario. The pollutants emitted by coal and paraffin using households are also presented.

5.2 The Base Case energy demand

In the Base case, a steady increase in energy demand is observed for high and middle income households. For low income households, energy demand is almost constant throughout the modelling period. These energy demand trends are illustrated in Figure 5-1.

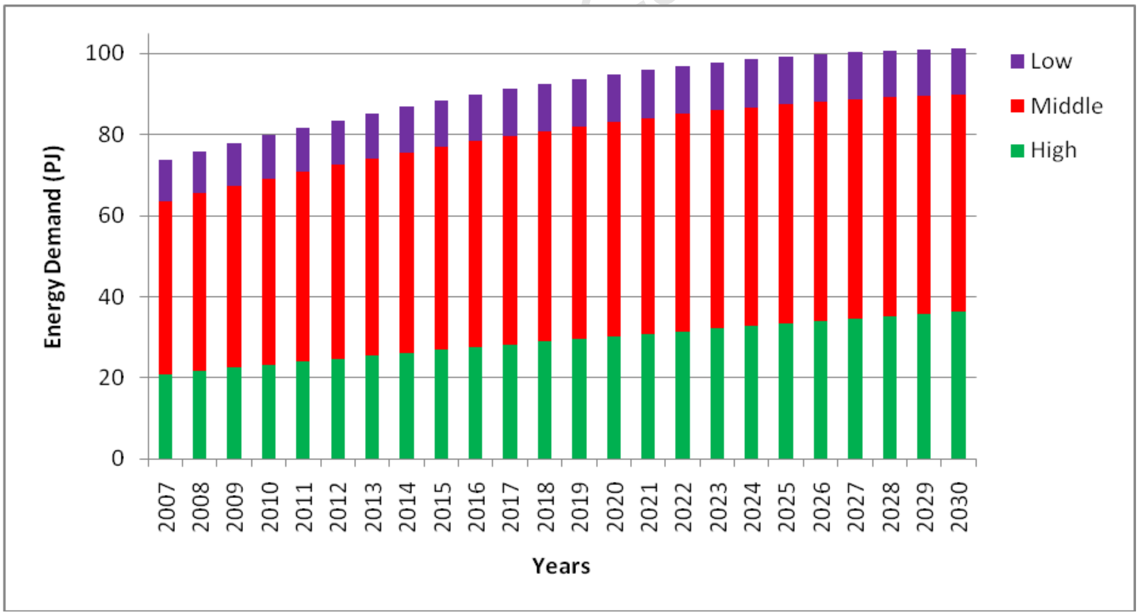

Figure 5-1 : Energy Demand by households' category

The expected growth in energy consumption in Gauteng is a result of demographic and economic changes that are likely to occur in the province. These changes were thoroughly explained in Chapter 4. More energy was consumed by middle income households. 58% and 53% of energy demand was consumed by middle income households in 2007 and 2030 respectively. High income households increased their energy demand share by 8% between 2007 and 2030 while low income households decreased their energy demand share by 2% between 2007 and 2030.

Given the fact that the number of high and low income households increased by 4% and 2.88% respectively, it would be expected that their energy demand share would also increase. But the low and middle income households experienced reduced energy demand by 2030. The reduction occurred because it was assumed that these households abandoned coal use for electricity and LPG to do cooking and space heating. Abandoning coal use resulted in a dramatic decrease in energy demand in both middle and low income households because households that used coal used more energy than households that used LPG and electricity. For example if a low income household abandoned coal for space heating and instead used electricity, this would reduce its energy demand by 22.66 GJ, since 1.37 GJ (see Table 3-8) of energy is required when space heating with electricity whereas 24.06 GJ (see Table 3-13) of energy is required if coal is used for space heating.

The final energy demand for high income households grew by 0.67 PJ every year between 2007 and 2030. Final energy demand in the middle income category grew by 0.49 PJ annually in the period 2007 – 2030. The final energy demand consumed by low income households grew by 0.05 PJ annually.

5.2.1 BASE Case fuel demand

In the BASE case, electricity would still be the preferred fuel in Gauteng's residential sector by 2030. Figure 5-2 shows that electricity demand increased drastically while the demand for other fuels decreased.

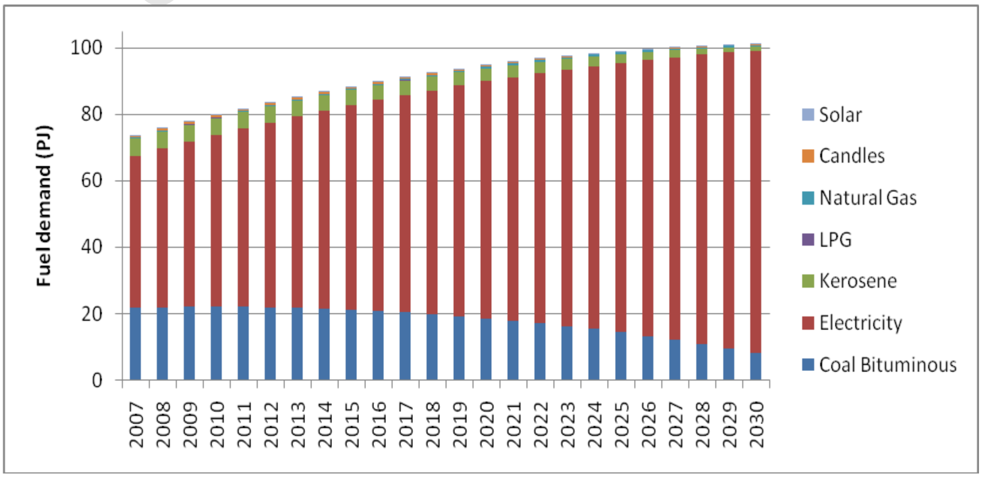

Figure 5-2 : Final Fuel Demand

Figure 5-1 and Figure 5-2 demonstrate that the total final energy demand in Gauteng's residential sector can increase to 99.8 PJ in 2030. The demand for all other fuels, except electricity is expected to be 2.3 PJ in 2030 while the demand for electricity would be 97.3 PJ. 55%, 42% and 3% of the electricity is consumed by the high, middle and low income household categories respectively. The increase in electricity demand is associated with dramatic decline in coal and paraffin energy demand. The decline in energy demand from other fuels occurs because every 5 years, 5% of households were assumed to abandon multiple fuel use. 92% and 82% of middle and low income households used electricity exclusively for all their end uses in 2030.

Although solar, candles, natural gas and LPG contributed a very small share of energy demand, Figure 5-3 shows that natural gas and solar energy demand were increasing with time. The scale of Figure 5-2 is large to see the energy demand growths and decline of candles, natutal gas and LPG. Figure 5-3 shows the energy demand for these fuels at a lower scale hence the changes can be seen more clearly than they were in Figure 5-2.

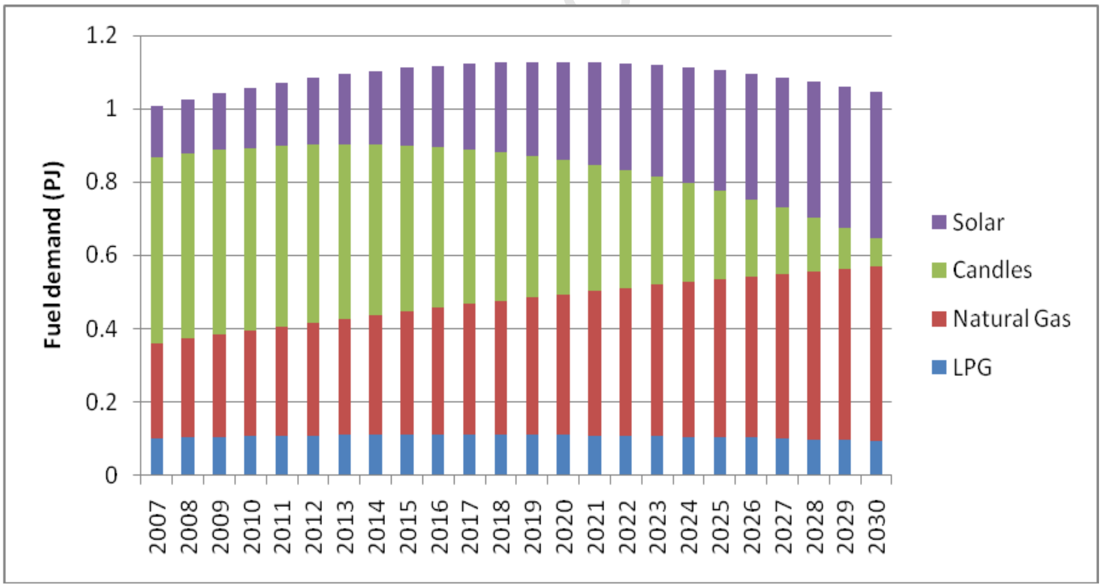

Figure 5-3: Solar, Natural Gas, LPG and candles energy demand 2007 - 2030

Figure 5-3 shows that the demand for LPG was almost constant throughout 2007 – 2030 while the demand for candles (non energy) decreased over the same period. Section 5.3 presents BASE case GHG and pollutants emissions that resulted from the fuel use trends shown in this section.

5.3 BASE case emissions

5.3.1 GHG emissions

If South Africa does not make significant changes in the electricity generation technologies (such as increasing renewable energy uptake), increasing electricity demand will result in increased emissions. Figure 5-4 shows the CO_{2equiv} emitted by Gauteng's residential sector between 2007 and 2030. The amount of $CO_{2\text{-}equiv}$ emitted almost doubled between 2007 and 2030.

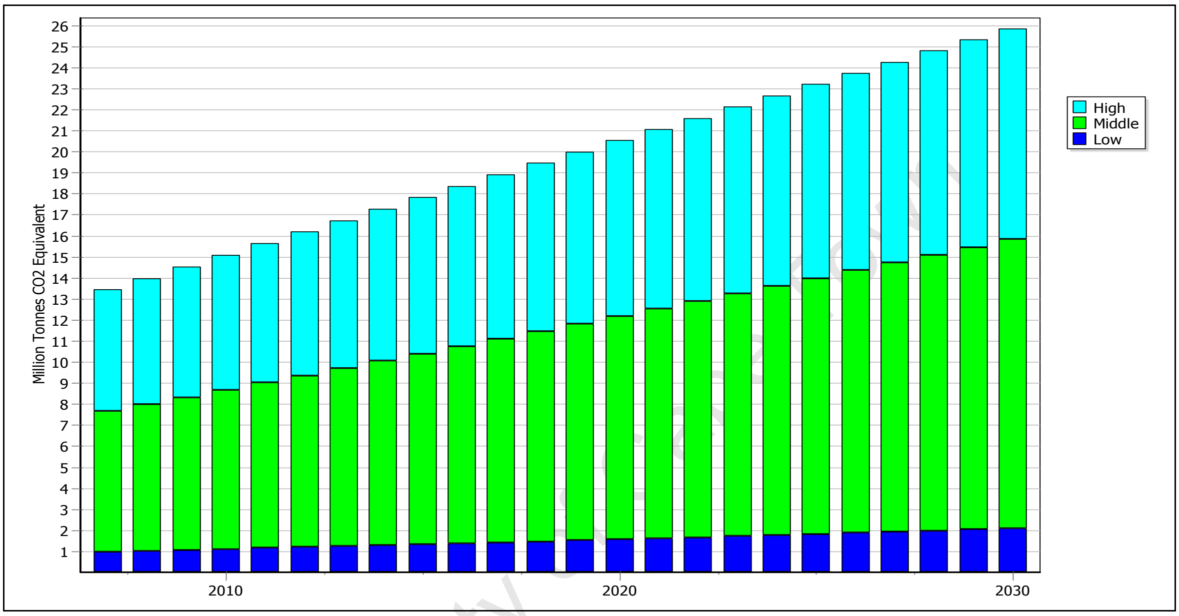

Figure 5-4: BASE case scenario $CO_{2\text{-}equiv}$ in Gauteng residential sector

As with the energy demand share, middle and high income households had higher emissions. Figure 5-5 shows that electricity contributed more than 95% of $CO_{2\text{-}equiv}$ emissions in both 2007 and 2030.

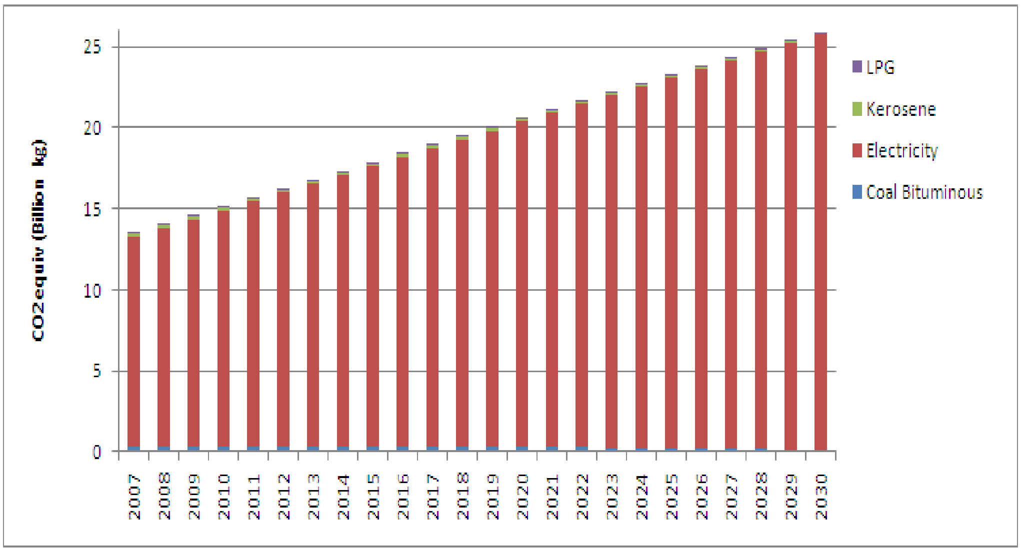

Figure 5-5: $CO_{2\text{-equiv}}$ emissions by fuel type in 2007 -2030

Coal contributed 2.2% and 0.4% of $CO_{2\text{-equiv}}$ emissions in 2007 and 2030 respectively. Figure 5-6 shows the changes in GHG emissions that came from LPG, coal and kerosene, because these changes could not be seen clearly in Figure 5-5.

