Energy demand projections and relevance of income dynamics in Gauteng's residential sector

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Abstract
Energy modelling serves as a crucial tool for informing both energy policy and strategy development. But the modelling process is faced with both sectoral energy data and structural challenges. Among all the sectors, the residential sector usually presents a huge challenge to the modelling profession due to the dynamic nature of the sector. The challenge is brought by the fact that each an every household in a region may have different energy consumption characteristics and the computing power of the available models cannot incorporate all the details of individual household characteristics. Even if there was enough computing power within the models, energy consumption is collected through surveys and as a result only a sample of a region is captured. These challenges have forced energy modellers to categorise households that have similar characteristics. Different researchers choose different methods for categorising the households. Some researchers choose to categorise households by location and climate, others choose housing types while others choose quintiles. Currently, there is no consensus on which categorisation method takes precedence over others.

In these myriad ways of categorising households, the determining factor employed in each method is what is assumed to be the driver of energy demand in that particular area of study. Many researchers acknowledge that households' income, preferences and access to certain fuels determine how households use energy. Although many researchers recognise that income is the main driver of energy demand in the residential sector, there has been no energy modelling study that has tried to categorise households by income in South Africa. This paper chose to categorise households by income because income is taken to be the main driver of energy demand in the urban residential sector. Gauteng province was chosen as a case study area for this paper. The Long-range Energy Alternatives Planning System (LEAP) is used as a tool for such analysis.

This paper will further reveal how the dynamics of differing income across the residential sector affects total energy demand in the long run. The households in Gauteng are classified into three income categories – high, middle and low income households. In addition to different income categories, the paper further investigates the energy demand of Gauteng's residential sector under three economic scenarios with five energy demand scenarios. The three economic scenarios are first economic scenario (ECO1), second economic scenario (ECO2) and third economic scenario (ECO3). The most distinguishing factor between these economic scenarios is the mobility of households from one income band to the next.

The model results show that electricity demand will be high in all the three economic scenarios. The reason for such high electrical energy demand in all the economic scenarios compared to other fuels is due to the fact that among all the provinces, Gauteng households have one of the highest electricity consumption profiles. ECO2 showed the highest energy demand in all the five energy demand scenarios. This is due to the fact that the share of high income households in ECO2 was very high, compared to the other two economic scenarios. The favourable energy demand scenarios will be the Energy Efficiency and MEPS scenarios due to their ability to reduce more energy demand than other scenarios in all the three economic scenarios.

Keywords: LEAP, final energy demand, income dynamics, scenarios, household mobility.

1. Introduction

This paper starts with the introductory section which explains the comparative analysis of how the income categories for the households were decided and also presents fuel use trends between 2001 and 2007 for Gauteng's residential sector. The section concludes by presenting the structure of the LEAP model for Gauteng's residential sector.

Section 2 presents the forecasts of drivers of energy demand in the residential sector and it explicitly explains how the economic scenarios were constructed. Section 3 discusses how the energy scenarios were constructed and assumptions that were made are explicitly explained. Section 4 presents the results together with their discussion. The paper ends with conclusions on the study and how future work can improve this study.

Gauteng is the smallest province in South Africa situated in the north-central part of the country. Although it is the smallest province in the country, it is the most populous province with approximately 10.5 million people (21% of the country's population) that occupy 3.175 million households (STATSSA, 2007). Despite being the smallest province, Gauteng is the power house of the South African economy contributing a third of the country's GDP (Ward & Schaffler, 2008). Proportional to its GDP contribution, Gauteng also uses one third of South African's final energy demand (GSSD, 2006). Figure 1 shows that the industrial and transport sectors consumed the greatest share of energy in both 2000 and 2007 followed by the residential sector.

Figure 1 also shows that energy demand in the residential sector almost doubled in 6 years. If energy demand increases at this rate in the future, Gauteng's residential sector would be a significant energy consuming sector in the next two decades. This paper analyses the impacts that household income would have on the future residential energy demand in the province. This analysis is taken because income drives almost all demand within households.

According to the econometric theory, households demand goods and services within their budget **[8].** Equation 1, taken from Louw *et al.* (2008), shows the role that income plays in the household demand function.

$$U = U\,(ES\,(E, A, F), G, S, z), \text{ subject to}$$
$$I = p_1x_1+p_2x_2+ \ldots + p_nx_n \qquad (1)$$

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 and z is the household's preferences. I is household's disposable income, $p_{1\ldots}p_n$ are the prices for $x_{1\ldots}\, x_n$ goods and services. Equation 1 shows that the extent to which the households demands goods and services is restricted by how much disposable income they have. As a result this paper asserts that disposable income/budget (I) of the household is a major determinant of how much energy is used within the household, as was discovered by Dzioubinski and Chipman (1999), White, Mofokane and Meintjes (1998), Akese (1998), Hunt, Lester, Judge, Guy Ninomiya and Yasushi (2003) and Prasad (2006).

The households in Gauteng were classified into three categories – high, middle and low income household categories. The income bands that were used to classify households were taken from Statistics South Africa's Community Survey 2007. The following sub-section gives an overview of how the categories were arrived at.

1.1 Comparative data analysis to determine household categories

The purpose for having different household categories is to be able to build a model which can incorporate and react to: energy use profiles, consumption levels across income categories and poli-

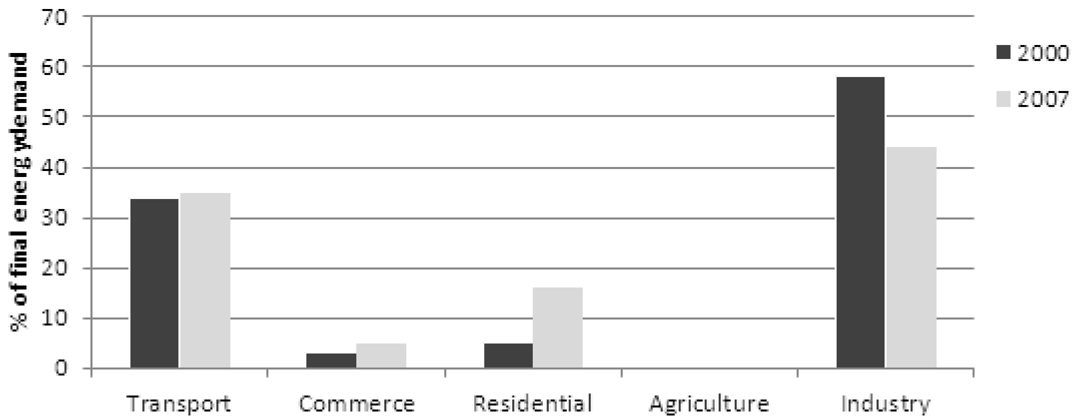

Figure 1: Gauteng's sectoral energy demand share 2000 and 2007
Source: Ward & Schaffler (2008)

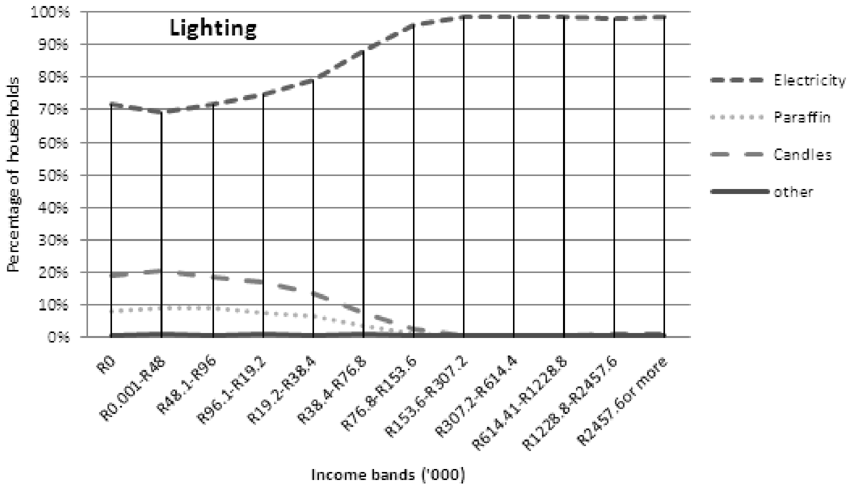

Figure 2: Primary fuel used for lighting per income group
Source: Community Survey 2007

