# The Energy Transition Patterns of Low-income Households in South Africa: An Evaluation of Energy Programme and Policy

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**Abstract**

South Africa is a country in energy transition. The government has introduced a number of national programmes to widen access to electricity and to address affordability. The study investigated the energy transition patterns and trends amongst low-income South African households. This was to determine whether the energy policies and programmes have achieved the objectives of contributing towards socio-economic growth and development for low-income households in the country. In order to track mobility of the households with respect to their main energy choice for the three main energy services (cooking, heating and lighting), and to identify the determinants of the energy transition process, balanced panel data was used from the four waves of the National Income Dynamic Survey (NIDS). The results suggested a broader spectrum of determinants driving the energy choice(s) and transition pattern for low-income households.

**Keywords**: energy ladder; energy stacking; low-income; energy policy; energy programme

## 1 Introduction

Energy choices households make have a major impact on the shape of the energy system of a country and economic development (Joyeux and Ripple 2007; Lay *et al.* 2013). If a household relies mainly on traditional fuels for cooking, space heating or lighting, modern economic activities may be hindered as a result of serious health problems and hence act as barriers to economic development (Lay *et al.* 2013; Liu *et al.* 2013; Van der Kroon *et al.* 2013). Shifting to modern energy carriers is associated with welfare improvement and it is considered as an important developmental goal to achieve, in order to eradicate energy poverty (Kowsari and Zerriffi 2011; Liu *et al.* 2013).

It was estimated that 1.4 billion people around the world that lack access to electricity and that 2.7 billion people rely on the traditional use of biomass for cooking (International Energy Agency, IEA 2010; Kaygusuz 2012). The projection suggests that 1.2 billion people will still lack access to electricity in 2030, with 87% of them living in rural areas (IEA 2010; Kaygusuz 2012). In the same scenario, the number of people relying on traditional energy carriers for cooking will rise to 2.8 billion in 2030, 82% of them in rural areas (Abbasi and Abbasi 2010; IEA 2010). Kowsari and Zerriffi (2011) and Takama *et al*. (2012) suggested that households in developing countries might switch from traditional energy carriers to electricity or other modern energy alternatives if available and affordable. This stresses the importance in understanding household energy choice and energy switching behaviour in searching for policies to support the transition process.

For a number of developing countries, particularly those in Africa, the issue of understanding the pattern that governs energy choice decision by households is necessary from a policy standpoint. This suggests either the 'energy ladder' or 'energy stacking' model of household decision-making. The Energy Ladder Model aligns with the economic theory of the consumer and it conceptualises a linear transition of household energy choices from traditional energy carrier to transitional energy carrier and to modern energy carrier (Hosier and Dowd 1987; Lee *et al.* 2015; Van der Kroon *et al.* 2013). On the other hand, the Energy Stacking Model or Multiple Fuel Use was developed based on findings that households choose to use a combination of energy carriers on both upper and lower stages on the energy ladder (Arnold *et al.* 2006; Davis 1998; Kowsari and Zerriffi 2011; Lee *et al.* 2015; Martins 2005). The influence of some household characteristics also determine household energy choices and transition (Kowsari and Zerriffi 2011; Mekonnen and Köhlin 2008; Pachauri and Jiang 2008; Van der Kroon *et al.* 2013).

This paper aims to investigate if low-income households in South Africa adopt the energy ladder or energy stacking models for their cooking, heating or lighting energy services. There is also a critical need to examine the characteristics of the low-income households that explain energy transition behaviour. This is to determine if the energy policies and programmes targeted towards low-income households are fulfilling their objectives. The study begin by reviewing the electricity policies and programmes in South Africa and the energy consumption patterns amongst the low-income households. This paper reports the findings from the use of the National Income Dynamics Survey (NIDS) dataset covering 2008 to 2014. This was to track the mobility of the households with respect to their main energy choice for the three main energy services.

## 2 South Africa's Electricity Programmes and Policies

South Africa is a middle-income developing country with uneven social and economic development due to apartheid, which was abolished in 1994 (Winkler and Marquand 2009; Ziramba 2009). Programmes and policies in South Africa are initiated to comply with the provisions of the Constitution of the Republic (Department of Energy 2015). In addressing the energy imbalance and demand in the residential sector, the National Electrification Programme (NEP) was implemented between 1994 and 1999. The main objective of the programme was to electrify the residences of rural and urban low-income households that had been deprived of access to electricity during the apartheid period. The programme expected that electrified households would switch from using wood, candles and batteries to using electricity for their household needs. In 2000, the government announced a policy to provide free basic services (water, sanitation and energy) to poor households (Adam 2010; Bhorat *et al.* 2012). The Department of Minerals and Energy (DME) in 2003 launched the Free Basic Electricity (FBE) Policy as a complementary policy to the NEP, to bring about relief to the newly electrified households (Bhorat *et al.* 2012; DME 2003). The FBE policy states that an allocation of 50kWh of electricity per month be provided free of charge to poor households connected to the national electricity grid (DME 2003; Inglesi 2010; Ruiters 2009).