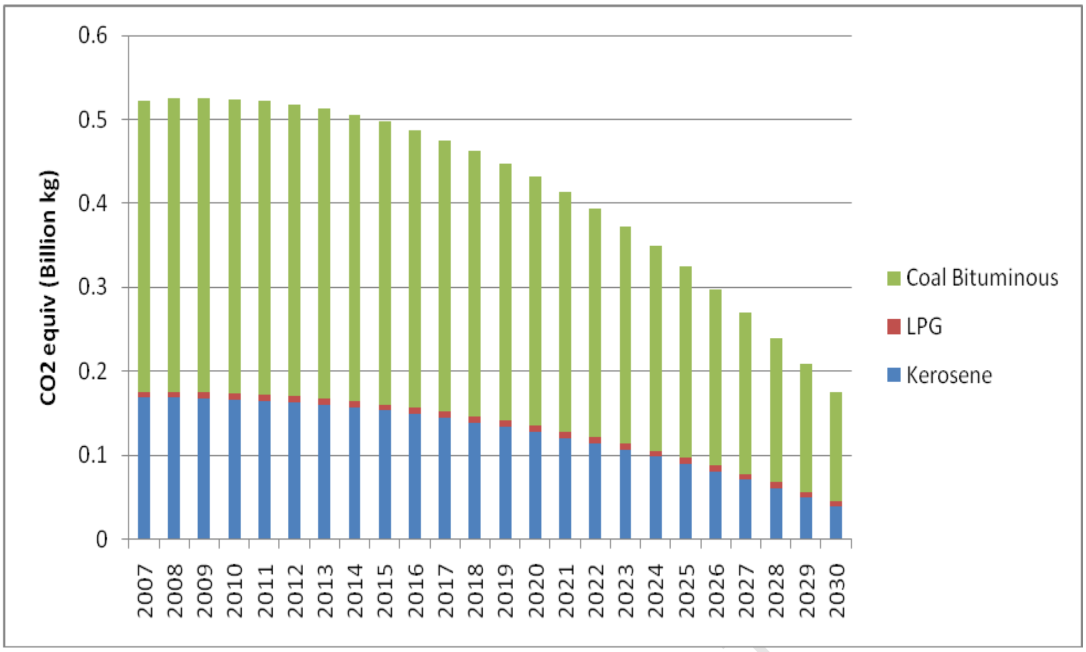

Figure 5-6: GHG emissions associated with LPG, illuminating paraffin and coal use

Figure 5-6 shows that LPG contributed a very small amount of CO_{2equiv} relative to paraffin and coal and the emissions have been constant from 2007 till 2030. GHG emissions from other fuels decreased but GHG emissions from electricity increased. The promotion of solar energy and LPG in Gauteng's residential sector would contribute to reduced GHG emissions. If these sources of energy are used, electricity use would decrease and GHG emissions would be reduced. Figures 5-4, 5-5 and 5-6 show annual GHG emissions, but when considering the build up of these gases in the atmosphere up to 2030, Gauteng's residential sector would have emitted almost 480 million tonnes of CO_{2equiv} as shown in Figure 5-7.

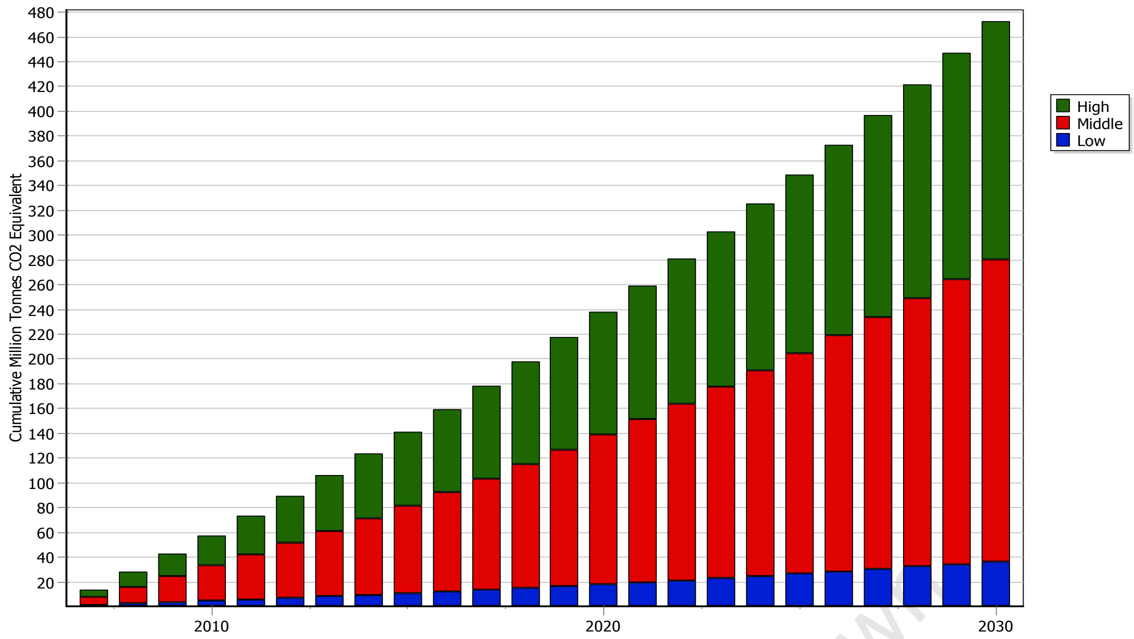

Figure 5-7: Cumulative emissions

5.3.2 Pollutant emissions

Air pollution is a major problem that undermines sustainable energy use in households that still use coal and paraffin. Figure 5-8 shows the pollutants produced from fuel use in Gauteng households over the modelling period 2007 – 2030.

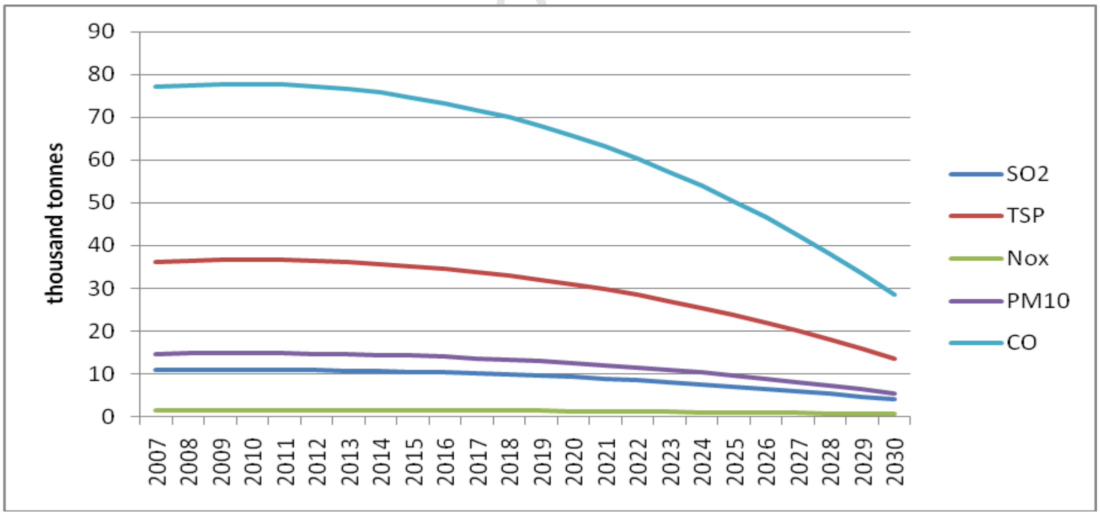

Figure 5-8: Pollutants from all household

Almost all of the pollutants shown in Figure 5-8 occurred in middle and low income households with three quarters of the pollutants coming from middle income households. 76% of CO, SO_2 and TSPs were emitted by middle income households while 24% of pollutants were emitted by low income households. 75% and 74% of PM_{10} and NOx emissions were emitted by the middle income households. The decline in pollutant emissions shown in Figure 5.8 was associated with a decline in coal use as 5% of low and middle income households were assumed to abandon coal use every 5 years. Households that still used coal in 2030 were assumed to practice the Basa Njengo Magogo which reduces emissions by almost 50%.

5.4 BASE CASE energy demand comparison with other scenarios

Figure 5-9 shows energy demand per scenario from 2007 to 2030.

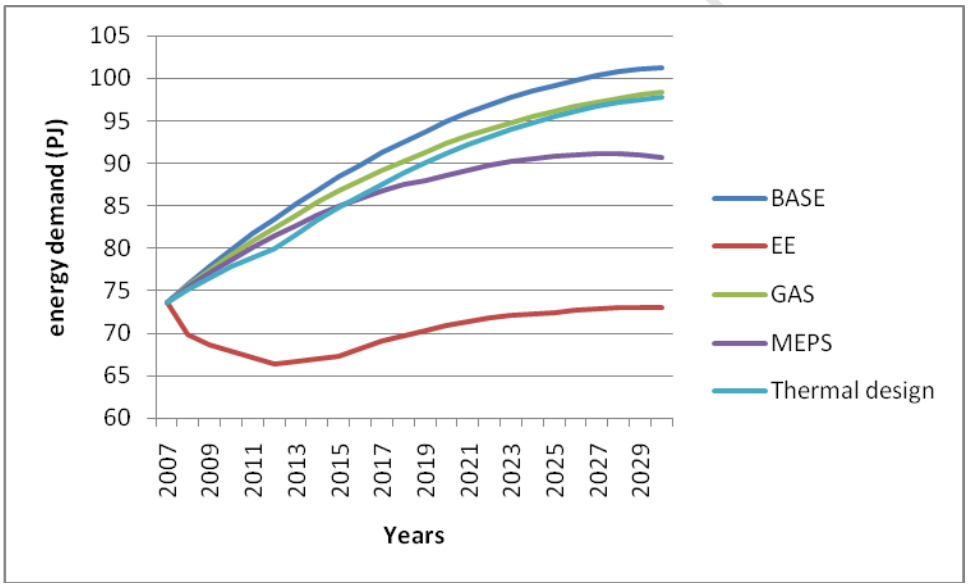

Figure 5-9: Sectoral final energy demand per modelled scenario

The energy efficiency (EE) scenario resulted in the greatest energy savings, followed by the minimum energy performance standards (MEPS), thermal design and GAS scenarios. The EE scenario reduced energy demand by 36% by 2030. The EE scenario is made up of three energy efficiency measures and one energy conservation measure. The energy efficiency measures are – the increased use of CFL's for lighting, Basa Njengo Magogo and solar water heating and the energy conservation measure was the ceiling and insulation installation.

The scenarios shown in Figure 5-9 achieve different energy savings in the three households' categories. Figure 5-10, Figure 5-11 and Figure 5-12 give the impacts of each scenario in the low, middle and high income households' categories.

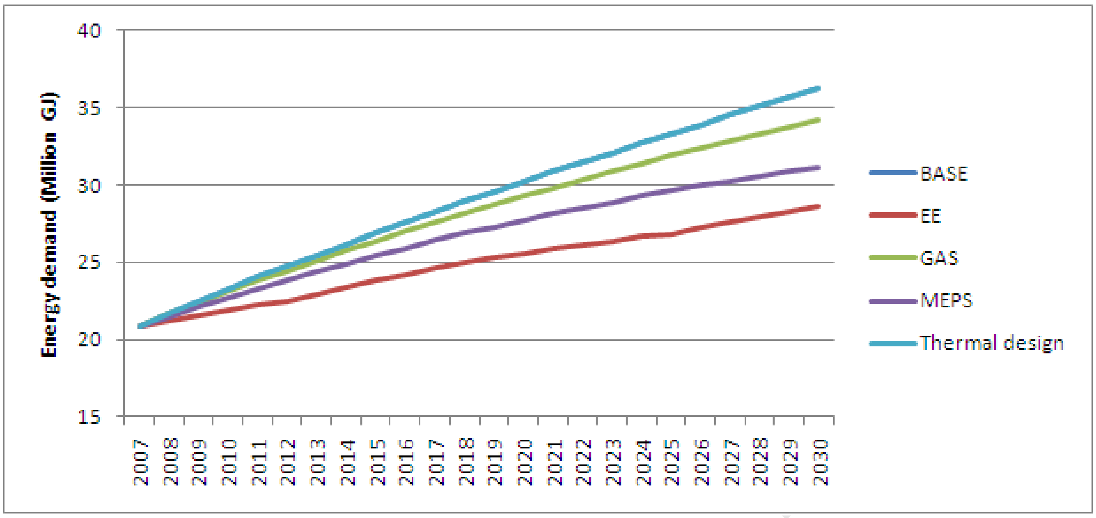

Figure 5-10: Scenarios performance in high income households

Figure 5-10 shows that the energy demand of the high income household category increased in all scenarios. The EE scenario showed the slowest growth rate in energy demand growth, followed by the MEPS and GAS scenarios. The EE scenario increased annual energy demand by 1.6% while the GAS and MEPS scenarios increased by 2.78% and 2.14% respectively. The BASE case resulted in 3.2% annual energy demand increase. Relative to the Base case scenario, the EE, GAS and MEPS scenarios saved 21%, 5.5% and 14% of energy demand in 2030. Figure 5-11 shows the impacts the different scenarios had on energy demand in middle income household category.

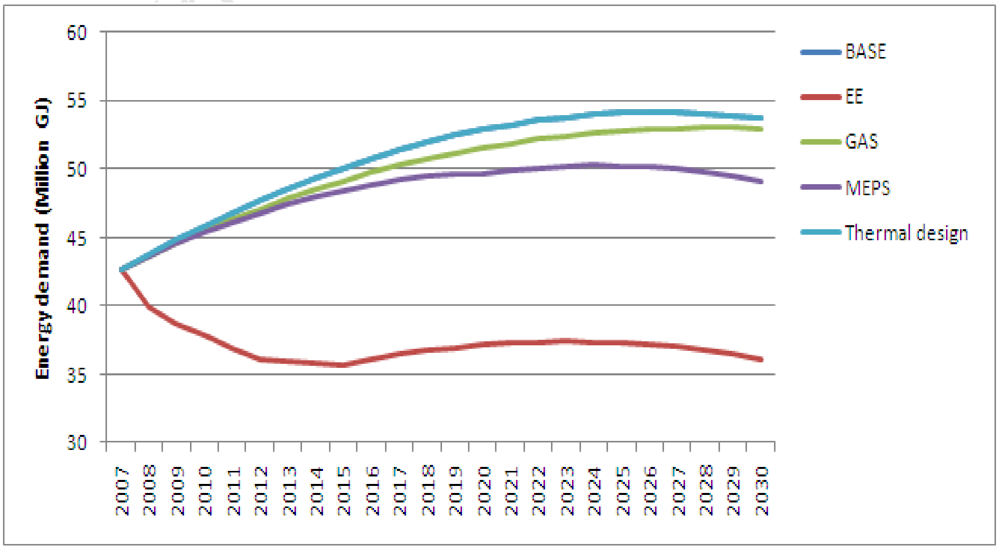

Figure 5-11: Scenario performance in middle income households

Despite the fact that the number of households and population were increasing, Figure 5-11 shows that the EE scenario has the potential to reduce energy demand below the base year energy demand. In 2007, middle income households consumed 43 PJ. The EE scenario reduced the demand to 36 PJ in 2030. In 2030, the Gas and MEPS scenarios reduced energy demand by 1.4% and 8.6% respectively relative to the BASE case.

Figure 5-12 presents impacts of scenarios on energy demand in low income households' category.