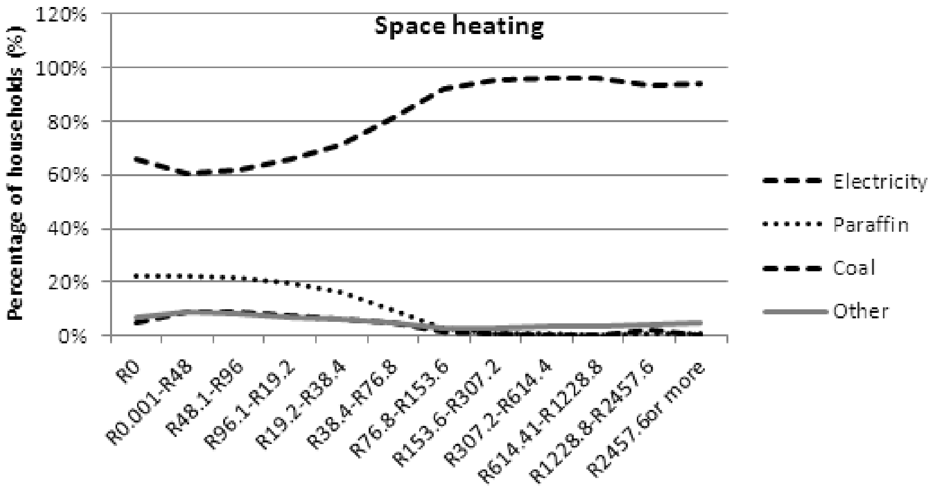

Figure 3: Primary fuel used for space heating per income group
Source: Community Survey 2007

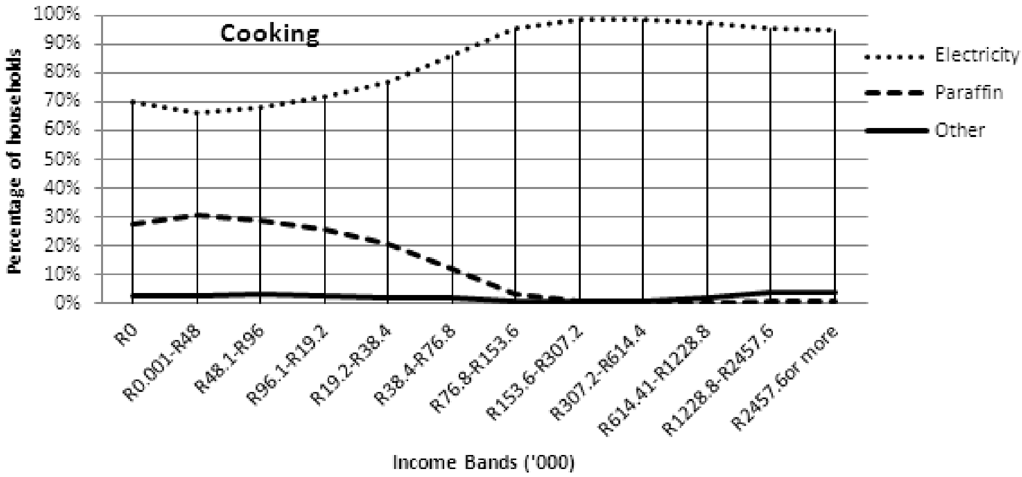

Figure 4: Primary fuel used for cooking per income group
Source: Community Survey 2007

cy interventions which are relevant to certain household categories.

The three household categories that are modelled in this paper were created based on income bands found in the 2007 Community Survey (CS2007) of Statistics South Africa. The income categories were decided based on households' energy use profile from CS2007. The survey reported households that used energy for cooking, lighting and space heating. The energy use patterns for cooking, space heating and lighting were examined to determine the cut off points for the low, middle and high income household categories.

Figures 2, 3 & 4 show a similar trend in choice of electricity and other fuels used for cooking, lighting and space heating for households falling within the following ranges ‘R0–R9 600’, ‘R9 601–R153 600’ and ‘R153 601 upwards’. All income is reported in 2007 Rands

The energy use patterns in Figures 2, 3 and 4 gave an indication of which income bands can be used to define, low, middle and high income household categories. As a result, households that earned an income between R0 and R9600 a year were classified as low income households, those earning between R9601 and R153 600 were classified as middle income households and those earning above R153 600 were classified as high income households.

1.2 Overview of energy use profile for Gauteng households energy

1.2.1 End use energy intensities

Besides the differing energy use patterns shown above, the other two distinguishing actors among the three household categories are the appliance penetration rates and the amount of fuels consumed between these households. The high income households consumed more energy than the middle and low income households. Tables 1, 2 and 3 present the energy intensities for the different end uses in the three household categories.

Table 1 shows that almost all the end uses are achieved with electricity in high income households. Even within these households there are some end uses that are more energy intensive than others. The energy consumed to heat water is almost half of the total household’s energy demand.

Table 2 shows that water heating and space heating consume more energy than any other end uses in middle income households. 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 literature that electric geyser consumes the greatest share of energy demand in households using it. There might be prolonged time for space heating in this household category relative to high income households. The prolonged time for space heating might occur because according to National Load Research (NRSO34) database few households in the middle income category owned insulated homes but a higher number of high income households owned insulated homes.

Table 3 shows that refrigeration is the greatest energy consuming end use in low income households. According to Afrane-Okese (1998), the reason for such high energy consumption is the fact that low income households use fridges with very low energy efficiencies.

Table 1: High income households’ end use energy intensity (GJ/annum)
Source: COJMM (2007), CTMM (2006), EMM (2004), Winkler (2005)

End-uses	Electricity	Gas
Lighting	4.7	_
Cooking	6.4	2.2
Refrigeration	2.0	_
Water Heating	16.4	_
Space Heating	1.8	_
Other	5.2	_
Total	36.4	_

Table 2: Middle income households’ end use energy intensities (GJ/annum
Source: COJMM (2007), CTMM (2006), EMM (2004), Simmonds and Mammon (1996), Winkler (2005)

End-uses	*Electricity*	*Coal*	*Paraffin*	*Candles*	*Gas*
Lighting	1.4	_	2.2	1.4	_
Cooking	2.6	_	4.0	_	2.3
Refrigeration	2.1	_	_	_	_
Water heating – Kettle	1.4	5.8	2.7	_	_
Water heating – Geyser	3.8	_	_	_	_
Space heating	2.8	30.2	2.33	_	_
Other	1.8	_	_	_	_
Total	15.2	36.0	11.2	1.4	2.3

Table 3: Low income households’ end use energy intensities (GJ/annum)
Source: COJMM (2007), CTMM (2006), EMM (2004), Simmonds and Mammon (1996), Winkler (2005)

Enduses	*Electricity*	*Coal*	*Paraffin*	*Candles*	*Gas*
Lighting	0.97	_	2.20	0.56	_
Cooking	1.08		1.47	_	1.00
Refrigeration	2.41	_	_	_	_
Water heating	0.88	5.83	1.33	_	_
Space heating	1.37	24.06	2.33	_	_
Other	0.60	_	_	_	_
Total	7.31	_	_	0.56	1.0

1.2.2 Electrification and fuel con-sumption trends

According to the 2007 Community Survey, 83% of households were electrified in 2007 (STATSSA, 2007). Although Gauteng has high electrification level, when examining Figure 5, it is clear that it experienced a slower rate of electrification compared to other provinces. Gauteng had the second highest percentage of electrified households in