## 3 Energy Consumption Patterns in South Africa

The country's household energy mix includes electricity, liquefied petroleum gas (LPG), coal, wood, paraffin and solar energy (Department of Energy, DoE 2012; Swart and Bredenkamp 2012). However, it is evident that considerable differences in patterns of energy mix are likely to exist between electrified and non-electrified households (Swart and Bredenkamp 2012; Vermaak *et al.* 2014). It was found that households with electricity, use this energy source for lighting, cooking or space heating; though it was reported that other sources such as candles, paraffin, wood and LPG continued to be used in at least a fifth of cases (DoE 2012; Sustainable Energy Africa, SEA 2014). Non-electrified households were found to rely primarily on candles for lighting and paraffin, coal, gas and wood for cooking and space heating (DoE 2012; SEA 2014). Dry cell batteries are used for powering appliances (DoE 2012; SEA 2014). The use of car batteries or generators and solar energy is apparent in both electrified and non-electrified households (DoE 2012).

The patterns of energy use by low-income households, electrified or non-electrified, also show a mix of different energy carriers (DoE 2012; Statistics South Africa 2008). The energy carriers chosen by low-income households depend on budget, need, availability and preferences (DoE 2012; SEA 2014). Low-income households often experience erratic cash flows, giving rise to expenditure patterns that do not allow for large amounts of income to be spent on energy, such as paying an electricity bill at the end of the month or buying a large quantity of fuel for the month (DoE 2012; SEA 2014). Thus, energy is usually purchased in small amounts, for example, a bucket of coal, a litre of paraffin or purchase on a prepaid electricity card for a minimum amount of R20 (2012 rand value) (DoE 2012; SEA 2014). Traditional and transitional energy carriers are used for domestic activities such as cooking, lighting and space heating, and this is in spite of some households having electricity connections (DoE 2012; Statistics South Africa 2008). In addition, due to increases in the cost of electricity coupled with interruptions in electricity supply, households use candles as a source of lighting (DoE 2012; Swart and Bredenkamp 2012). The energy use patterns of low-income households are therefore shown as portraying a complexity of social and economic factors (SEA 2014; Swart and Bredenkamp 2012).

Each year, thousands of South Africans (especially from low-income households) die due to respiratory illnesses caused by indoor air pollution (Barnes *et al.* 2011; Swart and Bredenkamp 2012). The use of candles, paraffin or wood can lead to devastating shack fires (Kimemia *et al.* 2014; Kohler *et al.* 2009). Paraffin poisoning is a common incident in low-income settlements as children sometimes drink paraffin, due to mistaken identity of paraffin, which is usually stored in a beverage or cool drink bottle (Kimemia *et al.* 2014; Swart and Bredenkamp 2012). Approximately, 80 000 children are poisoned each year in South Africa from accidentally drinking paraffin and paraffin related incidents cost the economy R104 billion (2009 Rand value) annually (Adams 2010; Kimemia *et al.* 2014). School children who want to study at night have to do so by the dim glow of a candle (Kohler *et al.* 2009; Swart and Bredenkamp 2012). Kohler *et al.* (2009) highlighted that access to efficient and affordable modern energy carriers are vital to alleviating the effects of energy poverty.

## 3. Data and Methodology

### *3.1 Data Description*

The data employed for the analysis comes from the four waves of the National Income Dynamics Survey (NIDS). The NIDS is the first national longitudinal panel study of individuals and households established by The Presidency of South Africa (Leibbrandt *et al.* 2009; Woolard *et al.* 2014). The survey began in 2008 (the baseline wave), with a nationally representative sample of 28 000 individuals residing in 7 300 households across the country (Leibbrandt *et al.* 2009; Woolard *et al.* 2012). The survey continues to be repeated every two years with the same group of households or individuals using a combination of household, adult, child and proxy questionnaires (Brown *et al.* 2012; Leibbrandt *et al.* 2009; NIDS 2012).

### *3.2 Model Specification*

An ordered logit model, also known as the proportional odds model, is a statistical technique that does take ordering into account and the odds ratio of the event is independent of the category $j$ (Greene 2008). In addition, an ordinal logit regression considers the probability of the event and all others above it in the ordinal ranking. In other words, an ordinal logit regression is concerned with cumulative probabilities rather than probabilities for discrete categories (Agresti 2010).