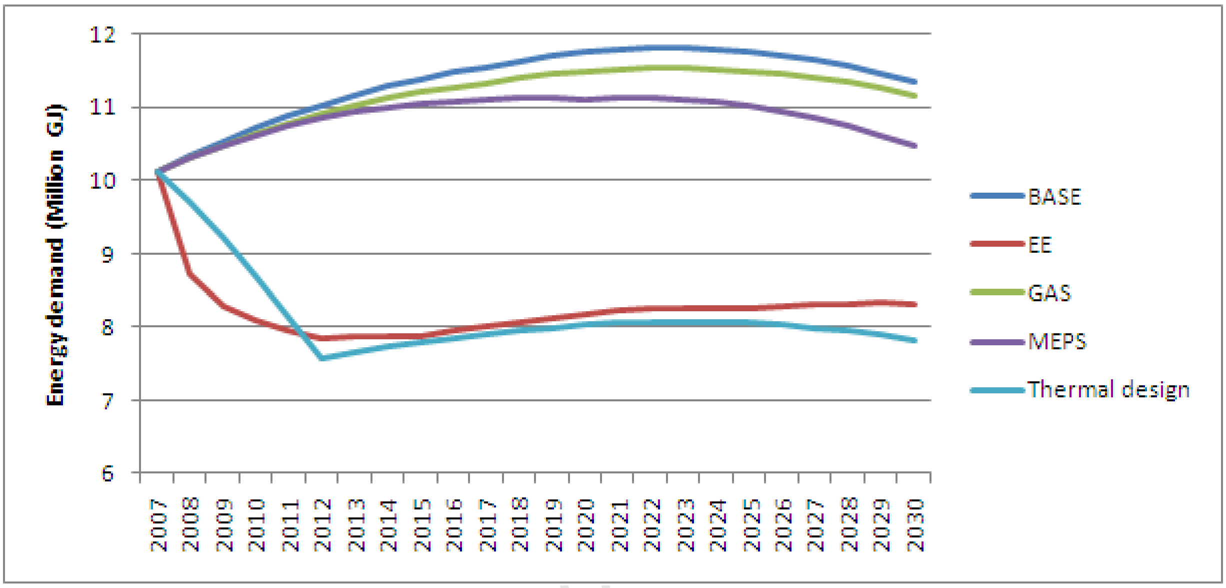

Figure 5-12: Scenario performance in low income households

In low income households, both the thermal design and the EE scenarios have the potential to reduce energy demand to a value below the base year energy demand. The EE and thermal design scenarios have the potential to reduce base year energy demand by 18% and 23% respectively. The MEPS and GAS scenarios reduced energy demand by 1.6% and 7.6% respectively relative to the BASE case.

The energy reduced in the low income households is not always desirable since, low income households already have suppressed energy demand. To attain an improved standard of living, sometimes low income households have to increase their demand. But even if the energy demand in low income households is increased, the EE scenario would still save energy relative to what would have happened if no EE was implemented.

If all the scenarios that are modelled in this work are implemented in Gauteng' residential sector, coal demand would decrease together with illuminating paraffin. Figure 5-13 shows the demand for fuels if all the modelled scenarios are implemented.

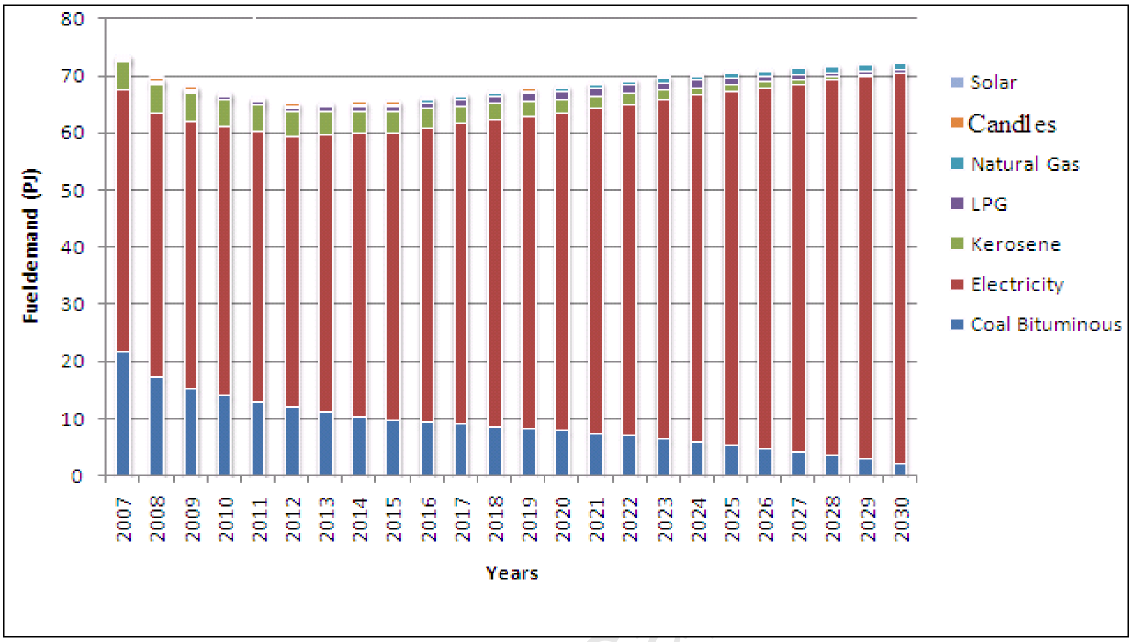

Figure 5-13: Fuel demand if all scenarios are implemented

Solar and natural gas would contribute small shares of energy demand. Although, there is an increase in solar and natural gas energy, the rates at which these fuels make contributions are very slow. Figure 5-14 shows energy demand for LPG, natural gas, solar and candles (non-energy).

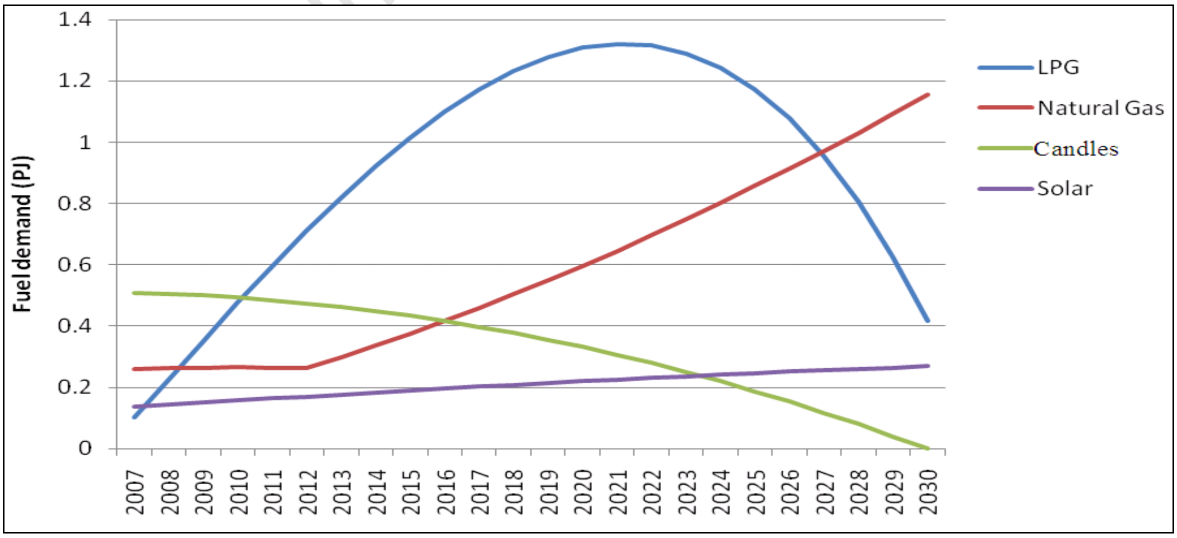

Figure 5-14: Changes in LPG, natural gas, solar and non energy demand

Figure 5-14 shows that LPG demand initially increased rapidly and then declined after 2020. The input assumptions are responsible for this trend. It was assumed that LPG was used by non electrified households and that as time went on and more and more households were electrified LPG usage would drop. Both Natural gas and solar energy demand are increasing slowly but steadily. By 2030, candles (non energy) would not make any contribution to the energy demand in the residential sector.

5.5 GHGs and pollutants emissions comparisons between scenarios

Section 5.4 showed that the EE scenario saved more energy than all other scenarios, the expectation is therefore that the EE scenario would also reduce more $CO_{2\text{-equiv}}$ emission than the other scenarios. Figure 5-15 shows potential for $CO_{2\text{-equiv}}$ reduction of all the modelled scenarios.

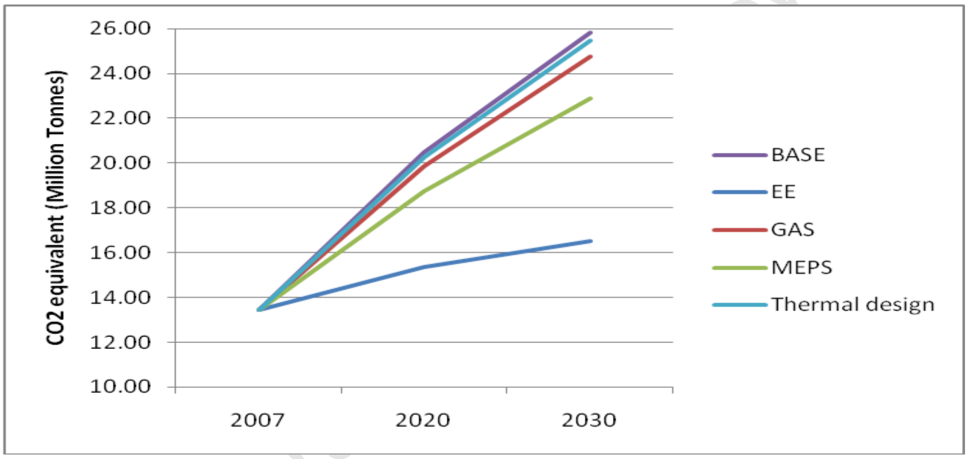

Figure 5-15: Sectoral $CO_{2\text{-equiv}}$ emissions per scenario

The EE scenario outperforms the other scenarios in its ability to reduce $CO_{2\text{-equiv}}$ emissions. Figure 5-16, Figure 5-17 and Figure 5-18 present the potential of this scenario to reduce $CO_{2\text{-equiv}}$ in high, middle and low income households.

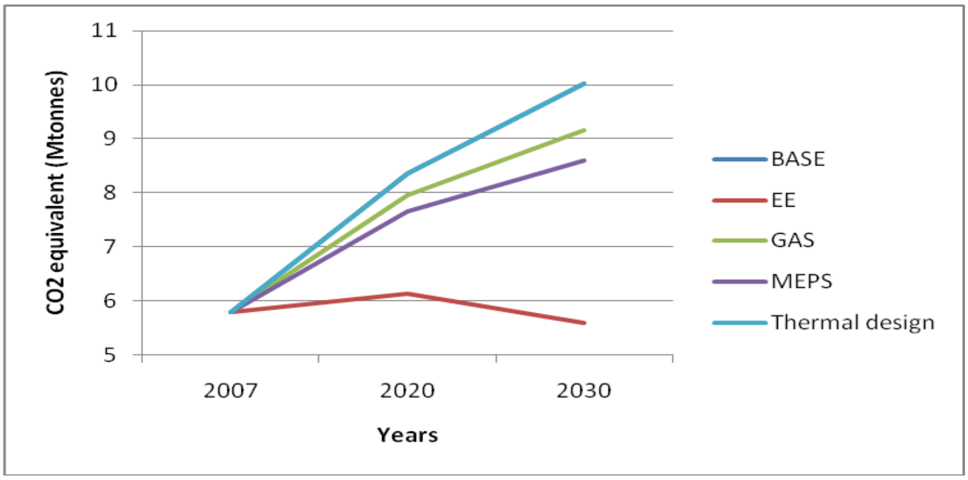

Figure 5-16: High income households' $CO_{2\text{-equiv}}$ emissions per scenario

The EE scenario reduced $CO_{2\text{-equiv}}$ emissions to below the base year value in 2030. Both the MEPS and GAS scenarios showed increased $CO_{2\text{-equiv}}$ emissions but the increase was at a lower rate than in the BASE case scenario.

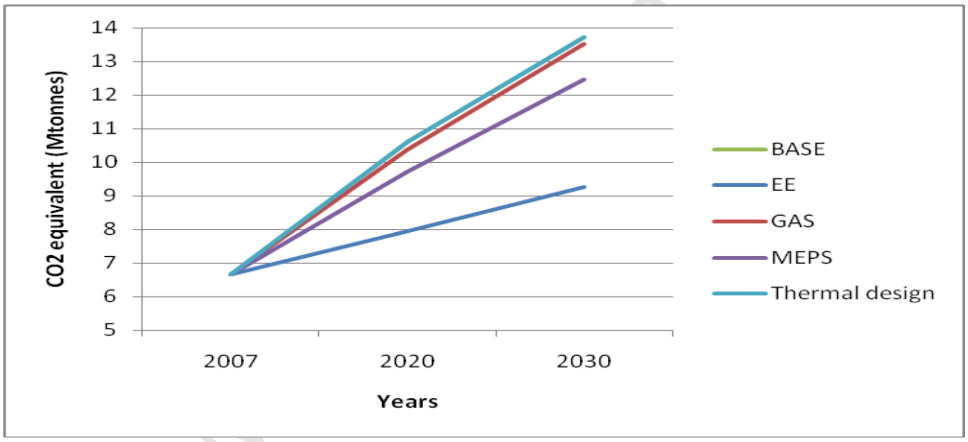

Figure 5-17: Middle income households' $CO_{2\text{-equiv}}$ emissions per scenario

The EE scenario out performed the other scenarios in terms of reducing energy related emission in middle income households, but the emissions of each scenario increased over the modelling period. The upward trend of $CO_{2\text{-equiv}}$ emissions shown by the EE scenario in Figure 5-17 presents a different $CO_{2\text{-equiv}}$ emission trend to that shown by high income households in Figure 5-16. The reason for this difference is due to the input assumption that high income households would be aggressive in their uptake of SHWs compared to middle income households (70% of high income households were assumed to have SWHs in 2030 while 30% of middle income households were assumed to have SWHs in 2030).

Figure 5-18 shows that the thermal design and EE scenarios resulted in the largest $CO_{2\text{-equiv}}$ emissions reduction in low income households.

