Temporal analysis of electricity consumption for prepaid metered low and high income households in Soweto, South Africa

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Abstract

This study explores the temporal trend in electricity consumption since the introduction of prepaid meters in low income households of Soweto, and compares the findings with high income households. Monthly electricity consumption data (over 96 months: 2007-2014) on 4427 households in Soweto, for both low and high income households, was collected from Eskom. Using a simple linear model to analyse consumption trends in low income households, we ascertain that electricity consumption has decreased by 48% since the inception of prepaid meters. Nonetheless, it is noted that 60% of household incomes are spent on electricity bills, which is way above the threshold set for energy poverty. Comparatively, high income households consume lower electricity than low income households do. Overall, the prepaid meter programme is producing expected results for Eskom but remains a challenge for low income households, which are still entrenched in energy poverty. We call for an energy policy that is tailored for each income groups and the formulation of laws and policies to protect the energy vulnerable households.

Key words: Electricity consumption; high income household; low income household; prepaid electricity meter; socio-economic

Introduction

Household electricity debt continues to plague South Africa's electricity supplying utility – Eskom – as only 16% of households pay for the electricity service Eskom provides (Timeslive 2015). The consequence of non-payment on public utilities is enormous. First, it is an important constraint to the provision of electricity services (Szabo and Ujheyli, 2014). Second, the shortage in revenue that comes with non-payment ultimately results in maintenance backlogs, system deterioration, inability to purchase fuel to operate the generating units, and the deterioration of the economy (World Bank, 1999). Third, studies have found that there is a correlation between non-payment and expenditure ratios: households with increasing electricity consumption (as a percentage of total household expenditure) are more likely to not pay for regularly their consumption (World Bank, 1999; Lampietti *et al*., 2007).

Different countries experience the problem of non-payment differently and deal with it in different ways. In 2003, the South African government persuaded Eskom to erase electricity household debt of R1.4 billion (US$ 1.2 million), under the Free Basic Electricity (FBE) policy (Styan, 2015). Then, the government took some measures to avoid further debt in the future. These measures included the introduction of prepaid meters and a free monthly allocation of electricity incentive (50 kWh) for all indigent households that agree to have prepaid meter installed (DME, 2003). As opposed to the expected outcome of these policies (e.g. Free Basic Electricity, free 50 kWh electricity consumption), household debt increased to R13.6 billion (US$1.14 billion), of which Soweto township alone owed R8.6 billion (US$7.2 million; 60% of the total amount) due to massive electricity non-payment (Styan, 2015). As a result, Eskom has resorted to intensifying its efforts of deploying household prepaid meters in the township.

In 2007, the first official pilot project of prepaid electricity-meter was undertaken in the small region of Soweto known as *Chiawelo*. To date, more than 45% of low-income households in Soweto are prepaid metered; the target is that all households be connected to this model of payment by 2020 (City Press, 2016). While households have protested and rejected the prepaid meter technology, Eskom has persistently echoed that the technology stands to benefit rather than harm households (Ruiters, 2007; Makonese *et al.*, 2012; Chinomona and Sandada, 2014; City Press, 2015; Jack and Smith, 2015 & 2016; Press Reader, 2015; Timeslive, 2015; SABC, 2016; IOL, 2017) and this view is supported by several studies across various geographic regions where significant decrease in electricity consumption was reported (Darby 2006; Fischer 2008; Faruqui *et al.* 2010; Gans *et al.* 2013; Qui and Xing 2015). For example, Faruqui *et al.* (2010) found that, in North America, the prepaid-meter technology reduced electricity consumption by 7% whereas in Northern Ireland, Gans *et al.* (2013) reported a decrease of 11-17%. Similarly, Martin (2014) also reported that households using prepaid electricity meters in Kentucky, USA, have their electricity consumption reduced by 11%. A study conducted in Canada noted that, 25% of the sampled households' utilized 20% less electricity with prepaid-meter technology (Casarin and Nicollier, 2009). This decrease is the result of a direct feedback provided by prepaid meters on electricity consumption, thus enabling consumers to monitor their electricity consumption.