Households face choices between traditional, transitional and modern energy carriers for cooking, heating and lighting purposes and are assumed to maximise their utility by choosing one of the energy carriers as their main energy for the specific end-use. Following the approach of O'Connell (2005), suppose data ($Y_i$, $X_{1i} \ldots X_{ki}$) for observations $i = 1, \ldots, n$, where $Y$ is a response variable with C ordered categories: $j = 1, \ldots, C$, with probabilities, $P(Y = j) = \pi^{(j)}$ and $X_1 \ldots X_k$ are $k$ explanatory variables and observations $Y_i$ are statistically independent of each other. Consider the C – 1 cumulative probabilities:

$$\gamma^{(j)} = P(Y \leq j) = \pi^1 + \ldots + \pi^{(j)} \text{ for } j = 1, \ldots, C-1 \qquad \text{(Equation 1)}$$

$$\gamma^{(j)} = P(Y \leq j) = \pi^2 + \ldots + \pi^{(j)} \text{ for } j = 2, \ldots, C-1 \qquad \text{(Equation 2)}$$

$$\gamma^{(j)} = P(Y \leq j) = \pi^3 + \ldots + \pi^{(j)} \text{ for } j = 3, \ldots, C-1 \qquad \text{(Equation 3)}$$

The following holds for $\Upsilon_i^{(j)} = P(Y_i \leq j)$ for each unit $i$ and each category $j = 1, \ldots, C-1$:

$$\log [\Upsilon_i^{(j)} / 1 - \Upsilon_i^{(j)}] = \log [P(Y_i \leq j) / P(Y_i > j)] = \alpha^j - (\beta_1 X_{1i} + \ldots + \beta_k X_{ki}) \quad \text{(Equation 4)}$$

Assume that the observed ordinal variable is $Y_i$ is related to the latent variable according to the following scheme:

$Y_i = k$ if $\mu_{k-1} \leq Y_i^* \leq \mu_k$ for $k = 1, \ldots. K$ (Equation 5)

The model for the cumulative probabilities is:

$$\Upsilon^{(j)} = P(Y \leq j) = \frac{exp[\alpha j - (\beta 1X1i + \ldots + \beta kXki)]}{1 + exp[\alpha j - (\beta 1X1i + \ldots + \beta kXki)]} \quad \text{(Equation 6)}$$

The intercept terms must be $\alpha^{(1)} < \alpha^{(2)} < \ldots < \alpha^{(C-1)}$, to guarantee that $\Upsilon^{(1)} < \Upsilon^{(2)} < \ldots < \Upsilon^{(C-1)}$. The parameters $\alpha$, called thresholds are in increasing order ($\alpha^{(1)} < \alpha^{(2)} < \ldots < \alpha^{(C-1)}$), $\beta_1, \ldots, \beta_k$ are the same for each value of $j$. This is good for the parsimony of the model because it means that the effect of an explanatory variable on the ordinal response is described by one parameter (Agresti 2010; Grilli and Rampichini 2014).

In the case of three ordered categories, the equation simplifies to:

$$P(Y=1) = \frac{1}{1+exp(\beta 1X1i - k1)} \quad \text{(Equation 7)}$$

$$P(Y=2) = \frac{1}{1+\exp(\beta 1X1i - k2)} - \frac{1}{1+\exp(\beta 1X1i - k1)} \quad \text{(Equation 8)}$$

$$P(Y=3) = 1 - \frac{1}{1+\exp(\beta 1X1i - k2)} \quad \text{(Equation 9)}$$

By maximum likelihood, estimates for $\alpha$ and $\beta$ can be obtained. The likelihood function for each $i^{th}$ observation can be expressed as:

$$\ell_i(\alpha, \beta) = 1[Y_i = 0] \log[\Lambda(\alpha_1 - X_1\beta)] + [Y_i = 1] \log[\Lambda(\alpha_2 - X_1\beta) - \Lambda(\alpha_1 - X_1\beta)] + [Y_i = 1] \log[1 - \Lambda(\alpha_3 - X_1\beta)] \quad \text{(Equation 10)}$$

According to Greene (2008), the parameters for an ordered logit model can be difficult to interpret. Therefore, reporting marginal effects after an ordered logistic regression can make the results more understandable (Greene 2008; Long and Freese 2014). For this study, the marginal effects are calculated at the mean values in a covariate model showing how P(Y=1) changes as the variables changes from 0 to 1, holding all other variables at their means. In other words, the marginal effect approximates how much the dependent variable is expected to increase or decrease for a unit change in an explanatory variable: that is, the effect is presented on an additive scale (Buis 2010). The marginal effects are obtained by taking the partial derivatives of Equations 7, 8 and 9, which is written as:

$\partial Pr\ (Y=0|X) / \partial X_k = -\beta_k \lambda\ (\alpha_1 - X\beta);$

$\partial Pr\ (Y=j/X) / \partial X_k = \beta_k\ [\lambda\ (\alpha_{j-1} - X\beta) - \lambda\ (\alpha_3 - X\beta)]$, *for 0<j<3; and*

$\partial Pr\ (Y=3/X) / \partial X_k = \beta_k\ \lambda\ (\alpha_3 - X\beta)$ (Equation 11)

The predicted probabilities are estimated as:

P (Y_ordinal = 'less preferred') = P (S+ u ≤ _cut1)

P (Y_ordinal = 'moderately preferred') = P (_cut1< S+ u ≤ _cut2)

P (Y_ordinal = 'most preferred') = P (_cut2< S+ u) (Equation 12)

In which the basic formula is written as:

$Pr(Y = j|X) = F\ (\hat{T}_j - X_1\hat{\beta}) - F\ (\hat{T}_{j-1} - X_1\hat{\beta})$ (Equation 13)

Based on the assumptions of the 'energy ladder', modern energy carriers should be the source most preferred (being on top of the ladder) by the low-income households for cooking, heating and lighting. Transitional energy carriers are assumed to be moderately preferred being in the middle of the ladder, whilst traditional energy carrier will be less preferred because it is at the bottom of the ladder.

### *3.3 Procedures and Technique of Analysis*

The description of low-income households for the allocation of FBE is different from the description of low-income households, by the South African Bureau of Market Research (2011) and Statistics South Africa (2011). The South African Bureau of Market Research (2011) and Statistics South Africa (2011) defined low-income households as earning R0 – R18 000 per annum or households with an income below R1 500 per month. However, the Department of Mineral and Energy, DME (2003), defined qualified low-income households for FBE, as households whose gross monthly income of all the members of the household does not exceed two old age pensions. In this study, the description of low-income households by DME is considered as it captures the households that are qualified for the FBE policy. The dataset therefore contained 10 804 observations. In order to track the energy transition of the low-income households, a balanced panel data model was used for the analysis. According to Hsiao (2003), a panel is said to be balanced if it has the same time or periods, t = 1 … T, for each cross sectional observation. In other words, a balanced panel dataset will contain all elements observed in all period allowing an observation of the same household across the years of survey. An average observation of 700 low-income households was used for the analysis. Data analysis was done using STATA version 12.

The independent variables (or the endogenous characteristics) (see appendix for the description and measurement) to be used were first tested for multi-collinearity. The independent variables include income, age, gender, rurality, household size and dwelling type. The variable 'Year' is also included as part of the independent variables. The variance inflation factor (VIF) and tolerance value were used to detect if multi-collinearity exists amongst the variables. As a rule of thumb, a variable whose VIF value is greater than 10 or the tolerance value is lower than 0.1 means that there is a linear combination of other independent variables and thus may merit further investigation (Gujarati and Porter 2009). The test result shows that the VIF for each independent variable is less than 1.5 and the tolerance value ranges between 0.7 to 0.9. As such, multi-collinearity is not a threat for the regression analysis.

## 4 Results

The result of the marginal effects after ordered logistic regression with respect to cooking energy service is shown in Table 1. The marginal effects provide the amount of change in Y that will be produced by a unit change in $X_k$ holding other independent variables constant at their reference points. The reference points for dwelling type is modern dwelling, gender is female, rurality is urban and household size is small house size (1 -4 persons). Income and age are set at their means, which are R825.88 and 50.82 years respectively. For the 'year' variable, STATA sets a mean for 2010, 2012 and 2014. It is important to note that in this study, modern energy carriers include electricity from mains, gas, electricity from generator and solar energy. Transitional energy carriers comprise of paraffin and coal while traditional energy carriers include animal dung and wood.

**Table 1: Marginal Effects for Energy Choice for Cooking**

| | Marginal effects for traditional energy carrier | Marginal effects for transitional energy carrier | Marginal effects for modern energy carrier |
|---|---|---|---|
| Income | -2.07e-05 | -2.30e-05 | 4.38e-05 |
| Dwelling type (modern dwelling) | -0.1023*** | -0.0865*** | 0.1889*** |
| Age | 3.25e-04 | 3.61e-04 | -6.875e-04 |
| Gender (female) | -0.0043 | -0.0047 | 0.0090 |
| Rurality (urban) | -0.1527*** | -0.1126*** | 0.2654*** |
| Household size (small household size) | -0.0498** | -0.0485** | 0.0983** |
| Year (2010) | -0.0266** | -0.0305** | 0.0572** |
| Year (2012) | -0.0371*** | -0.0429*** | 0.0801*** |
| Year (2014) | -0.0365*** | -0.0423*** | 0.0788*** |

t-statistics in parentheses: * significant at 10% ** significant at 5%; *** significant at 1%

One does not usually interpret insignificant variables. However, since income is such an important variable, as it determines the evidence of which pattern of energy transition the low-income households adopts, it will be discussed in brief for the three main energy end-use.