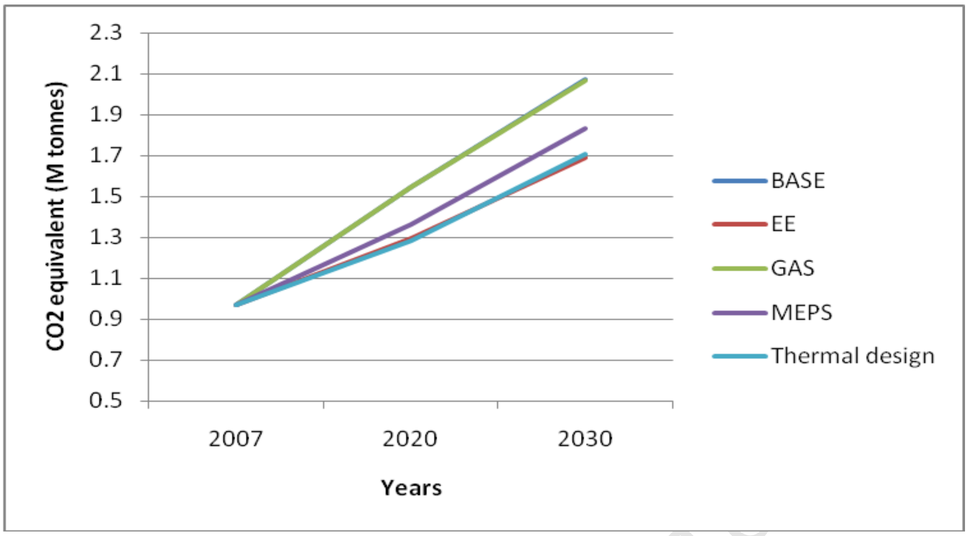

Figure 5-18: Low income households $CO_{2\text{-equiv}}$ emissions per scenario

When the thermal design scenario is implemented in households, it was assumed that these households would abandon coal use. Given the high amount of coal consumed in households that use coal, abandoning coal would also mean significant reduction in associated emissions.

It is clear from Figure 5-18 that both the EE and the thermal design scenarios have similar potential to reduce $CO_{2\text{-equiv}}$ emissions in low income households. The changes in fuel consumption resulted in changes in the amount of pollutants emitted. Figure 5-19 shows the pollution avoided if all the scenarios were implemented in Gauteng's residential sector. These avoided pollutants are measured relative to the base case.

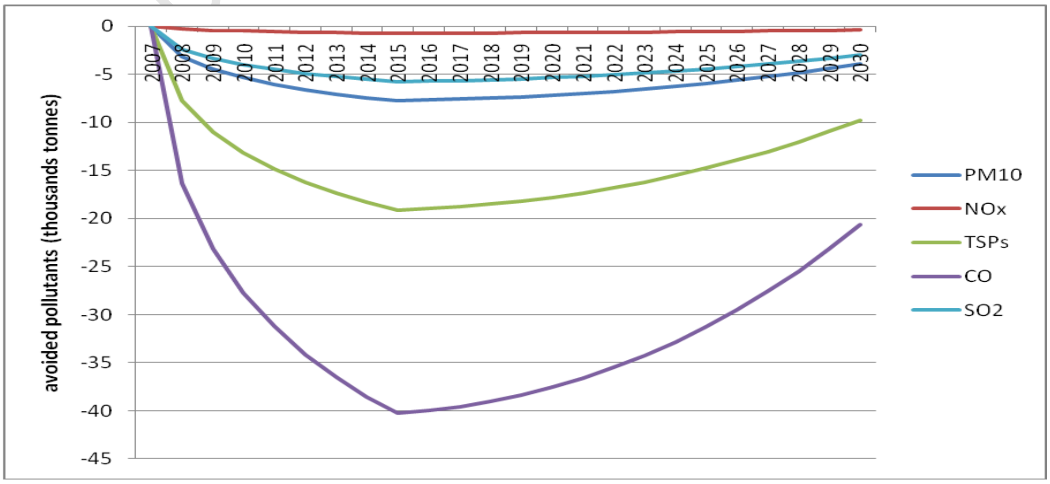

Figure 5-19: Avoided pollutants relative to the base case

There was a rapid decline in carbon monoxide and total suspended particulate matter between 2007 and 2015, after 2015, the emissions increased. The rapid decrease of CO and TSPs shown in Figure 5-19 was a result of people practicing Basa Njengo Magogo and due to abandoning of coal use in thermally designed households. The avoided CO and TSPs decreased beyond 2015 because there were no major interventions that occurred in coal using households after 2015. The emission increased after 2015 due to the increase in number of households.

5.6 Conclusion

This chapter has shown that the EE scenario reduced both energy and emissions more than any other scenario in all household categories. Thermal design scenario reduced energy demand similarly to the EE scenario in low income households. The EE scenario respectively saved 27%, 33% and 22% of energy demand in low, middle income and high income households respectively relative to the Base case by 2030. In terms of emissions, the EE scenario reduced more $CO_{2\text{-equiv}}$ in high and middle income households than in low income households. In low income households the thermal design scenario reduced 0.4 Mega tonnes of $CO_{2\text{-equiv}}$ more than other scenarios.

The MEPS scenario resulted into small energy demand growth rates across all household categories. The annual energy demand growth rates in MEPS scenario were 0.15%, 0.65% and 2.14% in low, middle and high income households respectively. The energy demand reduced by GAS scenario was small across all household categories. By 2030, the GAS scenario reduced energy demand by 0.3 PJ, 0.7 PJ and 0.2 PJ in high, middle and low income households respectively relative to the BASE case.

Although these scenarios reduce energy demand and emissions, it is also essential to understand their financial implications and their contribution to sustainable energy use as defined in Chapter 1, Section 1.1. The next chapter assesses the implications of the modelled scenarios to sustainable energy use.

6. Implications of sustainable energy use

6.1 Introduction

This chapter assesses the implication of the modelled policies on Gauteng's residential sector. It starts by presenting and explaining the energy indicators that were used to assess sustainable energy use.

6.2 Indicators for sustainable energy use

The energy indicators that were used to measure sustainable energy use are shown in Table 6-1.

Table 6-1: Sustainable energy indicators for Gauteng residential sector

SOCIAL				
Theme	Energy Indicator	Symbol	Assessment level	Sustainability target
Accessibility	Share of households with electricity	SOC1	Sector	100% electrification anticipated by 2012 (DME, 2005)
ECONOMIC				
Prices	End use energy prices by fuel	ECO1	Household	Make clean energy affordable (1998, Energy White Paper)
EMISSIONS				
Atmosphere	Climate Change	ENV1	Sector	According to DEAT and GPG emissions have to be minimal from all sectors of the economy
Atmosphere	Air Pollution	ENV2	Household	Local air quality has to conform to SANS 1929:2005

Source: derived from Energy Indicators for Sustainable Development: Guidelines and Methodologies by IAEA

Table 6-1 presents the four energy indicators used in this study to assess sustainable energy use in Gauteng's residential sector. There is one social indicator (SOC1), one economic-energy indicator (ECO1) and two environmental-energy indicators (ENV1 and ENV2). SOC1 is a measure of the percentage of households that are connected to the grid. ECO1 compares the cost of fuels, together with the cost of investment associated with different scenarios to the households. ENV1 measures general GHG emissions from the residential sector; ENV2 measures the 4 most significant pollutants resulting from paraffin and coal use in Gauteng households - sulphur dioxide (SO_2), carbon monoxide (CO), PM_{10} and total suspended particulate matter (TSPs). ENV1 and SOC1 are sector level indicators while ENV2 and ECO1 are household level indicators.

6.3 Dimensions of sustainable development

Sustainable energy use and production helps a region (country, province, village etc) achieve its goals of sustainable development. Section 1.1 in Chapter 1, explained that a sector where the three dimensions[40] of sustainable development can be assessed is the residential sector. Winkler (2005, 2009), identified the three dimensions as the social, economic and environmental aspects of development. The energy indicators in Table 6-1, which are chosen to aid the analysis of sustainable energy use in this study, fall under these three dimensions of sustainable development. The inter-linkages between the three dimensions of sustainable development are strong in the residential sector. In simple terms, the link is as follows; the energy used within households should be affordable and should not harm the environment and people's welfare.

6.3.1 Social dimension

Usually, the social dimension assesses the impacts of energy use on the welfare of the members of the households (Winkler, 2005, Winkler, 2006, Prasad, 2006). From the available literature, the welfare and living standards within households are compromised when the people are exposed to dangerous pollutants resulting from the use of coal and sometimes paraffin (DEAT, 2004; Horen, 1994). The air pollution resulting from the use of these fuels put people at risk of acquiring pulmonary diseases (Terblanche, 1992). Since the direct health impacts of energy use cannot be measured in this study, the social dimension of sustainable development only measures access to electricity. This study assumed that electrification determines what fuels are used within households. 5% of households were assumed to abandon the use of dirty coal and paraffin every 5 years. As households reduce the use of dirty fuels the health problems associated with pollution from energy use could be reduced. In addition, Winkler (2009) and Prasad (2006) argue that access to electricity serves as an enabling factor to poverty eradication, although it does not directly eradicate it. Therefore, promoting greater access to electricity which is clean at the point of use is

[40] In chapter 1 it was shown that sustainable development has three dimensions – which are social, environmental and economic.

essential to sustainable use of energy.

6.3.2 Economic dimension

The economic indicator (ECO1) is used to compare the costs of using certain fuels within low income households. It highlights which multiple fuel use combinations make economic sense in low income households. The indicator is further used to analyse the financial implications of the EE scenario on a typical low, middle and high income household.

6.3.3 Environmental dimension

The environmental dimension assesses the impact of energy use on the environment (local pollution and global GHG). The impacts of GHG's (ENV1) on the environment are assessed at sector level while pollutants (ENV2) are assessed at household level. ENV2 is considered a household level indicator because Spalding-Fecher (2003), Scorgie (2003) and Mathee (2004) showed that the most critical problems of air pollution occur at the household level, – from consumption of fuels such as coal and paraffin for cooking, heating and lighting, rather than large-scale industrial use. This study does not quantify the impacts, but just presents absolute pollutants emissions resulting from fuel use in the scenarios.

6.4 Understanding the challenges of assessing sustainability

Sustainability targets present a challenging phenomenon in the residential sector, because high income households have higher demand for energy services than lower income households. Although all households need a basic level of energy service for all the end uses (cooking, space heating, lighting, water heating etc), there is no single desired energy service value that would be considered sound in sustainability terms. Apart from that, some energy efficiency interventions have inherent benefits which cannot be quantified. For example Boardman (1991) identified that 60% of energy efficiency improvements in low income households contributed to improved living standards.

The absolute values of environmental indicators cannot measure sustainability well, because pollutants become dangerous if the ventilation is not good enough. For example a household burning coal in a stove/mbawula burning within a house can emit 20g of PM_{10} and if the house is well ventilated, the house would not have dangerous levels of pollution. However, if another household burning coal in a stove/mbawula produced the same 20g of PM_{10} within a house with poor ventilation, there may be dangerous concentrations of PM_{10}. The example given above shows how the environmental indicator – ENV2 can be subject to living conditions in the residential sector.

6.5 Assessment of sustainable use of energy at sector level

When assessing sustainable energy use at a macro level, the following two questions are answered:

1) To what extend do the modelled scenarios help Gauteng's residential sector reduce its energy use and related GHG emissions.
2) How many households have been electrified in Gauteng by 2030?

Chapter 5 showed that the BASE case is characterized with high GHG emissions, high energy use and a high percentage of both low and middle income households relying on dirty fuels (coal and paraffin). Chapter 5, Section 5.4 showed that the EE scenario reduced more energy use than any other scenario across all household categories.

Figure 6-1 provides normalised comparison of energy consumption between scenarios.

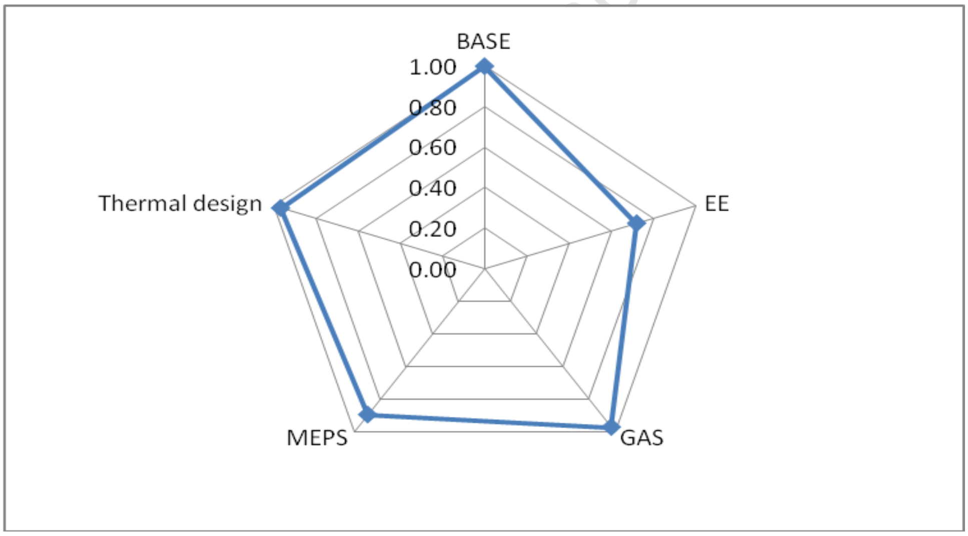

Figure 6-1: Performance of scenarios in their ability to reduce energy demand by 2030

Figure 6-1 shows that almost 25% and 10% of energy demand was saved by the EE and MEPS scenarios respectively relative to the BASE case. The GAS and thermal design scenarios differed slightly from the Base case and did not reduce energy demand significantly.

The reduced energy demand shown in Figure 6-1 was accompanied with reduced GHG emissions. Figure 6-2 shows the normalised reduction of GHG emissions in the scenarios relative to the BASE case.

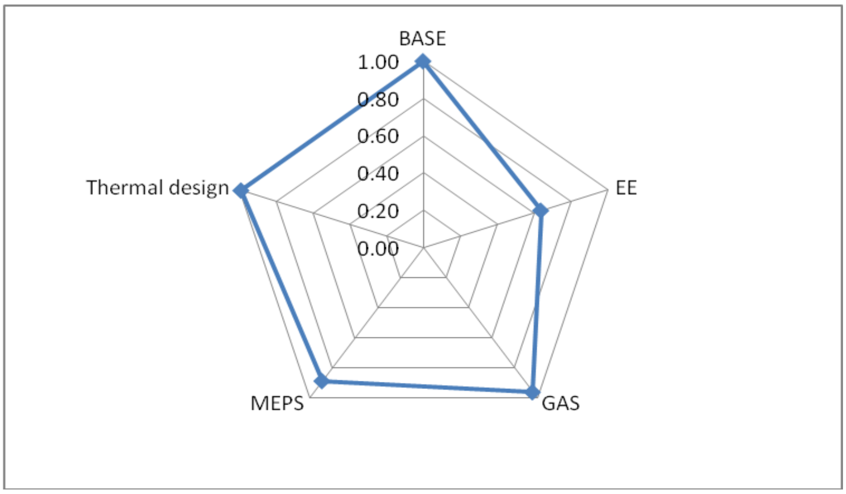

Figure 6-2: Comparison of scenarios in GHG emissions reduction impact by 2030

The EE scenario outperformed the other scenarios in terms of avoided $CO_{2\text{-equiv}}$. Figure 6-2 shows that the EE scenario has the potential to reduce 35% of the GHG emissions emitted by the BASE case. Figure 6-3 shows the performance of the modelled scenarios in terms of SOC1.