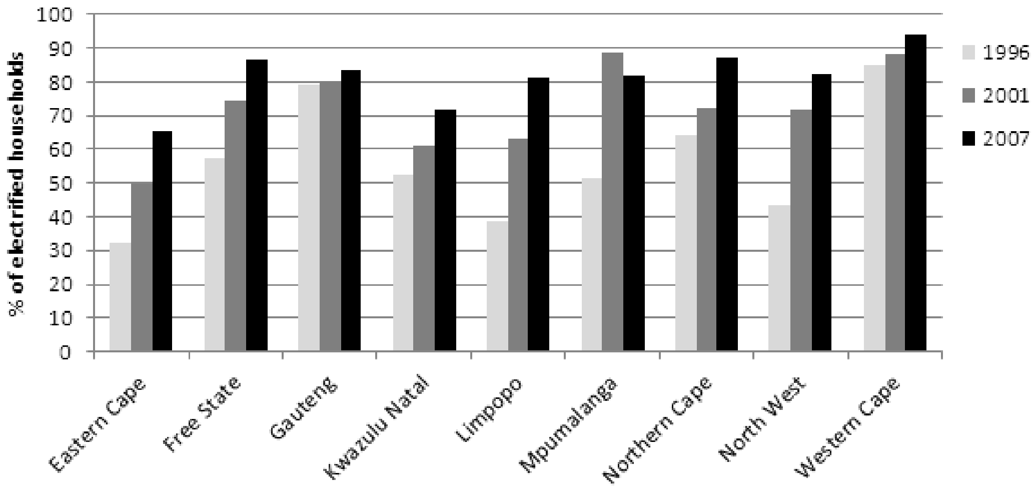

Figure 5: Provincial electrification status in 1996, 2001 and 2007
(Based on STATSSA, CS2007)

1996, but in 2007 it had the fourth highest percentage of electrified households.

The stagnant electrification growth rate is due to an escalating in migration into the province. Cowan (2005) identified that urbanization in South African cities has led to several problems, one of them being an inability to develop the infrastructure (such as extending grid electricity) and it seems that Gauteng is no exception.

According to Louw, Conrad, Howells and Dekenah (2008), access to electrification plays a significant role in determining the fuel mix a household chooses.

Table 4 shows percentage of households that used different fuels for lighting, cooking, and space heating in 2001 and 2007. It shows that the percentage of households that used electricity for the three end uses was increasing while the use of most fuels was declining. There was a sharp increase in gas lighting. This sharp increase in percentage of households that used gas for lighting is a bit ambiguous. But it might be attributed by the fact that the 2007 Community Survey took place at the time when the Department of Energy (then Department of Minerals and Energy) was undertaking some subsidy pilot studies regarding LPG use in low income households around Gauteng townships (DME, 2005). Another reason that might have caused such an increase is due to the fact that more high income households preferred Egoli gas according to *Engineering News* Online (2008) and there was no classification in the 2007 Community Survey Questionnaire of what type of gas households used.

1.3 Gauteng LEAP structure

Every LEAP model that is developed has its own structure but generally most residential energy demand models are described in terms of activities performed in the households. Figure 6 presents the

Table 4: Fuel use profile between census 2001 and CS 2007
Source: based on STATSSA, 2001 census, CS2007)

Fuels	*Census 2001 (%)*	*CS 2007 (%)*
Cooking		
- Electricity	72.4	81.3
- Gas	1.4	0.9
- Paraffin	22.1	16.5
- Wood	0.8	0.5
- Coal	2.8	0.7
- Animal dung	0.2	0
- Solar	0.2	0
- Other	0.1	0.1
Total	100	100
Lighting		
- Electricity	80.4	83.3
- Paraffin	2.8	0.2
- Candles	16.3	4.9
- Gas	0.2	11
- Solar	0.1	0.1
- Other	0.1	0.5
Total	100	100
Space heating		
- Electricity	69.8	76.7
- Gas	1.4	1
- Paraffin	12.3	12.8
- Wood	2.4	2.1
- Coal	11.2	4.9
- Animal dung	0.1	0
- Solar	0.2	0
- Other	2.6	2.4
Total	100	100

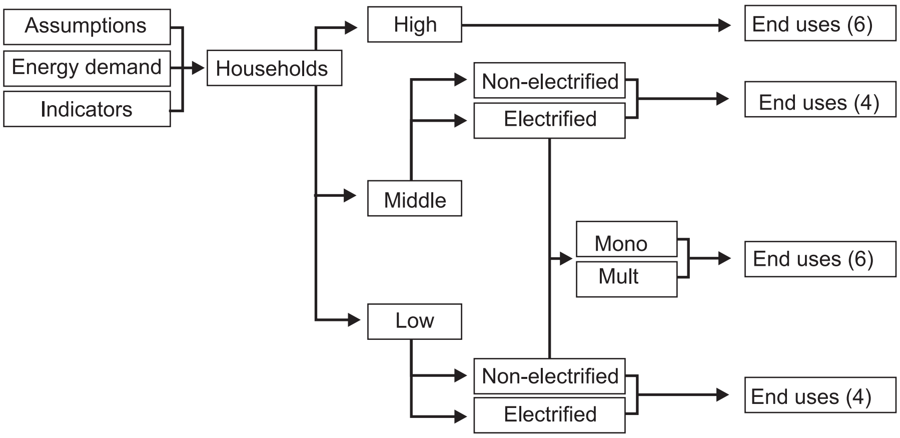

Figure 6: The Gauteng LEAP model structure

LEAP model structure for Gauteng's residential sector.

The LEAP model structure shown in Figure 6 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 household categories. 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 households (households that use electricity only to meet their energy needs) and multiple households (multiple 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.

2. Forecasting drivers of household energy demand

To conduct energy demand modelling, it is essential to know the drivers of energy demand and estimate how they would evolve in the future. Population and households growths are the sectoral (macro) drivers of energy demand in the residential sector. Although this study took income as the main micro-driver of energy demand at household level, the impacts of other macro drivers such as electrification levels, population and household growths cannot be ignored.

2.1 Projected households and population

Population and household growths are linked because one is the result of another, although the relationship is not linear. Based on the 2007 Community Survey and Landau and Gindrey's (2008) findings, this paper assumed Gauteng's population to grow at 1.6% annually which will result into 23 million people in 2030. The 2007 Community Survey estimated that there were 3.175 million households in Gauteng in 2007 while census 2001 reported that there were 2.74 million households in 2001. Based on these two values, the number of households has been growing at an annual rate of 2.3%. It is clear that the rate at which households were growing was higher than the rate at which the population was growing. This is because the average household size in Gauteng reduced from 3.9 people in 2001 to 3.3 in 2007. To forecast the number of households till 2030, it was assumed that the household size will not fall below 3 any time in the future. If the household size does not fall below 3 and the population grows as estimated, the household growth rate is estimated to be 2.30% per annum during the modelling period (2007- 2030).

2.2 Electrification growth rate

The rate at which households are electrified affect the way energy would be used in the future, as a result it is essential to estimate how electrification would evolve when doing energy demand modelling. This paper assumed that the current annual electrification rate of 0.56% will continue in Gauteng. If this rate of electrification is maintained, Gauteng will result in 96% electrification level by 2030. At this rate of electrification, it is clear that the government's goal of 100% electrification by 2012 (DME, 2005) cannot be possible given the high urbanisation level in the province.

2.3 Households mobility across income categories

When looking at the structure of the LEAP model in Figure 6, it is obvious that there can be three types of mobility experienced by households. There can be income level households' mobility (high income→ middle income → low income or vice versa). Secondly, there can also be household mobility between electrified and non-electrified households falling in the same income category and lastly there can be mobility between mono and multiple household categories in electrified middle and low income households.