Table 1 shows that income is not statistically significant for traditional, transitional and modern energy carriers, which is likely to reflect an 'energy stacking' behaviour with respect to cooking energy service. Therefore, for the sample of low-income households in South Africa, income is not found to be a statistically significant determinant of energy choice for cooking when controlling for all other variables in the model such as household size, rurality, dwelling type, and age and gender of the household head.

The results reveal that dwelling type (modern), rurality (urban) and household size (small household size) have negative signs and are statistically significant at 1%, 1% and 5% level of significance respectively for traditional and transitional energy carriers. For dwelling type, for example, low-income households living in modern dwellings are 10% less likely to use traditional energy carrier and 8% less likely to use transitional energy carrier for cooking than their counterpart living in non-modern dwellings. For a modern energy carrier, the sign for modern dwelling type is positive. Therefore, low-income households living in modern dwellings are 19% more likely to use a modern energy carrier than low-income households living in traditional or informal dwellings for their cooking. Thus, the inference that modern dwelling enhances a higher probability of choosing a modern energy carrier for cooking was substantiated. Suliman (2013) identified that modern roofs significantly increased the probability of Sudanese households adopting modern energy carriers as modern dwellers tend to avoid roof stains that occur in the course of using traditional energy carriers.

For rurality, urban low-income households are 15% less likely to use traditional energy carriers and 11% less likely to use transitional energy carriers for cooking than rural low-income households. For the modern energy carrier, the sign for urban is positive. In consequence, urban low-income households' are 27% more likely to adopt modern energy carrier for cooking compared to rural low-income households. Baiyegunhi and Hassan (2014) also confirm a similar result in a study conducted in Kaduna State, Nigeria. The study showed that urban households use modern energy carrier for cooking because the kitchen is not external (i.e. not outside the house).

For household size, low-income households with small household sizes are 5% less likely to use a traditional energy carrier for cooking than their counterparts with larger household size. In addition, low-income households with small household size are 5% less likely to use a transitional energy carrier for cooking than low-income households with larger household size. For modern energy carriers, the sign for small household size is positive. It implies that low-income households with small household sizes are 10% more likely to use modern energy carriers for cooking than their counterparts with larger household size. Barnes *et al.* (2005), Guta (2012) and Van der Kroon *et al.* (2013) have also found that increasing family sizes limits the need to use modern energy carriers for cooking since there is abundant labour available for fuel collection (e.g. wood).

The 'year' variables, 2010, 2012 and 2014 have negative signs for traditional and transitional energy carriers. The implication is that, in 2010, 2012 and 2014, low-income households are 3%, 4% and 4% less likely to use traditional energy carriers for cooking, respectively than in 2008. Further, low-income households are 3% less likely to use transitional energy carriers for cooking in 2010, 4% less likely in 2012 and 2014 than in 2008. However, for the modern energy carrier, the sign for 2010, 2012 and 2014 is positive. This implies that low-income households are 6% more likely to use modern energy carriers for cooking in 2010 than in 2008 and 8% more likely in 2012 and 2014 than in 2008. Therefore, one could say that South Africa is making progress in terms of improving access to modern energy sources. This could be because of addressing accessibility and affordability issues, for example, expansion of the national electricity grid or because of policies such as FBE.

Finally, the variables, age (at mean 50.82 years) and gender (female) of the household head are not statistically significant indicating they are not relevant in influencing the choice of energy carriers (traditional, transitional or modern) for cooking by low-income households, holding all other variables in the model constant.

The study further analysed the predicted probabilities of the low-income households for the choice of energy for cooking in order to see their probability of preference and to determine if the result of the logistic regression makes sense.

| | 95% confidence interval |
|---|---|
| Pr (y=1= less preferred \| x: 0.1826 | [0.1531, 0.2120] |
| Pr (y=2=moderately preferred \| x: 0.1803 | [0.1504, 0.2102] |
| Pr (y=3=most preferred \|x: 0.6371 | [0.5987, 0.6755] |

The interpretation of the result is that there is a 64% probability of the choice of modern energy carriers being most preferred for cooking by low-income households, holding other variables constant at their reference points. Further, there is 18% probability that low-income households will choose transitional energy carriers, which is a moderately preferred energy choice for their cooking, holding other variables in the model constant at their reference points. Lastly, there is 18% probability that the low-income households will choose the option of traditional energy carriers for cooking, which is a less preferred option, holding other variables in the model constant at their reference points.

**The Result of the Marginal Effects for Energy Choice for Heating**

Table 2 reveals the result of the marginal effects after ordered logistic regression with respect to heating energy service.