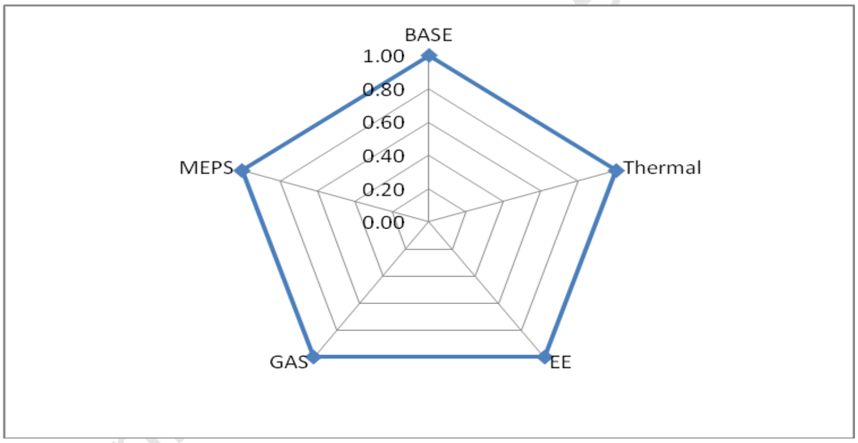

Figure 6-3: SOC1 performance relative to the BASE case

Electrification levels were the same in all the scenarios, which is why all scenarios were at 1 relative to the BASE case scenario. The next section analyses sustainable energy use at household levels using the two indicators ENV2 and ECO1.

6.6 Assessment of sustainable energy use at the household level

6.6.1 Performance of ENV2

One of the major challenges faced by households that use coal is air pollution. In middle and low income households, SO2 and PM10 and TSPs were quantified for households that used paraffin, LPG and coal. Table 6-2 presents emissions of the modelled pollutants for each scenario in 2030.

Table 6-2: Absolute pollutants emissions for different scenarios in 2030

Indicator		BASE	Thermal	EE	GAS	MEPS
ENV2 ('000 tonnes)	CO	28.5	20.6	8.30	26	28.5
	SO_2	4	2.8	1.08	3.80	4
	TSPs	13.5	9.70	3.91	12.7	13.5
	PM10	5.5	3.9	1.60	5.20	5.5
	NOx	0.55	0.40	0.17	0.54	0.6

Table 6-2 shows that the EE scenario would have the least of all pollutant emissions in 2030. Because the household mobility[41] was the same for all the scenarios, the reduced pollutants emissions are due to the improved energy efficiency in energy use between the different scenarios.

Figure 6-4 shows the relative performance of the modelled scenario in their ability to reduce the identified pollutants.

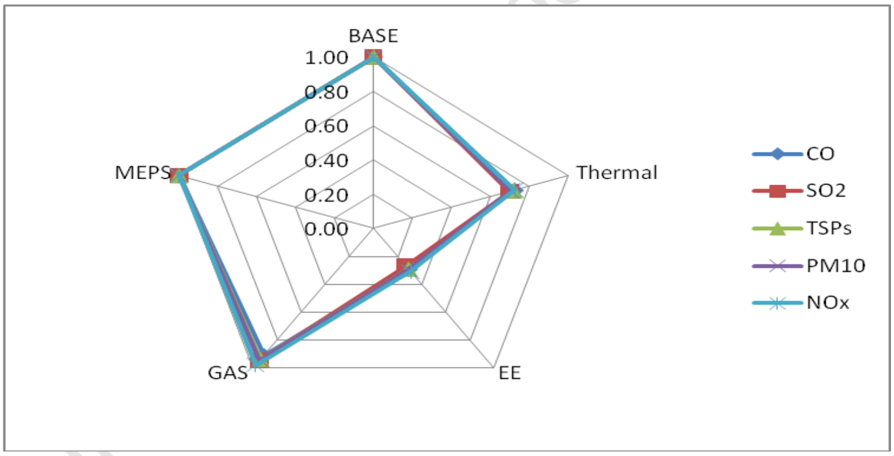

Figure 6-4:ENV2 performance on sustainability scale

The EE scenario reduced all the pollutants similarly relative to the BASE case. Given the fact that all pollutants except CO, were emitted in low and middle income household categories, Figure 6-4 shows that both the Thermal Design and EE scenarios are important scenarios in multiple fuel using households. The Thermal Design scenario reduced more pollutant in low income households only, as the scenario was applied in low income households only, while the EE scenario reduced pollutants

[41] There were 3 forms of mobility in the modelling. The first one being, the households that abandoned dirty fuel use, households that moved from low income category to higher income category and finally households that moved from non electrification to electrification status

in both middle and low income households hence why the overall pollutants reduced by EE scenario exceeded those reduced by the Thermal Design scenario.

6.6.2 Performance of economic indicator (ECO1)

Winkler (2009) stressed that when assessing sustainable energy use in the residential sector it is better to assess the cost of cooking rather than just assessing the household's access to electricity. For the purpose of this work, an economic indicator (ECO1) is used to assess which scenarios lower energy expenditure in different households' categories with more emphasis in low income households.

The emphasis on the assessment of this indicator at the micro level is put on low income households, as middle and high income households are assumed to have financial means that enable them to overcome energy and appliance investment challenges faced by low income households. This advantage means that both middle and high income households choose fuels based on what is convenient and preferable to them and to a lesser extend on the costs of the fuels. Energy expenditure is one of the economic challenges faced by low income households.

The questions that can contribute to an understanding of the impact that the modelled policies have on ECO1 are:

1) What is the contribution of each scenario towards reducing the energy burden of low income households?
2) What role is played by VAT and free basic electricity (FBE) in reducing the energy burden of these low income households?

In trying to answer the above questions, the prices of different fuels used in Gauteng's residential sector are discussed and analysed.

6.6.3 Fuel Prices

LPG

The price of LPG is currently R22/kg (DME, 2010). Without any form of subsidy, LPG is currently more expensive than coal and paraffin for low income households.

Paraffin

The Minister of Minerals and Energy approved the implementation of a Single Maximum National Retail Price (SMNRP) for illuminating paraffin which took effect on the 2nd of April 2003 (DME, 2003). SMNRP is the recommended retail price for paraffin but it is not enforced down the paraffin distribution chain. For example Cowan (2008) highlighted that the paraffin retail price was higher than the recommended SMNRP in Imzamo Yethu (a township in City of Cape Town) in 2008. Cowan reported that the price of 1 L of Paraffin was close to R15.00 during the time of his study, but according to the DME website, the highest SMNRP in that year was R12.59. Given the spatial distribution[42] of low income households in Gauteng, it is also possible that households that use paraffin might pay higher price than the recommended SMNRP as was the case in Imzamo Yethu. For simplicity in the cost analysis, the SMNRP value is assumed to be the retail price of paraffin in Gauteng in this study.

Figure 6-5 presents the annual SMNRP price from August 2007 to May 2010.

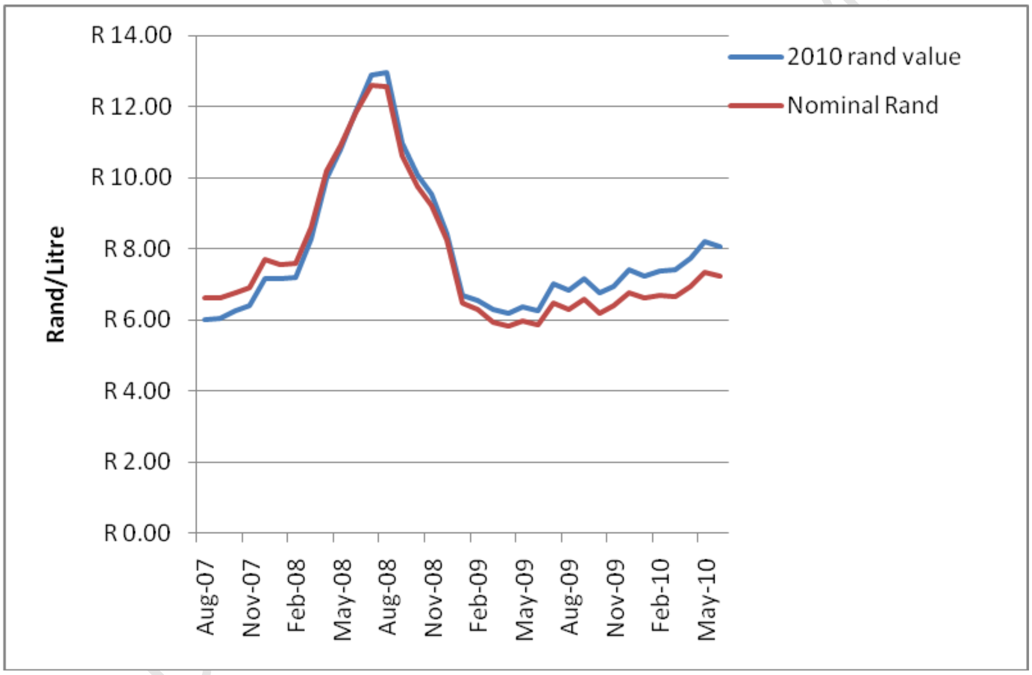

Figure 6-5: Paraffin price fluctuations in real and nominal terms

Besides the 2008 paraffin price hike, Figure 6-5 shows that paraffin price has stayed between R9.00 and R6.00 since 2009.

Coal

Coal is not currently regulated which poses challenges when collecting coal prices for the residential sector. For this study, the findings of Vogel and Mdluli (2010) in two townships in Mpumalanga were used as the cost of coal in Gauteng. The study found that households in Doornkop paid R35

[42] Majority of low income households are on the outskirts of Gauteng hence making the transportation of paraffin to these places more costly.

per 70 kg coal bag while households in Kwaguqa paid paid R27 per 70 kg coal bag. Doornkop was further from the mines than Kwaguqa hence the difference in the cost of a bag. It was assumed that households in Gauteng paid a similar price to that of Doornkop.

Electricity

As of April 2010, the electricity price in the residential sector was classified into four different categories depending on consumption levels of households. Households that consume higher amounts of electricity are charged more than households that consume lesser electricity. Table 6-3 shows different electricity prices for households falling in different consumption categories (Block 1 – Block 4). A household that uses more than 600 kWh of electricity (a household falling under Block 4) pays 95.46 cents per kilowatt-hour of electricity, whereas a household that uses less than 50 kWh pays 62.36 cents per kilowatt-hour of electricity.

Table 6-3: Non municipal residential electricity block tariff in 2010

	Energy Charge [c/kWh]	VAT Incl	Environmental levy [c/kWh]	VAT incl	Total	VAT incl
Block 1 [≤ 50 kWh]	52.70	60.08	2.00	2.28	54.70	62.36
Block 2 [51 -350 kWh]	56.48	64.39	2.00	2.28	58.48	66.67
Block 3[351-600 kWh]	74.35	84.76	2.00	2.28	76.35	87.04
Block 4 [> 600 kWh]	81.74	93.18	2.00	2.28	83.74	95.46

Source: ESKOM, 2010

The Block2 tariff shown in Table 6-3 was applied to low income households, block3 and block4 were applied to middle and high income households respectively. High income households have an additional R1.27 daily service charge added to the 95.46 c/KWh.

6.6.3.1 Fuel cost comparisons in low income households using different fuels

To enable fuel price comparison, the costs for all fuels was converted to R/GJ. Table 6-4 shows that coal is extremely cheap relative to electricity, LPG and paraffin.

Table 6-4: Cost of different fuels

Fuel	Cost (R/GJ)
Coal	R 20.58
Paraffin	R 187.00
electricity	R185.35
LPG	R404.93

LPG is the most expensive fuel in energy terms while paraffin and electricity are similar. The appliances used with the fuels (shown in Table 6-4) can determine whether fuels become expensive to use. For example a household that uses coal, paraffin, electricity and LPG to cook pay different energy prices. Cowan (2008), highlighted that the quantities of useful energy required for cooking will depend on many factors, including the quantities of food cooked, types of food, and cooking methods. To facilitate the comparison it was assumed that households use these different fuels to cook a similar meal.

Table 6-5 presents the cost incurred by low income households using different fuels for cooking.

Table 6-5: The cost of fuels used for cooking in low income households

Fuel	Energy used (GJ/annum)	Cost to house-hold (Rands)	Appliance efficiency	Energy used for cooking (GJ/annum)	energy service cost
Coal	23.33	R480.13	0.08	1.87	R38.41
Paraffin	1.47	R274.89	0.4	0.59	R74.80
Electricity	1.08	R200.18	0.65	0.70	R130.12
LPG	1.00	R404.93	0.65	0.65	R263.20

A low income household that uses coal to cook uses 23.33 GJ annually, a household that uses paraffin consumes 1.47 GJ annually, a household that uses electricity uses 1.08 GJ annually and a household that uses LPG uses 1 GJ annually. From Table 6-5, it appears that coal is the most expensive fuel to cook with because only 8% of the money used to buy the fuel translates into energy for cooking. Table 6-5 shows that, coal is almost twice as expensive as electricity to cook with. Electricity is the cheapest fuel to cook with.

The concept of useful energy (energy service) was used with care in this work. When comparing useful energy demand between two different fuels, other factors should be kept constant so that the comparison is credible. For example if a household uses electricity and LPG to cook 200g of rice, the useful energy can be compared in this circumstance. But if one household uses electricity to cook 400g of rice and uses LPG to cook 200g of rice, the useful energy of cooking in this instance cannot be compared. To enable useful energy cost comparisons, it was assumed that the same meal is cooked with different fuels and the house with the same floor area is heated under similar weather conditions.

Although the choice to use coal may appear to be economically sound for low income households, households that use coal pay R280, R205 and R75 more for energy than households that use electricity, paraffin and LPG for cooking respectively. Although LPG is 20 times more expensive than coal (see Table 6-4), using coal for cooking is more expensive than using LPG (see Table 6-5). The money that is used to buy paraffin and coal is lost due to the low efficiencies of appliances used with paraffin and coal. This highlights that there is a need for improved paraffin and coal appliances efficiencies because low income households could continue using coal as it is sold in affordable smaller quantities. Table 6-6 shows different costs of space heating with different fuels.

Table 6-6: Fuels used for space heating in low income households

Fuel	Energy used (GJ/annum)	Cost to household (Rands)	Appliance efficiency	Energy used for Space heating (GJ/annum)	energy service cost (Rands)
Coal	24.06	495.15	0.59	14.20	292.14
Paraffin	2.33	435.71	0.73	1.70	318.07
Electricity	1.37	253.93	1.00	1.37	253.93

Coal is also the most expensive fuel for space heating. But in terms of useful energy service, paraffin is more expensive than coal and electricity. Space heating with coal would cost a low income household 8% less energy than space heating with paraffin. If the same household chooses to use electricity instead of paraffin, the cost of energy would approximately be 20% less. But the cost to the household (the cost that a household pays for the fuel) is still high for households that use coal compared to households that uses paraffin or electricity. A household that uses coal pays 12% and 50% more than a household that uses paraffin and electricity.