2.3.1 Households' income mobility

Since households are classified by income categories, to undertake energy demand modelling, it is crucial to know household mobility between these three income categories. One of the most difficult assumptions one can make concerns estimates of future income within household. 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 rate (Raut, 1996).

According to Hair, Babin, Money and Samouel (2005) and Field (2009), the first thing to do before applying any mobility concepts is to verify that indeed mobility was experienced by the households. With that in mind, the starting point in this work was to investigate if there was any movement at all between the three household categories in Gauteng.

In skewed distributions such as income distributions, Hair, Babin, Money and Samouel (2005) identified that a good measure of central tendency is the median because the mean can be biased. As a result, this study used the median income to check the measure of central tendency (this measure was used to test whether there was any mobility between households within different income categories). The data that was used to check if there was any movement came from the censuses 1996 and 2001 and the 2007 Community Survey. The median income in the three years was used to observe the positional change of the median income for the three years. If median income increases over the years, it was then decided that more and more households are getting better off while a decrease would mean that households are getting poorer.

Figure 7 shows that the median income decreased in both real (median in 2007 Rands value) and nominal terms (median raw[1]) between 1996 and 2001 and thereafter, it started to increase till 2007.

Figure 7 conveys that more households moved to lower income bands between 1996 and 2001 but from 2002 to 2007, households started to go into higher income bands. The information contained in the median income, only highlights the movement of the middle income point, but does not say everything about the mobility of households between the three household categories that are modelled in this paper. To capture what was happening in all the income bands, some income mobility concepts had to be applied on the dataset.

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 Fields (2009) has discovered that household mobility can best be estimated from panel data.[2] The only study that collects panel income data in South Africa is the National Income Dynamics Study (NIDS) but the study is at its infancy. The National Income Dynamics Study (NIDS) undertaken by Southern Africa Labour and Development Research Unit (SALDRU) of University of Cape Town is still in its first wave[3] (which started in 2008), hence concrete conclusions regarding income mobility cannot be made from NIDS at present. Due to the lack of panel data related to income in South Africa and a harmonized methodological approach to forecast household income mobility, the household income data from the censuses 1996 and 2001 and the 2007 Community Survey was used to forecast household income mobility. Given the nature of available income data that was used for this study, and the absence of a harmonized methodological approach to forecast household income mobility, the next best mobility concept that can be used was extrapolation. Extrapolation was applied on 1996 and 2001 censuses data to compare households' income distributions and mobility in the three years (1996, 2001 and 2007).

The raw income data from the two censuses (1996 and 2001) and the 2007 Community Survey could not be directly used for linear extrapolation, since income bands in the three years were unique due to failure of Statistics South Africa to consider inflation when defining the income bands in the three surveys. To make the income bands comparable, the 1996 and 2001 income bands were inflated to the 2007 Rand value. After catering for inflation, linear extrapolation was applied on both cen-

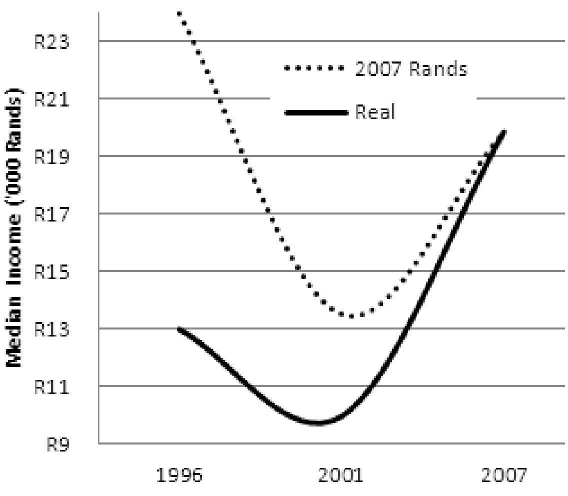

Figure 7: Median Income between 1996 and 2007

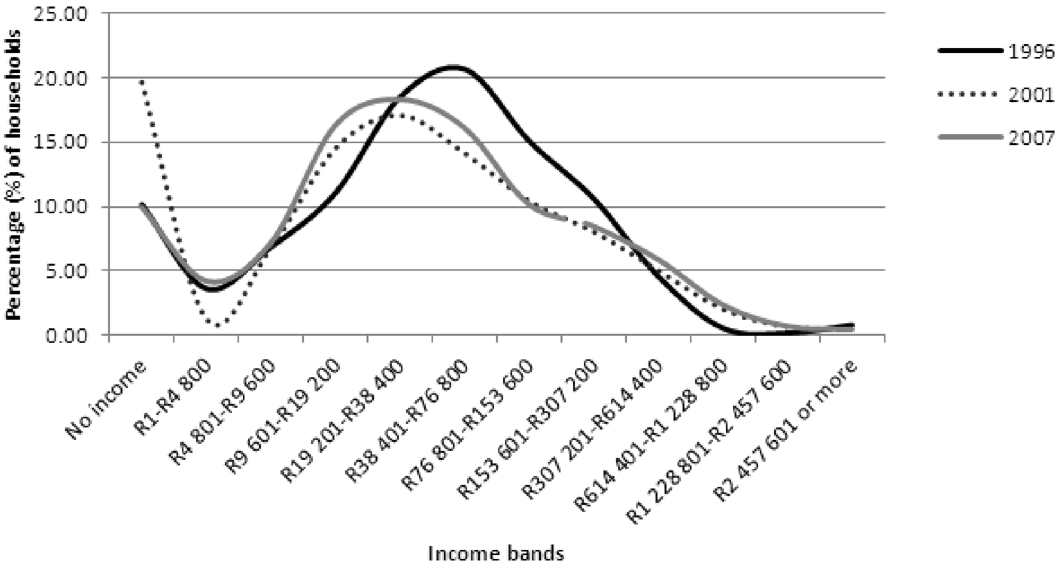

Figure 8: Households income distribution in 1996, 2001 and 2007

suses (1996 and 2001) income bands to align them to 2007 income bands so that income bands in the different years could be comparable. To perform this extrapolation, it was assumed that households were evenly distributed in each income band.

Figure 8 shows the positional changes in the income distributions of 1996, 2001 and 2007 after linear extrapolation was applied on 1996 and 2001 households' income data.

Although the fundamental shape of the income distributions did not change between the three years, Figure 8 shows that high percentage of households in 2001 and 2007 moved to lower income bands relative to 1996. Hence, there were more high and middle income households in Gauteng in 1996 than in 2001 and 2007. Even though there were more households in the *No Income* – income band in 2001 than in 2007, there was a slight shift of households to lower income bands between 2001 and 2007. The percentage of households in the *No Income*-income band in 2007 might have decreased due to high employment rate that the province experienced towards the 2010 World Cup, while in 2001; the economy was under strain (STATTSA, 2007). The economy experienced slowed economic growth due to contraction in real agricultural output and stagnant growth in mining and manufacturing sectors and slowed growth from other sectors (Reserve-Bank, 2003[4]). The performance of the economy showed unemployment rate decreasing between 2001 and 2007 as shown in Figure 9.

The performance of the economy can be linked to income because Amoetang and Heaton (2007) showed that 60% of households in South Africa received their income from employment.

Extrapolation was done to give a glimpse of households' income mobility trend between 1996 and 2007. Extrapolation results shown in Table 5 show that the share of middle income households in the three years was higher than those of low and high income households.