**Table 2 Marginal Effects for Energy Choice for Heating**

| | Marginal effects for traditional energy carrier | Marginal effects for transitional energy carrier | Marginal effects for modern energy carrier |
|---|---|---|---|
| Income | -2.98e-05 | -2.33e-05 | 5.32e-05 |
| Dwelling type (modern dwelling) | -0.1846*** | -0.0876*** | 0.2723*** |
| Age | 0.0007 | 0.0005 | -0.0013 |
| Gender (female) | 0.0086 | 0.0069 | -0.0156 |
| Rurality (urban) | -0.2047*** | -0.0916*** | 0.2964*** |
| Household size (small household size) | -0.0711** | -0.0462** | 0.1173** |
| Year (2010) | -0.0794*** | -0.0664*** | 0.1458*** |
| Year (2012) | -0.0621*** | -0.0517*** | 0.1138*** |
| Year (2014) | -0.0635*** | -0.0531*** | 0.1167*** |

t-statistics in parentheses: * significant at 10% ** significant at 5%; *** significant at 1%

Table 2 shows a similar result with the energy choice for cooking in Table 1.

There is an evidence of an ‘energy stacking’ behaviour by low-income households for space heating since income is not statistically significant.

Further, Table 2 reveals that dwelling type (modern dwelling), rurality (urban) and household size (small household size) are statistically significant at 1%, 1% and 5% level of significance respectively and have negative signs for traditional and transitional energy carriers.

For dwelling type, low-income households living in modern dwelling were 18% less likely to use traditional energy carrier, 8% less likely to use transitional energy carrier for heating and 27% more likely to use modern energy carrier for their space heating, holding other variables in the model constant at their reference points.

Further, urban low-income households were 21% less likely to use traditional energy carriers for heating, 9% less likely to use transitional energy carriers and 30% more likely to use modern energy carrier, holding other variables in the model constant at their reference points.

Low-income households with small household size were 7% less likely to use traditional energy carriers, 5% less likely to use transitional energy carriers and 18% more likely to use modern energy carriers for heating. Therefore, with household size, as found with the energy choice for cooking, small household size imply less energy demand, and as such, the low-income households will prefer to use a modern energy carrier for their space heating.

The inference for the 'year' variables is that low-income households were 8% less likely to use traditional energy carriers in 2010 than in 2008 and 6% less likely in 2012 and 2014 than in 2008. For modern energy carrier, low-income households were 15% more likely to use modern energy carriers for heating in 2010, 11% more likely in 2012 and 12% more likely in 2014 compared to 2008.

As found with the choice of energy for cooking, the variables, age and gender of the household head are not statistically significant indicating they are not relevant in influencing the choice of energy carriers (traditional, transitional or modern) for heating by low-income households, holding all other variables in the model constant.

The predicted probabilities for the energy choice for heating by low-income households is:

| | 95% confidence interval | |
|---|---|---|
| Pr (y=1= less preferred \| x: 0.2755 | [0.2380, | 0.3129] |
| Pr (y=2=moderately preferred \| x: 0.1886 | [0.1549, | 0.2223] |
| Pr (y=3=most preferred \|x: 0.5359 | [0.4934, | 0.5784] |

The outcome suggest that there is a 54% probability that the choice of a modern energy carrier will be chosen for heating among low-income households. Further, there is 19% probability that low-income households will chose a transitional energy carrier and 19% probability for the option of a traditional energy carrier for their space heating, holding other variables constant at their means.

**The Result of the Marginal Effects for Energy Choice for Lighting**

Table 3 reveals an interesting and different result for the marginal effects for lighting energy service compared to the ones revealed in Tables 1 and 2

**Table 3 Marginal Effects for Energy Choice for Lighting**

| | Marginal effects for candles | Marginal effects for transitional energy carrier | Marginal effects for modern energy carrier |
|---|---|---|---|
| Income | -2.67e-05 | -6.69e-06 | 3.34e-05 |
| Dwelling type (modern dwelling) | -0.1792*** | -0.0327*** | 0.2120*** |
| Age | 0.0001 | 2.76e-05 | -0.0001 |
| Gender (female) | - 0.0311 | -0.0074 | 0.0385 |
| Rurality (urban) | -0.0576*** | -0.0131*** | 0.0708*** |
| Household size (small household size) | -0.0176 | -0.0042 | 0.0219 |
| Year (2010) | -0.0155 | -0.0039 | 0.0195 |
| Year (2012) | -0.0303 | -0.0077 | 0.0380 |
| Year (2014) | -0.0498*** | - 0.0129** | 0.0627*** |

t-statistics in parentheses: * significant at 10% ** significant at 5%; *** significant at 1%

Table 3 presents an 'energy stacking' behaviour for lighting, with income being statistically insignificant, which is similar to the results of energy choice for cooking and heating.