6.7 The role of subsidies in reducing the energy burden of low income households

6.7.1 Introduction to the implemented energy subsidies

There are three forms of energy subsidies that are administered by the South African government. These are the free basic electricity (FBE), free basic alternative energy (FBAE) and the removal of

VAT from paraffin. FBE and VAT policies were implemented in 2003, while the FBAE policy was implemented in 2007. FBE suggests that poor households be given 50 KWh of electricity on a monthly basis (DME, 2003), but different municipalities around Gauteng administer it differently. Some municipalities give poor households the recommended 50 KWh monthly while others like the City of Tswane and City of Johannesburg give some poor households 100 KWh and other households within the same cities 50 KWh.

The City of Tswane and the City of Johannesburg have made significant positive strides in FBE administration and delivering the FBE. Since July 2008, the city changed its broad based approach[43] of allocating free basic electricity units, to a target oriented approach. Under this approach, households that are registered with the department of social development as poor, are allocated 100 KWh of electricity monthly and other low income households (about 22 000) who were not yet registered were allocated 50 KWh per month (SEED, 2009).

Prior to July 2008, all 'lifeline[44]' customers and all customers using less than 300 KWh each month were allocated 50 KWh per month in the City of Johannesburg. Since July 2008, all customers that are registered with the city's social department as poor, lifeline customers and customers consuming less than 300 KWh of electricity per month have been allocated 100 KWh monthly.

FBAE was designed as a subsidy for un-electrified households. The goal was to increase affordable energy access for low income households that have no access to electricity. FBAE was introduced because FBE appeared to discriminate against un-electrified households. FBAE has been applied in pilot studies in Gauteng in the form of an LPG subsidy in City of Tswane's un-electrified households (DME, 2006).

The LPG subsidy pilot studies that have been undertaken by DME are reported to be failing. The pilot subsidy programme was structured such that households were given energy coupons of R120 for LPG, together with the cylinder. Each household that was involved in the programme paid R10 towards a 9kg LPG cylinder (REEEP, 2009). When LPG prices increased, households ended up paying more than R10 and most households went back to using paraffin and coal, which were

[43] Under this approach all households that were electrified in Gauteng were given 50 KWh monthly.

[44] Lifeline customers are customers who chose to be billed on the lifeline tariff, which was structured to be beneficial to low-use customers but more expensive for high usage customers

comparatively cheaper. The following section discusses the impacts that FBE and VAT subsidies had on households that received them.

6.7.2 The impact of FBE and paraffin VAT removal on energy expenditure in low income households

The government removed VAT from paraffin because it was used mainly by low income households and it wanted to reduce the energy burden of low income households (DME, 2003). But this subsidy does not benefit low income households since the price of paraffin in local shops is not regulated. If the price in local shops is regulated down the paraffin distribution chain, VAT removal can save a household up to 14[45]% of paraffin cost.

A typical low income household in this study used 7.02 GJ of electrical energy annually. This is 1950 KWh per annum and FBE provides the households with 600 KWh (50 KWh x12) per annum or 1200 KWh (100KWh x 12). So 50 KWh of FBE only meets 31% of low income households electricity needs and 100 KWh meets 62% of low income household's electricity needs. Assuming that all electrified low income households in Gauteng fall under ESKOM's block 2 (51 ≥ 350 KWh) tariffs, Figure 6-6 shows the impacts of FBE on different scenarios.

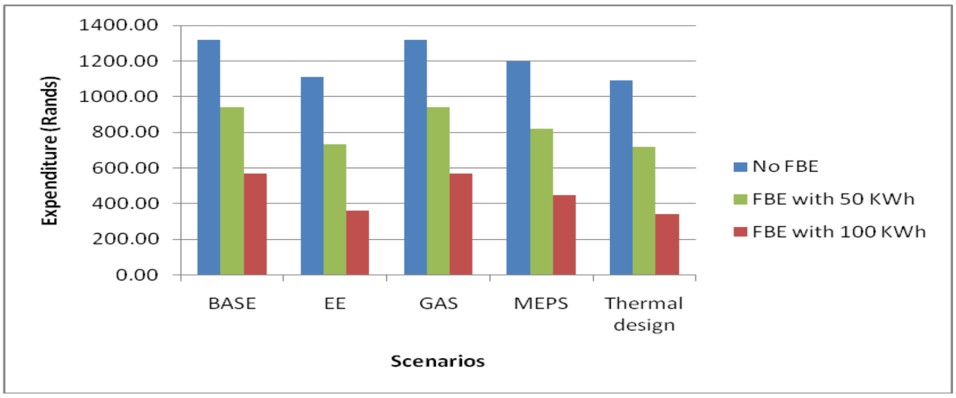

Figure 6-6: FBE impact on Income of low income household

Figure 6-6 shows that if FBE is coupled with energy efficiency interventions, poor households would be cushioned against electricity expenditure if the same level of energy service is maintained. The EE and thermal design scenarios showed that a typical low income household can save money if energy efficiency measures are practiced.

[45] The current South African value added tax is 14%.

The EE scenario appears to be a favourable scenario across all household categories in Gauteng in terms of reducing energy demand and the associated GHG emissions. Given the high level of investment required to make this scenario reduce the energy demand and GHG emissions as shown in Chapter 5, Sections 5.4 and 5.5, it was considered important to analyse the financial implication of this scenario across all household categories.

6.8 Scenarios costs implications in different household categories

This section demonstrates the costs that could be associated with the implementation of scenarios across all household categories. Chapter 5 has shown that the EE scenario is the most preferred scenario in terms of its potential to reduce energy demand and GHG emissions across all household categories. It would be expected that the EE would also result in higher monetary savings than any other scenario. In terms of the energy costs, the EE scenario would indeed reduce electricity expenditure for all households, but when the analysis includes the costs associated with overall investment involved in implementing the scenario, the EE is more expensive than other scenarios in all household categories. The analysis only includes households that use electricity only to all their energy needs.

The analysis considers the real cost of electricity (shown in Table 6-3), hence the price of electricity is assumed to be constant throughout the modelling period. The amount of energy consumed in high income households in the BASE, EE and MEPS scenarios was converted to kilowatt-hours to ease the calculation of electrical energy cost incurred by a typical high income household. Figure 6-7 shows the cost of electrical energy that a typical high income household would incur if BASE, EE and MEPS scenarios are implemented in these households.

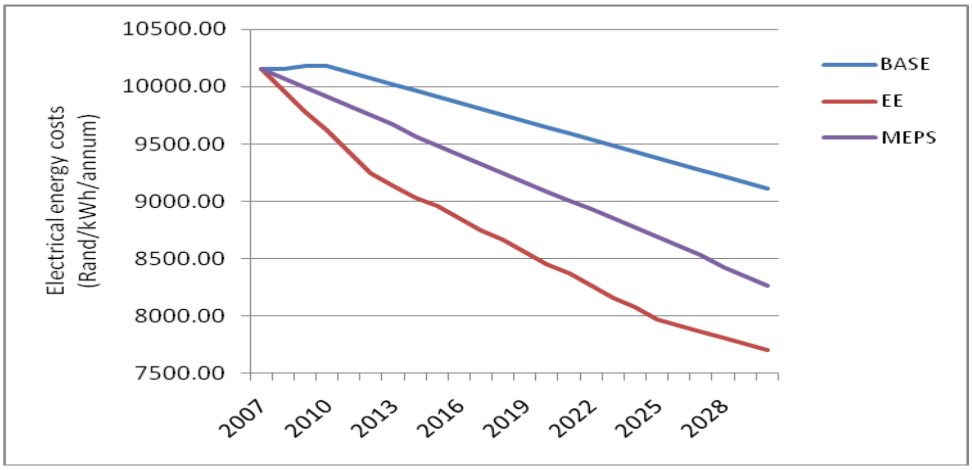

Figure 6-7: Electrical energy cost per scenario in a typical high income household

All the three scenarios in Figure 6-7 show a decrease in electricity cost. The reduced electricity cost in each scenario comes as a result of increased usage of energy efficient appliances. The BASE case had the least penetration level of efficient appliances; hence the least reduction in energy costs.

Although the electricity cost is reduced, it might be expensive to implement these scenarios. In order to see if indeed, the energy saving potential of the EE scenario extends to monetary savings, the costs of the interventions that made up the EE scenario were included. Figure 6-8 shows the monetary savings experienced by a typical high income household that implements the EE scenario relative to the one that does not implement the EE scenario (the BASE case shows savings of a household that does not implement the EE scenario). The GAS scenario is excluded from this analysis because the cost of having natural gas pipeline is not known. The pipeline cost R4000/km, but the spatial distribution of households around Egoli Gas's network in Johannesburg is not known (ENO, 2008); as a result the cost of having an Egoli Gas pipeline could not be estimated as the cost is dependent on how far the household is away from the gas pipeline network.

In high income households the EE scenario included ceiling and roof insulation, hot water pipe insulation and geyser blankets installation, using solar water geysers and exchanging CFL with incandescent lamps. All of the above interventions have cost implications and the assumed costs are shown in Table 6-7.

Table 6-7: Costs associated with the energy efficiency scenario

Energy Intervention	Material Cost	Installation cost	Lifetime
Geyser blanket	R299	Included in the cost	20
Ceiling and roof insulation	R10 000	included in the cost	30
SWH	R11 657	R2000	20

The costs shown in Table 6-7 were obtained from the internet from different companies that sell these appliances. The average cost that was found from the different suppliers was used for analysis in this study[46,47,48].

The annualized costs of the interventions shown in Table 6-7, were calculated using Equation [6-1]

$$Annualised\,cost = \frac{Investment\,cost(R)\times r\times(1+r)^t}{(1+r)^t-1} + Fixed\,O\&M\,(R/yr) + Variable\,O\&M\,(R/yr)\times hours\,of\,operation(h/yr) \qquad \textbf{[6-1]}$$

The Fixed O&M are the annual fixed operating and maintenance costs, variable O&M are the variable operating and maintenance costs, r is the discount rate[49] and t is the life time of the appliances. The fixed and variable operating and maintenance costs were assumed to be zero. Based on the previous work by Winkler (2006, 2009), the discount rate value was assumed to be 10% for both high and middle income households and 30% for low income households.

Figure 6-8 shows that the cost of the BASE case scenario is lower than the cost of the EE scenario when investment costs are included, hence showing that the monetary energy savings shown by EE alone cannot make the EE scenario favourable financially.

[46] http://www.sustainablehomedesign.co.za/geysers/geysers.html,

[47] http://www.sustainable.co.za/geyser-blanket-geyser-efficiency.html.

[48] http://www.gumtree.co.za/f-geyser-blanket-Classifieds-W0QQKeywordZgeyserQ20blanket

[49] Is used to bring the costs to present day prices

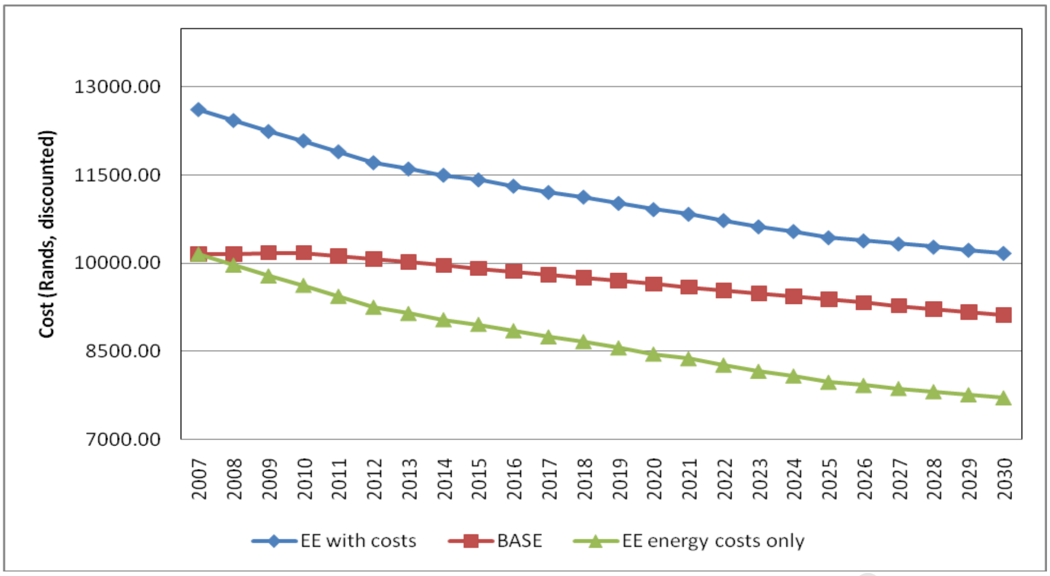

Figure 6-8 : Energy expenditure between BASE and EE scenario in a typical high income household

Initially the cost of the EE scenario is very high because of simultaneous investment in energy efficiency interventions. It can be seen in Figure 6-8 that the EE scenario is costlier to implement because a household that implemented the EE scenario could pay up to R2500 more than a household that did not implement energy efficiency. It is clear from Figure 6-8, that the EE does not show any breakeven on the cost during the modelling period but the cost difference between a household that implements energy efficiency measures versus the one that does not would have reduced to R1500 by 2030. The monetary savings from energy costs associated with the EE scenario should not be mistaken with the overall monetary savings of the scenario. Unless the SWHs and other subsidies are increased, there is no financial incentive associated with the implementation of the EE scenario.

Figure 6-9 shows electrical energy expenditure between the BASE, EE and MEPS for a typical middle income household.

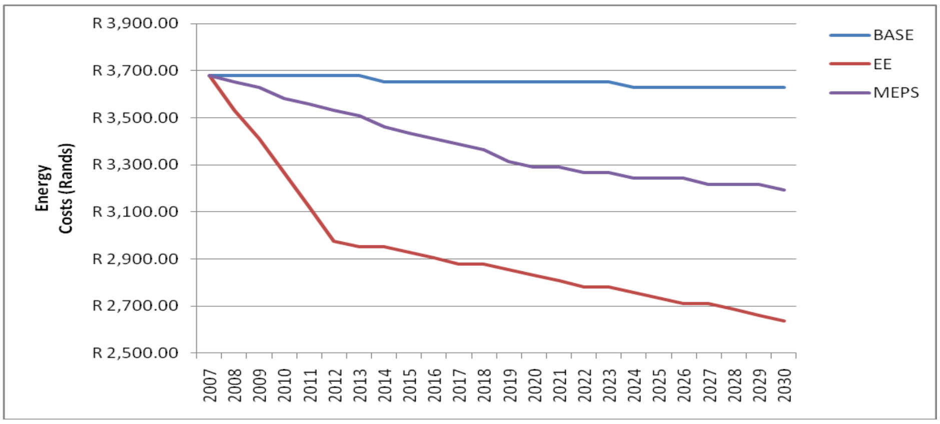

Figure 6-9: Energy expenditure between BASE and EE scenario in a typical middle income household

Figure 6-9 shows that the EE and MEPS scenarios save more energy costs than the Base case scenario, but when the costs of implementing the scenarios are included Figure 6-10 shows that the EE scenario is costlier than the BASE case scenario.