Although Qui and Xing (2015) confirmed the reduction pattern of electricity consumption in Arizona, USA, due to prepaid meters, they also called for caution in generalizing this trend as they pointed out that socio-economic factors matter in electricity consumption. Specifically, they indicated that low-income households tend to experience more electricity reductions than high-

income households, suggesting a context-dependent effect of prepaid meters on electricity consumption. Based on Qui and Xing's (2015) finding, we therefore hypothesise that low-income households in Soweto would also consume more electricity than high-income due to the differences in the types of appliances used in both income groups. This is in line with several other studies that questioned whether prepaid meters are truly beneficial to low-income households (Colton 2001; Ruiters 2007; van Heusden 2010; O'Sullivan *et al.* 2011; Hittinger *et al.,* 2012; Makonese *et al.* 2012; Malama *et al.* 2014). These studies have alluded to the fact that prepaid electricity meters have the potential of entrenching energy poverty, especially among energy-vulnerable households. Energy vulnerability precedes energy poverty. At the vulnerable phase, there is a set of prevailing household conditions or factors that may lead to poverty. An acknowledgement of this phase helps to identify groups of people that may be at risk of being energy-poor in the near future. In expenditure terms, these are households that tend to spend more than 10% of income to meet their energy-related needs (O'Sullivan *et al.* 2011; Bouzarovski and Petrova, 2015; Ismael and Khembo, 2015). Poor household energy efficiency, increasing electricity costs, and overcrowding are identified as key other causal factors of energy poverty (The Guardian, 2016).

For example, when, from 1990 to 2008, the price of electricity in New Zealand has markedly increased by 71%, this increase led to energy poverty in low-income areas but not in high-income households (O'Sullivan *et al.*, 2011; 2015). The differences in electricity consumption in low- versus high-income households are due to the differences in nature of dwelling and appliances used (Genjo *et al.*, 2005; Tso and Yau 2007; Druckman and Jackson, 2008; Wiesmann *et al.*, 2011; DoE 2012; Bedir *et al.,* 2013; Jones *et al.*, 2015). In such context, it is

not an effective measure to design a "one-size-fit-all policy" for electricity consumption across all households without taking into consideration socio-economic differences.

The gap and contribution of the present study are as follows. In the context of Soweto, we do not know the consumption patterns over time in low- versus high-income households and how consumption in high- compares to consumption in low-income households. The present study provides answers to this gap, and in so doing, contributes knowledge that can inform the prepaid meters programme in Soweto. Specifically, we aim to understand the influence of prepaid meter on electricity consumption in the South Africa's township. Our objectives are three-fold: i) to identify the trend of electricity consumption since the introduction of prepaid meter in 2007; ii) to identify the proportion of the change in consumption since 2007; and iii) to compare electricity consumption in low- versus high-income households in the Soweto township.

Material and method

Study area

The present study was conducted in Soweto, the largest (200.3 km²) township in South Africa with a population of about 1 271 628 inhabitants (Frith, 2017). Within the township, two areas were targeted, namely, Chiawelo and Diepkloof Extension.

Chiawelo is a largely low-income household area of Soweto, established in 1956. Its size is about 1.10 km², and was developed to provide cheap accommodation for black workers (specifically Tsonga and Venda-speaking South Africans) during the Apartheid era. Approximately 3 841 households are found in Chiawelo (Frith, 2017). The household structures

have 3-4 small rooms (with each room size of ~ 32 m²). A significant majority of these households generate money by renting the backyard dwellings (e.g. shacks). Eskom installed prepaid meters in the area in 2007. Until now, the area is considered as one of the socio-economically disadvantaged areas in Soweto.

Diepkloof Extension (DE) is a segment region of Diepkloof sub-township with a surface area of about 1.42 km² (Frith, 2017). It has about 1 564 households. The area developed in the early 1980s and 1990s (Alexander *et al.,* 2013). It was built for middle to upper class (wealthier blacks, who were largely professionals employed by the State, but also privately employed professionals) (Marx and Rubin, 2008; Alexander *et al.,* 2013). The area is therefore referred to as the "Rich Man's Acre"; the house structures are bigger and intended as a more exclusive area. Most households in DE are modern and constantly being renovated towards being energy efficient. They are noticeably distinct from houses in the old townships of Soweto, with structures that are more permanent, built with expensive building materials (brick and tiled roofs as opposed to corrugated iron walls and roofs). The houses' physical structure size is estimated to be between 200 and 300 m². The area received prepaid meters in 2013. Overall, this is a socio-economically well-off region of Soweto.

Data collection

The electricity consumption data in Chiawelo and DE was acquired from Eskom. The agreement between the utility and us is that the anonymity of each household data (electricity consumption and cost) is preserved. We maintained this anonymity by not sharing the collected raw data for each household. Prepaid meters were not installed in both Chiawelo and DE at the same time.