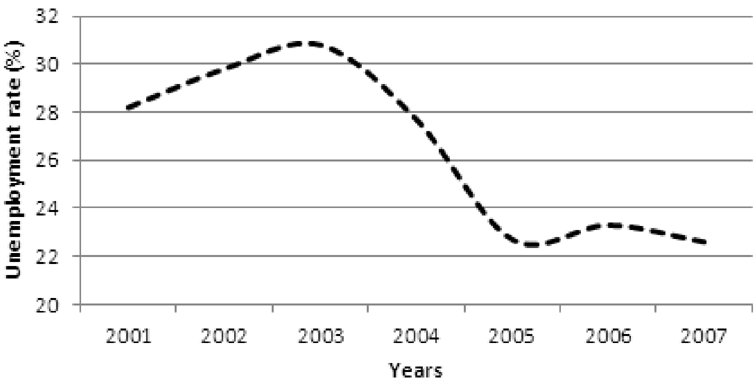

Figure 9: Unemployment rate in Gauteng between 2001 and 2007
(Source: STATSSA, 20075)

Table 5: Percentage of households

Category	*1996*	*2001*	*2007*
High	16.2%	16.2%	17.5%
Middle	63.7%	56.2%	60.9%
Low	20.1%	27.7%	21.7%

Interpolation was applied on the extrapolated results which forecasted the households' mobility trend between 2007 and 2030 and the interpolation results are shown in Figure 10.

Since there were only three data points used to forecast the share of households, the author acknowledges that this could introduce some biases on mobility. The share of low, middle and high income households would be 24.2%, 55.6% and 21.8% respectively by 2030. This mobility trend is assumed to exhibit an economic scenario and this scenario is termed the first economic scenario (ECO1).

The reliability of income mobility in this scenario is very low because only three data points were used. Raut (1996) and Fields (2009) argue that income mobility forecast strength is compromised if it is based on data that is less than 5 years. This low level of reliability on the income mobility forecast and the uncertainty of the future economic outlook in Gauteng as well as in the country prompted the exploration of the future under two other different economic scenarios. These two economic scenarios will result into different shares of the three modelled household categories.

These two extra economic scenarios – second economic scenario (ECO2) and third economic scenario (ECO3) assume that changes occur only in the share of high, middle and low income households while population, households and electrification growth rates are similar to the first economic scenario (ECO1). The second economic scenario (ECO2) uses the 2006 household mobility findings from the University of Cape Town's Unilever Institute. The Institute found that South Africa's black middle class households[6] had been growing at 3% annually since 1996. Given the fact that 75% of middle class households in Gauteng were black households in 2007 (STATSSA, 2007), the 3% was applied on all households irrespective of race. The fact that the definition of middle income in the Unilever's Institute study were classified as high income households for this study, therefore, the 3% annual growth was applied on high income households of this study. Applying this 3% growth on all high income households in Gauteng resulted in the following shares of household categories: 35.5%, 40.3% and 24.2% of high, middle and low income households respectively by 2030. The households that will be added into high income households are assumed to be moving from middle income households, while the low income households will be the same as in ECO1.

The third economic scenario (ECO3) is just a hypothetical scenario which is different from the first two but can be a plausible future. This third scenario assumes that middle income households will be moving into a low income household category at 3% annually instead of moving into a high income household category. This middle to low households' mobility will result into 39.1%, 39.4% and 21.5% of low, middle and high income households respectively by 2030.

The share of middle income households to that of both low and high income households is higher in the three economic scenarios. This shows that unless some drastic economic changes occur, there will always be high percentage of middle income households in the province.

2.3.2 Mono → multiple mobility

To calculate the number of households that use electricity only for all their end use in 2007, the electricity end-use ladder[7] derived from the World Bank (2008) was applied to 2007 Community

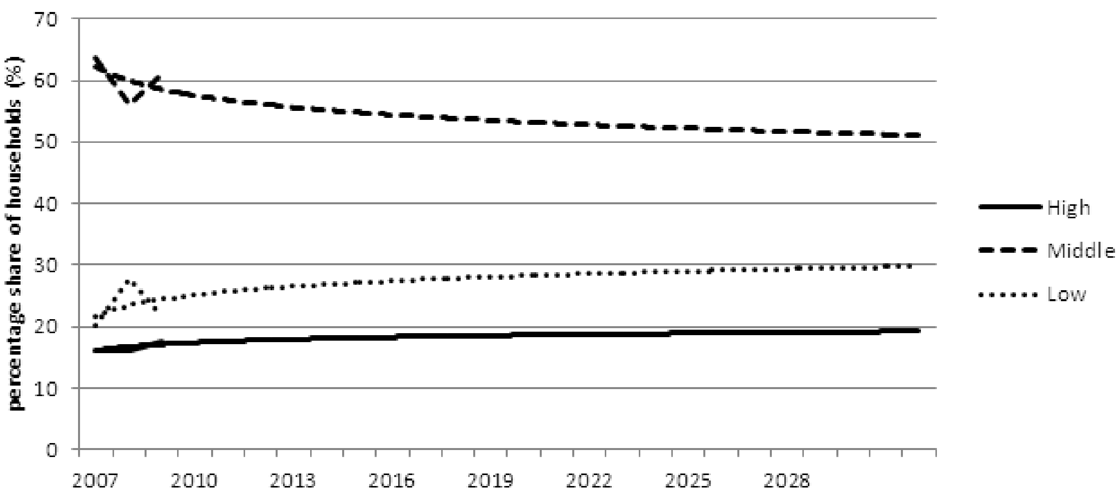

Figure 10: Future share of low, middle and high income households in Gauteng

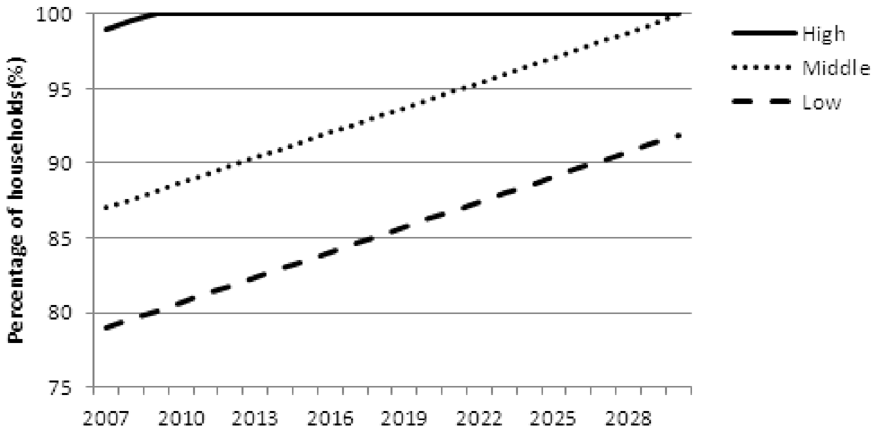

Figure 11: Electrification rates in 2030

Survey households. By applying the concept of the ladder, the study found that 96%, 76% and 64% of high, middle and low income households respectively used electricity only to meet all their energy needs in 2007. From this finding, it is evident that percentage of households that use electricity only for all their energy needs increase with income.

Based on how electricity was used for space heating in 1996 and 2001 censuses and the 2007 Community Survey (refer to Table 4), it was assumed that every 5 years, 5% of households in the multiple fuel categories will move into mono fuel categories. This would mean that from 2012 onwards, all high income households would be using electricity only for all their energy needs, 96% and 84% of middle and low income households would be using electricity only for all their energy needs respectively by 2030.

2.3.3 Non-electrified → electrified mobility

When applying the 0.56% annual electrification growth rate assumed earlier in section 3.2, Figure 11 shows that both high and middle income households would be electrified in 2030, while the low income households would have 92% electrification level.

Section 3 gives a detailed overview of how energy modelling was conducted.

3. Energy demand modelling

3.1 Modelling energy scenarios

Gauteng Integrated Energy Strategy (2010) highlighted a number of energy interventions that can be implemented in Gauteng's residential sector. The strategy identified that households could replace their incandescent lamps with CFL lamps and electric geysers with solar water heaters (SWH). To improve the thermal efficiencies of their houses, households could insulate hot water pipes and roofs and install some ceilings in the houses and the strategy suggests the implementation of SANS 204[8] for all newly built houses. For coal using households, the strategy suggested that these households can practice Basa Njengo Magogo (BnM). BnM is a technology by which coal lighting and stacking improves the coal brazier's efficiency. For space heating, the efficiency increases from 59% to 79%, while for cooking, efficiency increases from 8% to 11% (Gauteng Strategy, 2009).