The results reveals that dwelling type (modern dwelling) and rurality (urban) are statistically significant at 1% level of significance and have negative signs for traditional and transitional energy carriers.

Low-income households living in modern dwellings are 17% less likely to use candles, 3% less likely to use transitional energy carriers and 21% more likely to use modern energy carriers for lighting than those living in non-modern dwelling do, holding other variables in the model constant.

Further, the results draws that urban low-income households are 6% less likely to use candles for lighting, 1% less likely to use transitional energy carriers and 7% more likely to use modern energy carriers than rural low-income households, holding other variables in the model constant. What this marginal effect shows is that there is much less difference in the probability of using modern energy carriers for lighting between urban/rural than there was for cooking and heating. This corroborated the study by Barnes *et al.* (2011) and Khandker *et al.* (2012), who confirmed that lighting is the major use of electricity (a modern energy carrier) amongst rural households.

Table 3 further shows that 2014 is statistically significant at the 1% level of significance for candles and the 5% level of significance for transitional energy carrier and have negative signs. Thus, in 2014, low-income households were 5% less likely to use candles compared to 2008 and 1% less likely to use transitional energy carriers compared to 2008. For the modern energy carrier, the marginal effect suggests that the low-income households are 6% more likely to use modern energy carrier for lighting than in 2008, holding other variables in the model constant at their means. Unexpectedly, 2010 and 2012 are not statistically significant for the three energy choice options as they were for cooking and heating. This may be partly due to the electricity supply crises faced by South Africans, with emergencies in supply declared in 2008/2009.

Finally, in addition to the 'year' variables, age and gender of the household head and the size of the household were statistically insignificant, indicating they are not relevant in influencing the choice of energy carriers for lighting by low-income households.

The predicted probabilities for energy choice for lighting by low-income households is thus shown:

| | 95% confidence interval |
|---|---|
| Pr (y=1= less preferred \| x: 0.1871 | [0.0316, 0.0629] |
| Pr (y=2=moderately preferred \| x: 0.047 | [0.1572, 0.2168] |
| Pr (y=3=most preferred \|x: 0.7657 | [0.7329, 0.7986] |

It is important to note that in making the energy choice for lighting, 'less preferred' refers to candles, 'moderately preferred' refers to transitional energy carrier and 'most preferred' is modern energy carrier. The result suggested that there is 77% probability that a modern energy carrier will be chosen for lighting and less than 1% probability that the low-income households are likely to opt for transitional energy carriers. Lastly, there is 19% probability that low-income households will choose candles for their lighting.

An observation in the percentage probabilities of a modern energy carrier being preferred for the three energy-end use differs. For cooking, the predicted probability is 60%, 54% for heating whilst lighting is 77%. These percentages reflect the energy intensity needed for each service considering electricity as the source of energy. Whilst heating consumes a lot of electricity, lighting only takes a small share of energy consumption. Cooking on the other hand is in the middle of both, reflecting an average energy consumption.

## 5 Discussion and Conclusion

The results confirmed an 'energy stacking' behaviour by the low-income households for the energy choice for cooking, heating and lighting. The quantitative insight on energy stacking behaviour is one key finding in this study. In other words, low-income households in the rural or urban settlements do not fully ascend the 'energy ladder' as income increases. Rather, they prefer not to completely discard traditional or transitional energy carriers as income increases, but use them in conjunction with modern energy carriers. The result found support from previous studies that households do not move up the energy ladder as income increases, but rather engage in multiple fuel use (Guta 2012; Kowsari and Zerriffi 2011; Masera *et al*. 2000; Mekonnen and Kohlin 2008; Takama *et al.* 2011). One would expect that the energy policy, for example the FBE policy, would enable the low-income households to switch completely to modern energy carriers, which is at the top of the energy ladder. This suggests, perhaps, that one needs to look at other factors that influence household energy choice and transition other than household income or energy price, as widely assumed by the 'energy ladder' model. Nevertheless, the importance of adopting an energy ladder behaviour by the low-income households is to reduce the use of traditional or transitional energy carriers, which in turn leads to less indoor air pollution. Other positive externalities on the society include less deforestation and no emissions into the atmosphere.

The stylised facts that emerge for the energy choice for cooking and heating is that living in an urban settlement, in a modern dwelling and having a small household size (1 – 4 persons) encourages the adoption of modern energy carriers. Thus, urban low-income households, living in a modern dwelling and with a small household size have a higher probability of using modern energy carriers for cooking and heating than using traditional or transitional energy carriers. The White Paper on Population Policy for South Africa released in 1996 was aimed at addressing population issues focussing on fertility reduction, restricted population movement and controlled settlement patterns. This study therefore suggest an interaction between the population policy and energy policy and showing the need to resolve the evolution of energy poverty within the framework of these two policies. Thus, for the low-income households to adopt an energy ladder behaviour, it is likely to require deliberate concerted efforts and context-specific policies, which can be inferred from the results.