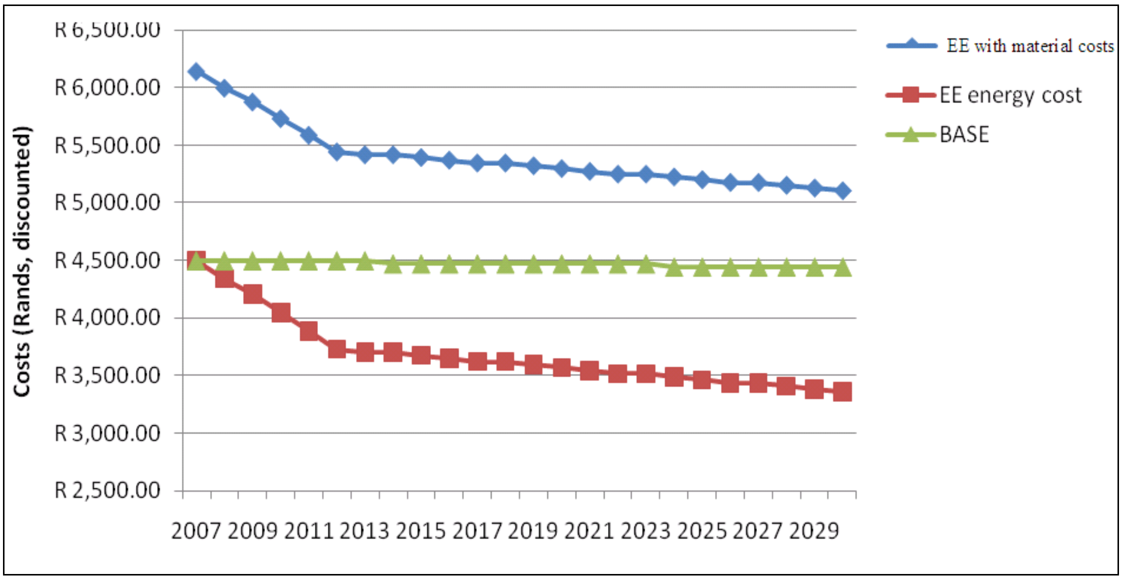

Figure 6-10: Energy expenditure for a typical middle income household when EE material costs are included

In low income households, both the thermal design and EE scenarios resulted in greater GHG emission and energy demand reduction than the MEPS scenario. Figure 6-11 shows the thermal design and the EE scenario result in higher monetary savings in low income households than any other scenario.

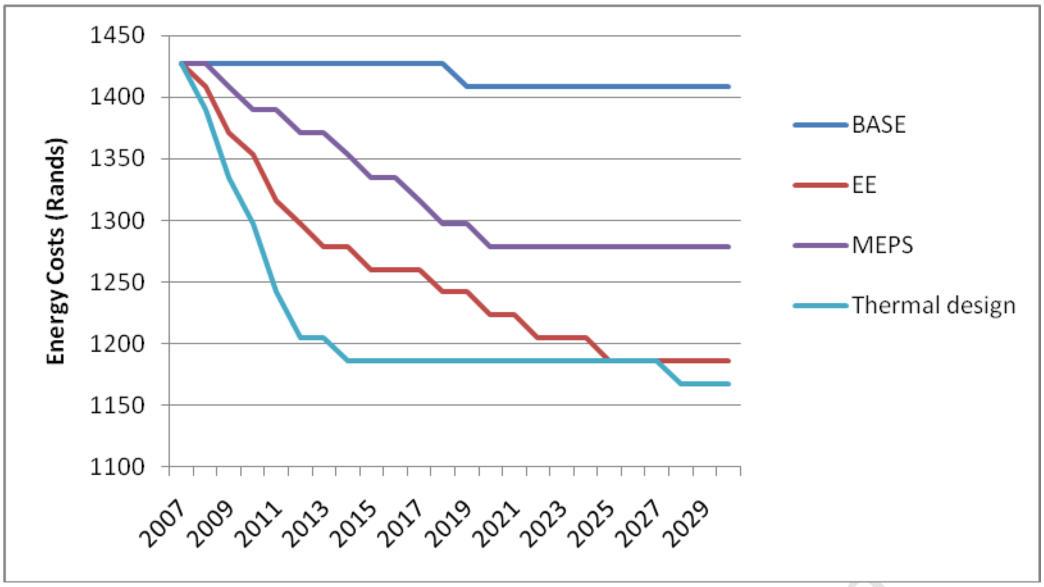

Figure 6-11: Low income households electrical energy expenditure per scenario

The MEPS scenario also shows that a low income household can reduce energy costs significantly. The SWH sub-scenario in chapter 4, assumed that low income households would install SWHs only through programmes such as KUYASA. Through these programs, low income households were assumed to pay nothing for the SWH. Since the thermal design scenario also assumes that thermal houses come as an RDP house package, low income households would again have no costs associated with the implementation this scenario. The thermal design scenario presents costs associated with energy (in this case electrical energy) only.

The costs associated with the EE would only come from ceiling and insulation installations. Figure 6-12 shows the difference in energy costs between scenarios in low income households when the investment costs associated with the EE scenario was included.

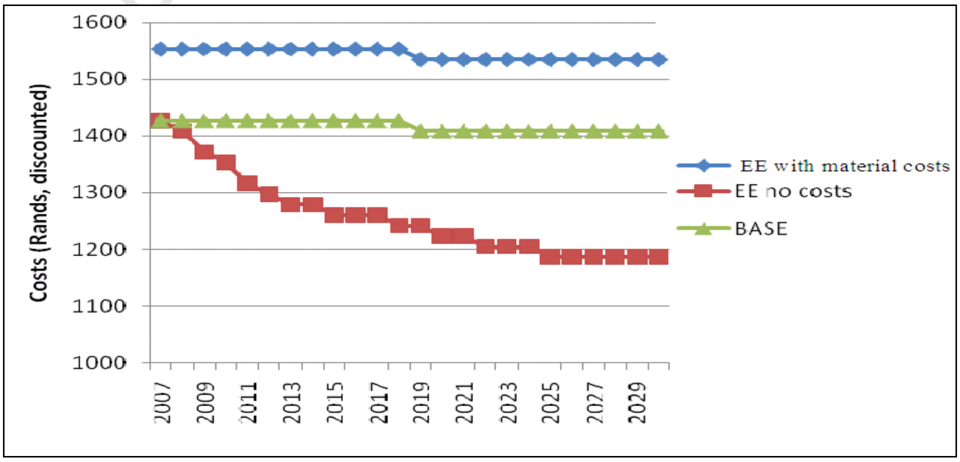

Figure 6-12: Energy expenditure for a typical low income household when EE with costs are included

Even in low income households, where financial investment was required for ceiling and insulation, the cost of the EE scenario does not make it favourable.

Energy efficiency interventions might not make economic sense but there are health related benefits associated with it. Boardman (1991) in her analysis of *low-income* households in the UK, estimated that 60% of the benefits of domestic energy conservation go towards improved health status (and comfort levels), while only the remaining 40% are realised in terms of energy savings.

6.9 Conclusions

In terms of reduced energy demand and GHG emissions the EE scenario is the most favourable scenario in Gauteng's residential sector. At household category level, the EE scenario is more favourable in both the middle and high income household categories whereas the thermal design scenario is more favourable in the low income household category. Across all household categories, the EE scenario is the most expensive when the costs of the material used to come up with EE scenario are included in the cost analysis.

Based on the definition of sustainability defined in Chapter 1 section 1.1, the EE scenario is dominant in moving Gauteng's residential sector towards sustainable energy use. At household category level, the EE scenario is dominant in moving both the high and middle income households towards sustainable energy use while the thermal design scenario is dominant in low income category.

Electricity is the cheapest to cook with in low income households, followed by paraffin and LPG and coal is the most expensive. Although coal may be cheap in the manner in which it is sold (small quantities of bags and buckets), the cost of the energy required to achieve cooking and space heating is higher compared to the other fuels used in Gauteng. Hence coal is more expensive than electricity and LPG. Given the sporadic nature of income in low income households, the way coal is sold gives it an advantage over other fuels hence coal will continue to be used in low income households.

7. Conclusion and Recommendations

7.1 Conclusions

This study achieved its objective of creating deeper understanding of energy consumption in Gauteng's residential sector. It was found that 76% of households used electricity only for their energy needs. The 76% was made up of 41%, 32% and 27% of high, middle and low income households respectively. The remaining 24% of households used coal, paraffin, LPG and natural gas to meet their energy needs. High income households used both LPG and natural gas for cooking and space heating. Middle and low income households used either coal or paraffin or a combination of three fuels for space heating and cooking and LPG was in some instances added to the fuel cluster for cooking purposes. Coal was the primary fuel used for space heating in both middle and low income households that practice multiple fuel use.

Coal use is not desirable because it was found that the problems with its use are not only related to pollution, but the costs associated with its use are also high considering the low efficiencies of appliances used with coal. Although the modeling assumed that coal use would decrease over time, the opposite could happen, if the problems associated with coal use are not addressed. Scourgie et al (2003) identified that rapid urbanisation, the proximity of Gauteng to coal mines and the well established coal merchant industry played major roles for promoting continued use of coal in low income households. With regard to urbanisation, Scourgie et al (2003) argues that rapid urbanization growth influences the formation of informal settlements hence exacerbating the electrification backlog in the province. Although being not electrified itself does not promote coal use, the poverty in households can cause people to choose coal over other fuel alternatives since coal is cheaper when bought in smaller quantities.

Through analysis of results from the LEAP model (Gauteng's residential sector), it was found that the EE scenario is more favourable because it has potential to move Gauteng's residential sector towards sustainable use of energy. But the cost implications for implementing the energy interventions that make up the EE scenario might remove the incentive of investing in such measures more especially in low income households. If the cost barrier associated with the implementation of the EE scenario is overcome, the EE scenario has the potential to reduce GHG emissions and energy demand by 36% and 30% respectively relative to the BASE case. The thermal design scenario (which is implemented only in low income households that use multiple fuels) reduces more energy and GHG emissions than the EE scenario in low income household category, hence it moves low income households towards sustainability faster than the EE scenario.

The ability of this scenario to move low income households towards sustainable energy use highlights that households that practice multiple fuel use in the low income household category have high energy demand for space heating. Despite its performance, the thermal design scenario is a very optimistic scenario. It assumed that 30% of informal houses within the low income household category would be delivered as thermally designed houses coming as an RDP housing package. This scenario is unlikely to occur given the fact that even 16 years after the promise of housing; the government is still battling with housing delivery (a backlog of 2 million households).

In order for Gauteng’s residential sector to be considered sustainable in its use of energy, there should be increased uptake of solar water heaters, increased use of LPG in non electrified households and reduced coal and paraffin use if coal and paraffin appliances are not improved. Truran (2008) stated that paraffin is not a dangerous fuel but the way it is packaged and the appliances used with it in South Africa makes it to appear dangerous. Paraffin packaging has improved since the late 1990s, however the challenge still rests on how to phase out the paraffin appliances that do not satisfy the South African Bureau of Standards (SABS) design standards[50]. To realise sustainable energy use without abandoning paraffin use, the sale of appliances that do not conform to the standards must be prohibited.

With regard to making energy affordable, it is hard to say which fuel would be cheaper in the future. Electricity generated from coal can be expensive if tighter environmental control measures are taken and paraffin and LPG prices are highly volatile due to fluctuating crude oil price. Affordable energy will be a sure reality if investments in renewable energy are promoted rather than investments that promote conventional energy sources.

Sections 5.4 and 5.5 have shown that the EE, thermal design and MEPS scenarios have significant potential to reduce energy demand and emissions. It is essential to identify the challenges that the scenarios could face, which could affect their energy demand and emissions reducing potential hence affecting sustainable energy use. For example, a thermally designed house could not save energy as expected if the use of dirty fuels continue because there will be a need to open the house for better ventilation, hence energy will be lost. Van Wyk and Mathews (1996) highlighted that emitted

[50] The standard for wick stoves is SANS 1906:2006 and the standard for pressure stoves is SANS 1243:2007. As of January 2007, SANS 1906:2006 was made compulsory as of January 2007.

pollutants force people to open doors and windows for proper ventilation hence the heat that could have been retained would be lost due to heat transfer. Basa Njengo Magogo on the other hand has wood challenges. To make a BNM fire as suggested in this study might not be always possible because Gauteng has a wood scarcity problem. As long as urbanisation rates continue, poor households would continue to use multiple fuels such as coal because the high urbanisation rate delays electrification and other services. In order to make sustainable energy use a reality in Gauteng' residential sector, there is a need for rural development so that migration to Gauteng from other provinces is reduced.

7.2 Recommendations

After finding that electricity and LPG can help low income households to have improved standards of living and reduce the cost of the energy service, this study suggests the strengthening of the policies that promote LPG and electricity use in low income households. A policy that promotes access to electricity has already been implemented; the onus rests upon improving the administration of the free basic energy, so that all poor people benefit from it. Chapter 6, sub-section 6.8.2 showed that 50 KWh of electricity per month is not enough for all basic end uses in poor households. This study suggests further research on the basic energy demand of low income households. With regard to LPG, the pilot studies that were done by the Department of Minerals and Energy in Pretoria during 2005 – 2006 pointed out that people abandoned LPG usage as the price of LPG increased. The pilot studies were designed such that the government would pay a fixed subsidy to the supplier per 9kg cylinder of LPG and the households paid the remaining balance which was R10 in 2006. As the prices of LPG increased, the difference that was paid by households went up to R32 hence they ended up paying more. This study suggests absorption of the LPG price fluctuations by the government, which will allow households to pay a fixed amount of money towards a cylinder. In this way, poor households would be protected from LPG price fluctuations. Free Basic Electricity (FBE) is administered in this manner. Irrespective of the cost of electricity, the households that benefit from FBE will always get 50 kWh of electricity monthly.

The challenge of promoting clean fuel use is brought on by the fact that low income households use coal to achieve space heating and cooking simultaneously, hence coal is favoured over other fuels. It might make economic sense to a typical low income household to buy a 70kg coal bag for R27.00 given the sporadic nature of income in those households, but over a long run (annually), coal is expensive because it has a low calorific value.

For further studies it is recommended that multiple fuel use pattern be studied so that residential energy demand modelling can be improved. It is evident that Gauteng's middle and low income households use multiple fuels to meet their end uses, but the fuel combination dynamics are not well known. For the purpose of modelling multiple fuel use, the frequency of fuel use is crucial. For example, several studies have reported that households use paraffin and coal for cooking but frequencies of use are not specified. The fuel use pattern can further be used to develop an energy use behaviour model that can capture the energy savings that come from energy efficiency interventions. The energy use behaviour model could be used to study rebound effects. Several studies have shown that the rebound effect reduce the impact of technical appliance efficiencies, but currently most modelling tools still model appliance efficiencies only.