While the prepaid meter programme was introduced to low-income households in 2007, the programme was introduced to high-income households only in 2016. As a result, data on consumption were not available for similar period. Data on electricity consumption and cost for Chiawelo (low-income households) were collected monthly over 96 months i.e. eight years (2007 to 2014) for 3 841 households whereas data for DE (high-income households) were collected for 1 564 total households only from June 2016 to February 2017 for the reason indicated above (i.e. prepaid meters were introduced to high-income households in 2016 and data for this income group are available for only 2016 to 2017).

Data analysis

All analyses were done in R (R-Development Core Team 2015). Firstly, we analysed the trend of electricity consumption over eight years (2007-2014) in low-income households. This analysis was done using a simple linear regression. Secondly, we assessed by how much the electricity consumption changes in low-income households over the study period (2007-2014) since the introduction of prepaid meter to this income group. This change was calculated as:

$C_{consumption} = \frac{C_{2014} - C_{2007}}{C_{2007}}$; C_{2014} and C_{2007} are the total electricity consumption in 2014 and 2007, respectively.

We then analysed the trend in monthly electricity consumption over the same period using the analysis of covariance (ANCOVA) with year and month as co-variates. To further understand the monthly patterns of electricity consumption, we ran a one-way ANOVA using consumption as a response variable and month as predictive variable.

Finally, we compared the consumption patterns between low- and high-income households. Because we have monthly consumption data for only a limited period of time (nine months: June 2016 to February 2017) in high-income households while we have monthly consumption for 96 months in low-income households, we tested the differences in consumption in both income groups by comparing the average monthly consumption in low-income households versus the average monthly consumption in randomly drawn years from 2007 to 2014 in low-income households. This comparison was done as follows. To this end, we selected randomly 100 times a year between 2007 and 2014, and calculated the average monthly consumption for each randomly selected year. Then, we calculated the actual monthly average consumption of high-income households over the period of June 2016 to February 2017 and compared this actual average to the average monthly consumption in low-income households of the randomly selected years. The significance of the difference between actual and random consumption was assessed using the 95% Confidence Interval (CI). For this particular analysis, the consumption data were $\log_{10}$-transformed to meet the normal error distribution.

Results

Our results indicate that electricity consumption in low-income households is decreasing significantly ($P < 0.001$) over the study period (2007-2014), following the trend $y = -63.78\ x + 129071.94$ (R^2=25.13%) (Figure 1). We also found that, since the introduction of prepaid electricity meters, the consumption levels decreased by a monthly average of 48% in low-income households over the study period. The decrease reached its lowest level in 2010 (610 – 930 kWh) (Figure 2). However, this overall decreasing trend hides some specificities in some months where the consumptions increased significantly in comparison to the average monthly

consumption. These months include May (β = 252.94 ± 122.62; P = 0.04), June (β =436.82 ± 118.72; P = 0.0004), July (β =453.73 ± 118.72; P = 0.0002) and August (β =310.69 ± 118.72; P = 0.01) (Figure 3). Finally we found that energy consumption in low-income households is significantly higher than the consumption in high-income household [(mean consumption in high-income household (log) = 6.28; CI=6.65-6.76)] (Figure 4). Our model [y = -63.78 x + 129071.94 (R^2=25.13%)] shows that the low-income household electricity consumption levels equal high household income levels in the year 2015.

Discussion

As a means to reduce the challenge of household electricity non-payment in Soweto, Eskom effected the process of prepaid electricity meter deployment in 2007. This study evaluates the role of the technology, particularly with electricity consumption, in low and high income households of the township. We firstly assessed the trend in prepaid electricity consumption in low-income households in Soweto. Using a simple linear model, we found that the rate of consumption has decreased by 48% between 2007 and 2014. We acknowledge that the strength of our model is weak (25%), suggesting that 75% of variation in electricity consumption remains unexplained by the linear model. However, our finding is broadly consistent with the general trend reported in several studies across various geographic regions (Canada: 20% decrease, Casarin and Nicollier 2009; North America: 7% decrease, Faruqui *et al.* 2010; Northern Ireland: 11-17% decrease; Gans *et al*. 2013; Kentucky: 11% decrease; Martin 2014; Arizona: 12% decrease, Qui and Xing 2015). It is also important to highlight that the decrease reported in our study is much higher (48%) than any other decrease reported elsewhere in relation to the installation of prepaid meters. This is potentially due to the fact that we focus only on electricity

consumption in low-income households whereas other studies analysed a combined dataset from both low- and high-income households (Qui and Xing 2015).