These results also corroborate the findings from other studies. For example, Suliman (2013) found that the effect of modern roof significantly increases the probability of choosing LPG (a modern energy carrier). In addition, Baiyegunhi and Hassan (2014) showed that households living in traditional houses are less likely to choose natural gas and electricity over wood. Further, Van der Kroon *et al.* (2013) found that increasing family sizes suggested there is abundant labour available for fuel collection, which limits the need to use modern energy purchased in the markets. Khandker *et al.* (2012), in an energy poverty survey in India, found that 90% of people without electricity lived in the rural areas, making traditional fuels the main source of energy. According to Mwaura *et al.* (2014), living in urban settlements is generally associated with access to more modern energy carriers and improved income.

The fact that emerged in the energy choice for lighting are that living in a modern dwelling and in an urban area encourages the adoption of modern energy carriers. As such urban low-income households, living in a modern dwelling have a higher probability of using a modern energy carrier for lighting than transitional energy carriers or candles. This finding therefore suggests that the likelihood of an energy ladder behaviour to be adopted by low-income households for lighting purposes is subject to rurality (urban) and type of dwelling (modern). In addition, it makes sense that small household size does not influence an energy ladder behaviour for lighting as it does for the energy choice for cooking and heating.

Finally, the findings show that the probabilities of modern energy carriers being most preferred by the low-income households for cooking is 64%, heating is 54% whilst lighting is 77%. These percentages reflect an association between energy intensity and energy service. According to Rantlo and Fraser (2015), lighting uses little electricity relative to other uses of electricity, justifying the reason why most low-income household opted for modern energy carriers (such as electricity) for their lighting. Between cooking and heating, cooking seems to have less energy-intensive thermal application (if electricity is the source) compared to heating. As such, most low-income households prefer to use modern energy carriers for lighting as it consumes less energy, followed by cooking and lastly heating, as these energy services consume the most energy. Aside from energy intensity, one could say that these probabilities show the scale of preference by low-income households once accessibility and affordability of electricity is in place. The implication is that low-income households will first address lighting when there is affordable access to electricity. As found with other studies, for example, Swart and Bredenkamp (2012) and Vermaak *et al.* (2014), electrified households use electricity differently from non-electrified households. It was found that households with electricity use this energy source mainly for lighting, then cooking and space heating (Swart and Bredenkamp 2012; Vermaak *et al.* 2014). A logical conclusion is that in South Africa, amongst the low-income households, the use of electricity for lighting is closely related with household access to electricity. A link to Sen's capability approach, access to good lighting source has increased the quality of life for the low-income households in terms of extended study time for students, extension of business hour for traders and perception of improved safety and security (Adam 2010; Ismail 2015; Mapako and Prasad 2005).

Considering the investment the government has put in to address the social welfare of the low-income households in South Africa, the study has revealed the state on the energy transition pattern and trend. This study recommended that there is a need for a systematic and comprehensive outlook in the alignment of policies between departments and between spheres of government. This would assist in bringing the kind of transformation and development that the country is working towards for the low-income households.

**Appendix: Variable description and measurement**

| Variable names | Variable description and measurement |
|---|---|
| **Dependent variables** | |
| Energy choice for cooking | Outcome1= traditional energy carrier (less preferred)<br>Outcome2= transitional energy carrier (moderately preferred)<br>Outcome3= modern energy carrier (most preferred) |
| Energy choice for heating | Outcome1= traditional energy carrier (less preferred)<br>Outcome2= transitional energy carrier (moderately preferred)<br>Outcome3= modern energy carrier (most preferred) |
| Energy choice for lighting | Outcome1= candles (less preferred)<br>Outcome2= transitional energy carrier (moderately preferred)<br>Outcome3= modern energy carrier (most preferred) |
| **Independent variables** | |
| Income | A continuous variable indicating the monthly household income in South African Rand |
| Age | A continuous variable indicating the age of household head in years |
| Gender | A binary variable indicating the gender of household head<br>1=female; 0=male |
| Rurality | A binary variable indicating the location where household lives<br>1=urban; 0=rural |
| Household size | A binary variable indicating the number of people living in a household<br>1= small household size (1-4persons); 0=large household size (5persons and above) |
| Dwelling type | A binary variable indicating the type of household dwelling<br>1=modern dwelling; 0=non-modern dwelling |
| Year | A nominal variable representing the year of survey, base=2008<br>Year 2010<br>Year 2012<br>Year 2014 |