Although the objective of this study is to inform policy and decision making, it is also crucial to improve the residential energy demand modelling because an informative model would also serve as a good tool for policy formulation. Systems dynamic modelling would help to capture dynamism that the residential sector possesses. The dynamism in the residential sector does not occur at household level only, even down at end use levels energy is used differently by different households. The LEAP model used in this study assumed that households that cook, follow one pattern and the changes made were as aggregate as possible.

It should be understood that the amount of energy that a particular household uses might change depending on what is cooked and how many people the food was for. That is a household that cooks for 10 people would use different energy to a household that cooks for two. To solve this problem of fixing end use energy demand, it is suggested that systems dynamics energy demand modelling be incorporated in residential energy demand modelling. For example, a household could use 5 GJ of energy for water heating this year when the family size is 6, but when the size of the family decreases the energy used for water heating would automatically reduce. Household size also plays a major role in determining the amount of energy used for cooking. An example of a cooking sub-model using systems dynamics approach that could be created for the residential sector is shown in Figure 7-1.

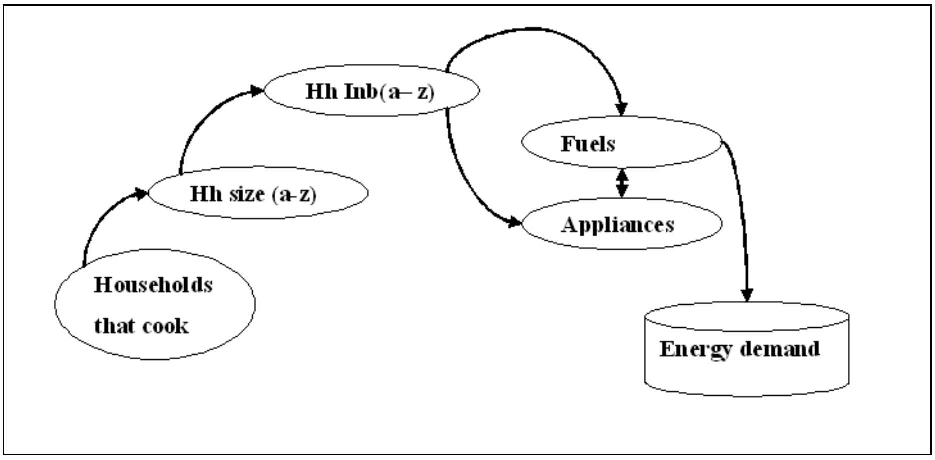

Figure 7-1: Example of a cooking model in system analysis approach

Figure 7-1 shows that one way in which system dynamics can be incorporated in end use energy demand modelling. Households that cook, can be classified by household sizes (Hh size a-z), then income bands (Hh inb a–z), then the fuel used to cook which can go together with the type of appliances used and all this could give total final energy demand for cooking in the residential sector. The advantage of using system dynamics would be to reduce fixing of the amount of energy used for a particular end use over a long period such as 20 years which my study could not overcome. Space heating could have a different system dynamic sub-model depending on the main drivers of space heating energy demand. For example, instead of household size (Hh sizeZ) in Figure 7-1, a heating sub-model could have number of rooms that are heated because the size of the household does not impact much on space heating energy demand.

This study modelled multiple fuel use in Gauteng households, but the quality of the data was not highly reliable as the study from which multiple fuel use data was taken from was done back in 1996. This thesis suggests improving the way the fuel usage data is collected by Statistics South Africa. The 1996 and 2001 censuses, together with the 2007 Community Survey did not ask households about their secondary fuel. The survey asked households what fuel is used most frequently by the household. An example of the question that was asked is to establish the fuel used for cooking was:

"What type of energy/fuel does this household MAINLY use for cooking?"

The answer to this question would give the primary fuel according to this study, but the secondary fuel was not asked. To improve policy, energy analysis should be supported with data. To capture multiple fuel use, this study suggests Statistics South Africa to ask the following question in addition to the previous question: *What type of energy/fuel does this household use in the absence of the MAIN fuel?*

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Appendices

Appendix A

Table 0-1: Number of households as classified by income in Community Survey 2007

2007 Community Survey					
Income Classification	Number of households	Percentage of Households	Number of Households per 3 income groups	Household classification	Percentage of Households
No income	532 212	19.3	978 863	Low	35.44%
R1 - R4 800	127 870	4.6			
R4 801 - R 9 600	318 781	11.5			
R9 601 -R 19 200	469 129	17.0	904 934	Middle	32.76%
R19 201 - R 38 400	435 805	15.8			
R38 401 - R 76 800	315 403	11.4	878 477	High	31.80%
R76 801 - R153 600	250 215	9.1			
R153 601 -R307 200	186 459	6.8			
R307 201 - R614 400	84 603	3.1			
R614 401 - R1 228 800	23 114	0.8			
R1 228 801 - R2 457 600	11 165	0.4			
R2 457 601 and more	7 518	0.3			
Total Households	3 172 295	100.0	3 172 295		

Table 0-1 shows the number of households in Gauteng according to income bands as classified in community survey 2007. The households were divided into three categories; High, Middle and Low.

Appendix B

Table 0-2 shows the residential areas where Domestic Load data was collected. The areas are classified by Gauteng municipalities, the year in which the area was studied.

Table 0-2: Gauteng study areas in the National Research Load database

Place	Municipality or City	Years of Study	Group Name	Group ID	Surveyed houses
Bassonia		2001	2001 Bassonia	105	
Moreletta Park	CTMM	2001, 2002, 2003	2001 Moreletta Park 2002 Moreletta Park 2003 Moreletta Park	109 122 1000018	50 56 58
Woodhill		2005, 2006	2005 Woodhill 2006 Woodhill	1000042 1000053	
Mont Clare/ Claremont	COJMM	1996, 1997, 1998	1996 Claremont 1997 Claremont 1998 Claremont	37 46 53	70 73 78
Sanctuary Gardens	COJMM	1999, 2000	1999 Sanctuary Gardens 2000 Sanctuary gardens	67 16	140 60

In the database the areas were represented by an identifier called the GROUP ID. An area was given a different groupID based on a year it was studied.

Table 0-3: Moreletta Park and Sanctuary Gardens appliance saturation rates

Moreletta Park				Sanctuary Gardens	Average number households	Average Penetration rates
Number of households	50	56	58	60	56	Any year
Appliances	2001	2002	2003	2000		
3 plate stove	0	3	0	0	1	1
4 plate stove	50	51	58	60	55	98
Hot Plate	0	3	0	0	1	1
Heater	31	15	22	33	25	45
Kettle	50	55	58	60	56	100
Iron	48	55	58	60	55	99
Geyser	50	56	58	58	56	99
Washing Machine	49	51	58	52	53	94
TV	50	55	58	57	55	98
HiFi	47	55	57	46	51	92
Lights	49	56	57	60	56	99
Fridge	50	56	58	59	56	100
Deep Freezer	36	19	51	14	30	54
Microwave	48	51	58	53	53	94
Tumble dryer	33	21	40	24	30	53

Source: base on NRS database (2001, 2002 and 2003)

Appendix C

<u>Base year data for households</u>

These tables present the base year energy data for all households' categories. The tables contain fuel used for a particular end use, energy intensity for that end use, percentage and number of households that practiced that end use and the total energy demand for each end use and the overall total energy demand per household category.

Table 0-4, Table 0-5 and Table 0-6 presents energy data for households that use electricity only to meet their energy needs. Table 0-7 and Table 0-8 present the base year energy data for middle and low income households that practiced multiple fuel use. Table 0-9 and Table 0-10 show base year energy data for non electrified households in low and middle income categories.

Table 0-4: High Income households base year data

End-uses	Fuel type	Energy-intensity (GJ)	% of hhs	# of hhs	Energy (TJ)
Lighting	Electricity	4.68	100.00%	952500	4457.70
Cooking	Electricity	6.40	97.00%	923925.0	5913.12
Refrigeration	Electricity	2.41	100.00%	952500	2295.53
Water Heating	Electricity	16.40	100.00%	952500	15621.00
Space Heating	Electricity	1.75	100.00%	952500	1666.88
Other	Electricity	5.20	100.00%	952500	4953.00
Total					*<u>34907.22</u>*

Table 0-5: Middle- mono fuel income households base year data

Mono				345440	
End-uses	Fuel type	Energy-intensity (GJ)	% of hhs	# of hhs	Energy (TJ)
Lighting	Electricity	1.4	100.00%	345440	484
Cooking	Electricity	2.6	100.00%	345440	898
Refrigeration	Electricity	2.12	88.00%	303987	644
Water Heating	Kettle	1.39	77.00%	265989	370
	geyser - electric	3.79	23.00%	79451	301
Space Heating	Electricity	2.8	90.00%	310896	871
Other	Electricity	1.1	100.00%	345440	380
Total					*3948*

Table 0-6: Low Income mono fuel households base year data

Mono				240944	
End-uses	Fuel type	Energy-intensity (GJ)	% of hhs	# of hhs	Energy (TJ)
Lighting	Electricity	0.97	100.00%	240944.4	233.7
Cooking	Electricity	1.08	100.00%	240944.4	260.2
Refrigeration	Electricity	2.12	55.00%	132519.4	280.9
Water Heating	Electricity	0.88	100.00%	240944.4	212.0
Space Heating	Electricity	1.37	80.00%	192755.5	264.1
Other	Electricity	0.6	100.00%	240944.4	144.6
					1395.5

Table 0-7: Middle income- mult households' base year data

			518160			Amount of individual fuels		
End-uses	Fuel type	Energy-intensity (GJ)	% of hhs	# of hhs	Energy (TJ)	ele (TJ)	para	coal
Lighting	Electricity	1.42	100%	518160	736	736		
Cooking	Electricity	2.60	53%	274625	714	714		
	Paraffin (9L)	4.00	0%					
	Paraffin+Electricity	3.53	3%	15545	55	13	41	
	LPG	2.33	4%	20726	48			
	electricity+Coal	8.15	40%	207264	1165	359		806
	Coal	11.66	100%	518160	1982			
Refrigeration	Electricity	2.12	88%	455981	967	967		
Water Heating	Electricity	1.39	67%	347167	483	483		
	electricity+Coal	2.87	33%	170993	491	158		332
	Coal (41kg)	5.83			973			
Space Heating	Electricity	2.80	41.00%	191201	535	535		
466344	Coal (207kg)	30.18	18.90%	88139	2660			2660
	Coal+Electricity	20.58	37.80%	176278	3711	165		3547
	Paraffin	2.33	1.80%	8394	20		20	
			100%	464012	6926			
Other		1.10	100%	518160	570	570		
Total Energy					12155			

Table 0-8: Low income mult households base year data

			536296			Amount of individual fuels			
End-uses	Fuel type	Energy-intensity (GJ)	% of hhs	# of hhs	Energy (TJ)	ele (TJ)	para	coal	LPG (TJ)
Lighting	Electricity	0.97	100%	536296	520	520.21			
Cooking	Electricity+Paraffin	1.21	40%	214518	259	154.45	105		
	Paraffin (3.3)	1.47	53%	284237	416		416		
	LPG (6kg)	1.00	7%	37541	38				37.6399196
	Electricity	1.08							
			100.00%	536296	713.32				
Refrigeration	Electricity	2.12	55%	294963	625	625.32			
Water Heating	Coal (20kg)	5.83	100%	536296	3128			3128	
Space Heating	Coal (165kg)	24.06	65%	278874	6709			6709	
	Paraffin (10.5)	2.33	15%	64355	150		150		
					6859				
			80%	343229					
Other	Electricity	0.60	100%	536296	322	321.78			
					12167				

Table 0-9: Middle income non electrified households base year data

			Total hhs	215900				
End-uses	Fuel type	Energy-intensity (GJ)	% of hhs	# of hhs	Energy (TJ)	para (TJ)	coal (TJ)	LPG (TJ)
Lighting	Candles (34)	1.41	71%	153721	216			
	Paraffin (5L)	2.22	29%	61747	137	137		
			100%	215468	353			
Cooking	Paraffin (9L)	4.00	72%	155448	621	621		
	Paraffin+coal	10.44	24%	51816	541	138	403	
	LPG (14kg)	2.34	4%	8636	20			20.2039289
	coal (80kg)	23.33						
					1182			
Water Heating	Paraffin	2.66	65%	140335	374	374		
	Coal (20kg)	5.83	35%	74486	434		434	
					808	808		
Space Heating	Paraffin (10.5)	2.33	12%	20726	48	48		
172720	Coal (207kg)	30.18	60%	103632	3128		3128	
	Coal+Paraffin	20.90	28%	48362	1011	38	973	
			100%		4187			
				Total	6531			

Table 0-10: Low income non electrified households base year data

			Total hhs	365760				
End-uses	Fuel type	Energy-intensity (GJ)	% of hhs	# of hhs	Energy (TJ)	para	coal	LPG
Lighting	Candles (11)	0.46	80%	292608	133			
	Paraffin (5L)	2.22	20%	73152	162	162		
	Candles+Paraffin	1.04						
			100%	365760	296			
Cooking	Paraffin (3.3)	1.47	72%	263347	386	386		
	Paraffin+coal	8.75	24%	87782	768	86	683	
	Coal (80kg)	23.33						
	LPG (0.6kg)	1.00	4%	14630	15			14.6252501
					1169			
Water Heating	Paraffin (3L)	1.33	73.00%	267005	356	356		
	Coal (41)	5.83	20.00%	73152	427		427	
					782			
Space Heating	Paraffin (10.5L)	2.33	25%	73152	171	171		
292608	Paraffin+coal	9.57						
	Coal (165kg)	24.06	34%	99487	2393		2393	
	Coal+Paraffin	16.815	41%	119969	2017	93	1924	
			100%	292608	4581			
					6828			

Appendix D

Census 2001 households' classification was similar to 2007 households' classification, but when inflation is considered, 2001 income bands were different from 2007 income bands.

Table 0-11: 2001 and 2007 households classified by income bands

	Number of households	
Income band	2001	2007
No Income	544883	315341
R1-R4800	131199	133635
R4801-R9600	324987	228051
R9601-R19200	489536	518869
R19201-R38400	456606	581943
R38401-R76800	320436	510997
R76801-R153600	253646	322115
R153601-R307200	188012	268386
R307201-R614400	84944	186276
R614401-R1228800	23251	74682
R1228801-R2457600	11302	21538
R2457601 and more	7536	13749
Grand Total	2836338	3175582

Table 0-12: 1996 census households classified by income bands

	Number of households
No Income	165870
R1-2400	50359
R2401-6000	154707
R6001-12000	199240
R12001-18000	207315
R18001-30000	215303
R30001-42000	126381
R42001-54000	95867
R54001-72000	109094
R72001-96000	79543
R96001-132000	91779
R132001-192000	67777
R192001-360000	54188
R360001 or more	15347
Unspecified/dummy	331943
Total	1964713