From the above measures and from the energy policies applicable in Gauteng's residential sector, four energy scenarios were constructed and modelled besides the base case scenario (which incorporates the current measures taken by Gauteng households without any policy interventions). The four scenarios were energy efficiency (EE) scenario, thermal design scenario, minimum energy 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. The energy policies that were considered for the construction of these scenarios were found in Winkler (2006), Gauteng Integrated Strategy (2009), Energy Efficiency Strategy (2005), City of Tshwane's State of Energy Report (2006), City of Johannesburg State of Energy Report (2007) and City of Ekurhuleni State of Energy Report (2004).

3. 1. 1 Base case scenario

The base case in LEAP represents a case without new policy interventions. In other words, it is a projection of energy demand in the absence of new energy policies or strategic energy interventions. The base case assumes low penetration rates for BnM at 3% and 30% in 2015 and 2030 respectively in households that use coal (in line with what the Long Term Mitigation Scenarios assumed). CFL usage is assumed to be very low with a penetration rate of 2% for all households' categories in 2007 and 30% by 2030. The penetration rate of solar water heaters is assumed to be 30% by 2030 in all households' categories (high, middle and low income households). No other appliance efficiency improvements are assumed to be made in the base case.

3. 1. 2 Energy efficiency scenario

This scenario makes some aggressive assumptions in the uptake of energy efficiency measures. The scenario assumes 90% CFL penetration level. This high penetration level of CFL is very aggressive given the fact that even in countries such as Australia and Denmark which are known for high usage of CFLs (Winkler, 2009), 50% of CFL penetration levels have not been attained. The strong political will to reduce greenhouse gas emissions coupled with Eskom's desire to reduce energy demand, it is assumed that more CFL roll-outs would be experienced throughout the country.

With the assumption that the awareness campaigns around BnM would have reached all coal using communities, it is assumed that all households using coal braziers would be practicing BnM by 2030. The assumption for the wide spread of BnM practice is brought by the fact that most demonstrations of BnM occurred around Gauteng and Mpumalanga provinces (DME, 2005) and if they continue, almost all communities would know about BnM by 2030.

With regard to retrofits, it is assumed that all existing middle and high income households and 40% of existing low income households would have installed ceilings and roofs and electric geyser insulation by 2030. Given the high level of investment required for solar water heaters, it is assumed that 70%, 50% and 10% of high, mono middle and mono low income households would have installed SWH by 2030. The higher penetration level for high income households is brought by the fact that these households can afford to finance the solar water heaters under the current Eskom rebate programme. Since the affordability reduces with reducing income there will be a lower penetration level of SWHs for middle income households. As for low income households, all households in this category were assumed to install SWHs through local development programmes such as the SWH mass rollout as was done in Kuyasa, Lwandle and the following municipalities: City of Tswane, Sol Plaatje and Naledi (DOE, 2011).[9]

3. 1. 3 Thermal design scenario

This scenario considered all new households that will be built, particularly RDP houses, will have adopted the new SANS 204 (building code that is still under review). If insulation material that is suggested by the Thermal Insulation Authority of South Africa (TIASA) is used, Mathews and Van Wyk (1996) showed that a household can save up to 90% of energy used for space heating. This scenario assumes that RDP houses that will be built from 2011 onwards would have incorporated SANS 204 hence saving 90% of energy needed for space heating in low income households. These savings are similar to what Sustainable Energy Africa's (SEA) found by simulating a standard RDP house if SANS 204 is implemented (Gauteng Integrated Strategy, 2009).

3. 1. 4 Minimum energy performance servicescenario

South Africa has embarked on voluntary appliance labelling since 2005 (DME, 2005). In the United States and United Kingdom, history showed that voluntary labelling cannot achieve significant energy savings alone (Wilkenfeld & Harrington, 1997; Wade, Pett & Ramsay, 2003). Nadel (2002), Wilkenfeld and Harrington (1997) and Wade *et al.* (2003) discovered that substantial energy savings were achieved when policies and regulations that require appliances to meet minimum energy performance standards (MEPS) were implemented. When MEPS is implemented, manufacturers can make 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. This paper assumes that strict MEPS and labelling would co-exist in South Africa where households would be encouraged to buy efficient appliances.

One of the main criteria for determining appliances that can be prioritised for labelling and MEPS is the contribution of each end use and appliance type to the total electricity or energy used in households. Refrigerators, CFLs and the appliances used for the 'other' end uses are considered to fall under the MEPS program because refrigeration, lighting and other end use significant amount of electrical energy in the three household categories. For refrigeration, all high and middle income households are assumed to use an A rated fridge with 90% efficiency.[10] All low income households are assumed to use C rated fridges and the efficiency is improved by 10%, to get energy efficiency of 70%. It is assumed that 50% of fridges used in all households' categories by 2030 would be using A rated for middle and high income households and C rated for low income households. For this study, it is assumed that the overall appliance efficiency improvement in appliances that are used to perform other end-uses would be 20%, 10% and 5%, in high, middle and low income households respectively.

3.1.5 Gas scenario

In Gauteng, two types of gases are used in the residential sector: namely LPG and Egoli Gas. Egoli Gas is used in 13 000 households in Johannesburg. Egoli Gas' 1 200 km pipeline network currently covers 25% of Johannesburg and due to geological reasons; the network cannot extend beyond Johannesburg (*Engineering News* Online, 2008, DME, 2009[11]). 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, 2009[12]). 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. With regard to LPG, there is low level of usage in all households categories (refer to Table 4). This scenario assumes that all non electrified middle and low income households would use LPG gas for cooking and space heating. The following section presents the energy demand for each of the five energy demand scenarios.

4. Results and discussion

This section presents the energy demand of the five energy demand scenarios under the three economic scenarios. The result of each scenario is compared to the BASE case. In Figures11, 12, 13, 14 and 15, it is clear that the second economic scenario (ECO2) will result in higher energy demand under all energy scenarios, with the BASE case having the largest energy demand of about 121 PJ. The reason for such high energy demand is due to the fact that ECO2 is characterised with high proportion of high income households (which have high energy intensities) relative to ECO1 and ECO2. The ratio of high: middle: low income households in ECO2 was 0. 4:0. 4:0. 2 while in ECO1 and ECO3, the ratios were 0. 2:0. 6:0. 2 and 0. 2:0. 4:0. 4 respectively.

The energy demand trend in the thermal design scenario for both ECO1 and ECO2 is similar to the BASE case scenario. ECO3 energy demand trend in thermal design scenario was different from ECO3

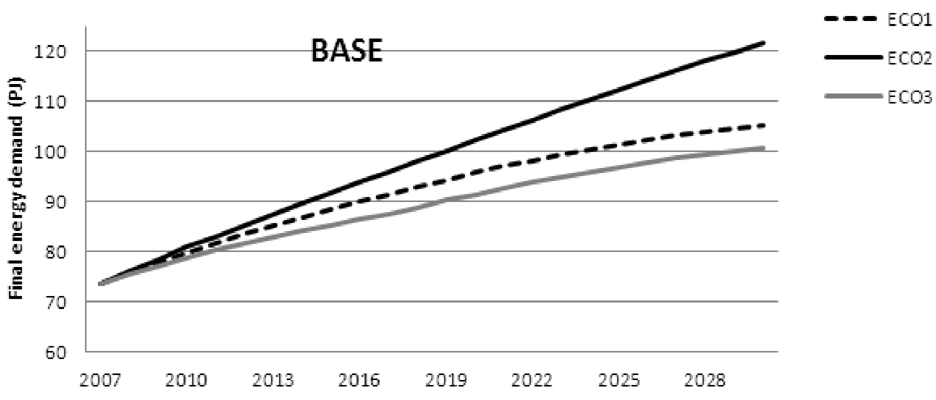

Figure 12: BASE case energy demand in all economic scenarios

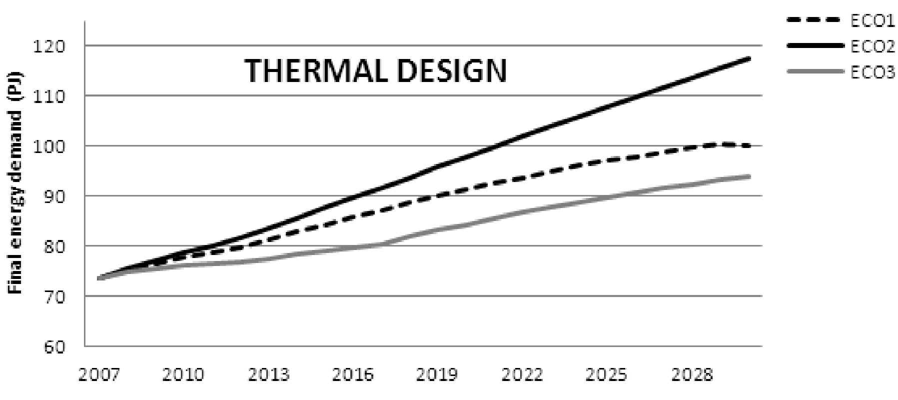

Figure 13: Energy demand from the Thermal design scenario

energy demand trend of the BASE case scenario. The ECO3 energy demand grew very slowly between 2010 and 2016 but after those years, the energy demand growth rate increased resulting into 93 PJ in 2030 relative to 100 PJ in the BASE case scenario.

The difference in energy demand trends between ECO3 in BASE case scenario (Figure 11) and ECO3 in thermal design scenario (Figure 12) comes from the fact that ECO3 has more low income households than ECO1 and ECO2 and the thermal design scenario is only applied to low income households. According to the thermal design scenario, low income households will reduce 90% of their space heating energy needs, as a result the impact of the thermal design scenario will be more visible in the economic scenario with more low income households, which in this case is ECO3.

Energy efficiency is a requirement in all sectors of the economy so that a low carbon South Africa can be realised. Figure 14 shows that if Gauteng's residential sector implements energy efficiency as suggested by the energy efficiency scenario above, it is possible to reduce the sectors energy demand by more than 30 PJ relative to BASE case scenario even under the high consumption economic scenario (ECO2).

Looking at Figure 15 it is evident that there is no major change in energy consumption between BASE case and the GAS scenario.

The similarity is brought by the fact that as households were electrified in the low and middle income households, they were assumed to abandon LPG use since the GAS scenario assumes that LPG is used by non electrified households. A small percentage of high income households continued using Egoli Gas and to a lesser extend LPG for cooking. The observed energy demand reductions came from the fact that Egoli gas appliances were assumed to be more efficient than LPG and electric stoves.

The energy demand results for MEPS scenario as shown in Figure 16, suggest that MEPS is the powerful scenario in reducing energy demand, second after the energy efficiency scenario.

MEPS becomes a powerful scenario in reducing energy demand because 76% of Gauteng households were using electricity in 2007 and by 2030, it was assumed that 96% of households will be using electricity. Since electrical appliance efficiency is improved in the MEPS scenario, energy demand reduction would be more evident.

The energy scenarios described in section 4 have a chance of occurring all at once in Gauteng if all the measures that the Gauteng Integrated Strategy suggests are implemented. If all the energy

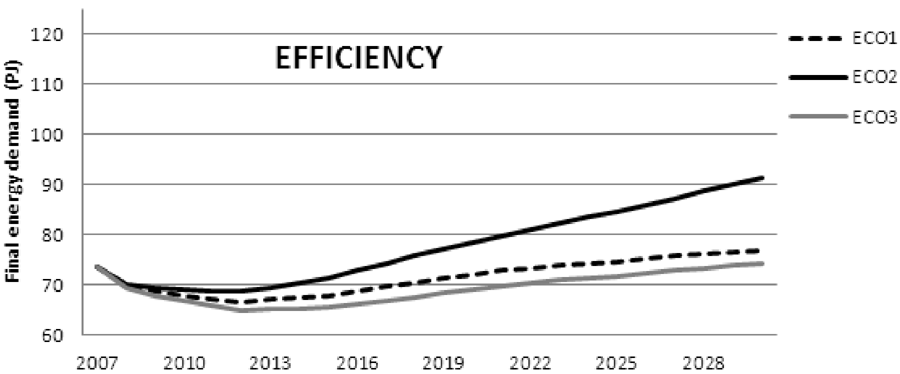

Figure 14: Energy efficiency energy demand in 3 economic scenarios

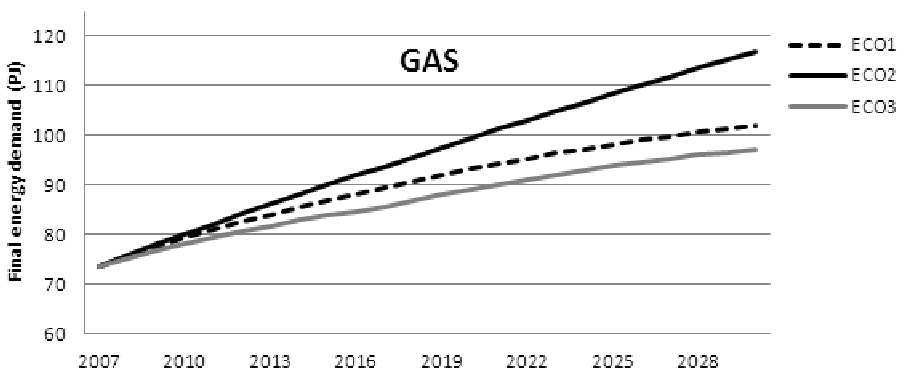

Figure 15: Gas scenario energy demand in all economic scenarios

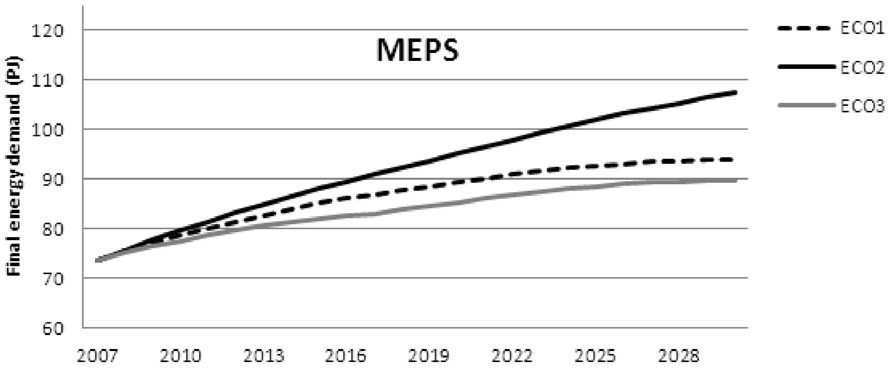

Figure 16: MEPS scenario energy demand in three economic scenarios

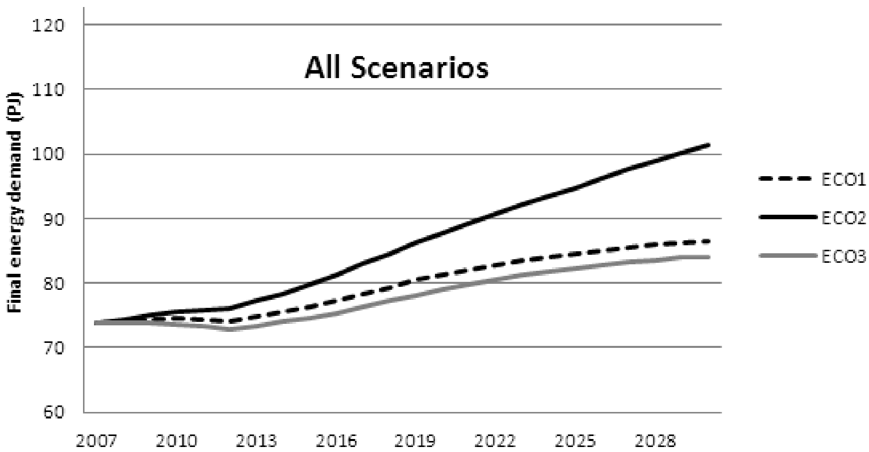

Figure 17: Final energy demand if all scenarios are implemented

demand scenarios are implemented as suggested in this study, Figure 17 shows that there will be significant energy demand reductions in all the economic scenarios. Energy demand is reduced such that even in ECO2 (the high demand economic scenario), the energy consumption will only be about 100 PJ by 2030.

The following section discusses the implications of fuel demand if all the scenarios are implemented in each economic situation.

4.1 Fuel demand implications

Figure 17 shows that in the base year (2007), 62%, 30% and 7% of Gauteng's residential sector energy demand was met by electricity, coal and paraffin respectively, with candles contributing a mere 1%.

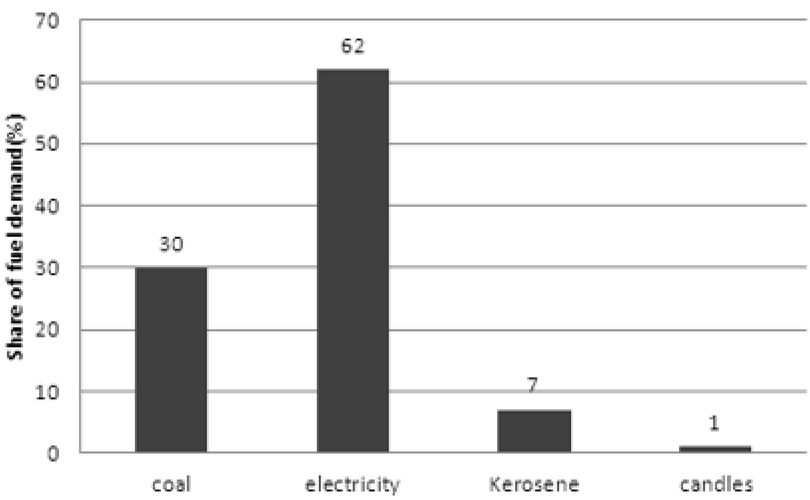

Figure 18: Fuel demand in base year in ECO1, ECO2 & ECO3

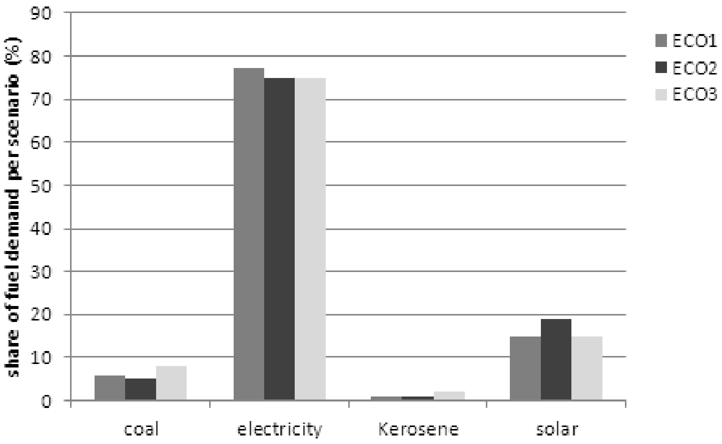

Figure 19: Fuel demand by 2030 in ECO1, ECO2 & ECO3

The contributions of other fuels such as LPG, Egoli Gas, solar energy were not significantly noticeable. It is essential to understand the implications of fuel demand in Gauteng that will be exhibited by the three economic scenarios. Understanding the fuel demand implications will help Gauteng to better plan for the supply of such fuels in the future. If all scenarios are implemented as assumed in this paper, Figure 18 shows that three quarters of Gauteng's residential sector energy demand would be met with electricity in each economic situation, followed by solar, then coal and lastly paraffin (kerosene).

Both paraffin and coal contributions to final energy demand are very small compared to the base year. It is evident that solar energy (through the use of SWH) will also make significant energy contributions to Gauteng's residential sector with almost 20% of energy demand being met by solar energy in ECO2 by 2030.

Electricity is the future fuel for Gauteng's residential sector. In light of the desire of the provincial government to move towards sustainable development it will be good to have more households using electricity as more lives will be improved. But high consumption of electricity will have some negative consequences on the environment due to emissions that come from electricity generation if the electricity supply industry in the country does not make radical changes to move towards renewable energy generation. The energy policies and strategies in the province should be steered towards encouragement of renewable energy use. Since the proportion of middle income households in the three economic scenarios would be high in Gauteng, viable financial incentives must be adopted by the provincial government if it wants to reduce electricity demand and GHG emissions. The incentives that can be used are the ones that will promote households to invest heavily in renewable energy technologies such as the Eskom rebate programme.

The modelling approach that was followed to model the energy demand in the residential sector of Gauteng is new. The model might not have given the good household mobility forecasts due to the income data limitations. However, there are future improvements on this work in 5 years time after the National Income Dynamics Study will have done more panel surveys. After 5 years, household mobility forecast will improve greatly and this methodology can be done at a national level which can also analyse the impact of income mobility on greenhouse gas emissions for climate policies. Such a study will inform most sustainable energy development policies.

It is well known that as household's income increases, appliance ownership also increases; detailed income mobility can help in forecasting electrical energy demand as income increases. Air conditioning is one end use that grows rapidly with income growth (Morna and. Van Vuuren, 2008). Seeing that electricity will likely be the main fuel used in Gauteng in future, it is necessary to do some studies that will analyse the correlation of electrical appliance ownership and income. McNeil and Letschert (2007) found that there is a strong correlation between household income and appliance ownership.

5. Conclusion

The most apparent discrepancies of the model are related to the fact that there is no panel income data that the mobility trends can be derived from. The mobility forecast taken in this paper opens paths for further research and refinement once the first wave of NIDS is finalised. The Energy Efficiency reduced significant energy demand more than any other scenario under the three economic scenarios. The significance of coal and paraffin would reduce over time irrespective of the economic situation. Solar did not make a significant energy contribution to overall energy demand in Gauteng in 2007, but in

2030, irrespective of the economic situation, solar will make significant energy supply contributions. Solar energy will make significant contribution if Eskom's fiscus and rebate programmes continue and households are willing to take advantage of these programmes.

Notes

1. This is the median income in the Rand value of the respective years
2. Panel data is a form of data where same households are followed year to year so that a trend can be established.
3. Round 1 means the first 5 years in which same households would be studied. Round 2 would be the next 5 years that follow the first 5 years.
4. SA Reserve Bank, 2003. Annual Economic Report 2003.
5. Labour force survey, 2007. Statistical release P0210.
6. The study defined a middle income household as a household that earned more than R154 000 per annum. This definition falls within the definition of high income household in this paper.
7. The ladder assumes that the last end use that electricity is used for is space heating. So if a household uses electricity for space heating it was classified as a mono fuel using household.
8. This code includes among other things, 15° North/South house orientation that allows a house to improve its thermal performance (which reduces heat flow in/or out of the house).
9. DOE website, http://www.energy.gov.za/files/swh_frame .html
10. An A+ rated fridge from one of the companies in South Africa consumed 0.975KWh/day (www.ardo.co.za/fr29all.htm).
11. This is the Gas infrastructure plan document
12. This is the Gas infrastructure plan document

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