Our results have also reflected that the overall declining trend camouflages some energy consumption specificities in some months. For example, despite the overall decreasing trend, the consumptions increased significantly in comparison to the average monthly consumption from May to August and the lowest consumption was observed in June 2010. The significant increased consumption in May-August is linked to winter period in South Africa where the response to the cold weather requires an increased in energy demand to warm houses. Households therefore spend more and become more energy vulnerable during winter seasons (Lampaetti *et al.* 2007). The sharp decline in electricity consumption in June 2010 in Soweto low-income households could be linked to the Soccer World Cup. Soccer in Soweto is almost a religion, and the world cup was an opportunity for people to experience the once-in-a-lifetime opportunity that the world cup provided. As such, people were mostly outdoors in different stadiums watching the game, or people convened in one single household to watch the game, and consequently the consumption of electricity dropped significantly explaining the lowest June 2010 energy consumption that we observed in our study. This is an illustration of how social events such as soccer world cup may contribute to energy efficiency in low-income households. However, it is also important to find out if this is true at national level.

The overall decreasing trend should not mask the socio-economic implications for low-income households. Understanding those socio-economic implications is very important in a policy making process that takes income level into consideration. For example, each household in

Chiawelo – the low income region in this study – consumed an average of 667.6 kWh in 2014. Assuming the 2014 electricity tariff of R0.98 per kWh, households therefore monthly spent R654.2. By applying the upper-bound poverty line (UBPL) (using the 2015 prices), low income households have a monthly income of approximately R992 per month (StatsSA, 2017), meaning that households spent about 66% of their monthly income just to cover their electricity consumption. This renders households vulnerable to energy poverty particularly in the context of recent and predicted increase of electricity tariffs in the future. Consequently, prepaid meters may lead to decreased electricity consumption, but it does not solve the problem of energy poverty in low-income households. This is in support of the previous views that prepaid meters may entrench socio-economic marginalisation and electricity inequality (Colton 2001; Ruiters 2007; van Heusden 2010), given that spending up to 46% of households income (in winter) only on electricity consumption would have severe consequence on many other sectors of the household lives including education, food, health, clothing, transport, etc. This is in contrast to an early claim that prepaid meter improves social welfare (Casarin and Nicollier 2009).

To alleviate the weight of electricity consumption, the incentive measures put in place by the government include free monthly consumption of 50 kWh. This is clearly not enough in light of the amount spent to cover electricity bill despite the remarkable decrease in the consumption. The current energy or electricity policy landscape for households is poor and limitedly offers energy security to the poor. It does not offer protection to energy vulnerable or impoverished households. The FBE policy is currently the main policy that provides an incentive for poor households. We strongly argue that it lacks relevance and needs to be evaluated and updated according to the socio-economic realities faced by indigent households.

Similar evidence of energy poverty has also been reported in many other countries. In Zambia for example, Malama *et al.* (2014) reported that low-income households suffer from prepaid meter disconnections because of high and unaffordable prices (Malama *et al.*, 2014). In response, low-income households shift from using electricity to alternative energy sources such as wood or coal burning stoves, paraffin fuelled heaters, gas heaters, hot water bottles, usage of bed-blankets. This is an important finding for policy makers because it carries indicators closely associated with fuel or energy poverty – that is the inability of households to acquire adequate household electricity (for safe and healthy indoor temperatures) (O'Sullivan *et al.*, 2013). Furthermore, according to Ismail and Khembo (2015), the energy poverty expenditure line is estimated to be 10-15% of income. Low-income households were found to spend about 66% of their income on electricity. This is an apparent indicator of socio-economic marginalisation of poor households. Higher expenditure on electricity among low income households means they become more energy vulnerable (World Bank, 1999; Lampietti *et al*., 2007). Again, with increasing unemployment and electricity tariffs (by 400% in the past decade) in Soweto, the ill effect of prepaid meters on energy poverty needs to be thoroughly studied. There is a need for policy makers to re-assess and monitor the prepaid meter programme, and as Colton (2001) advised, establish mechanisms (e.g. laws) protecting the fuel or energy vulnerable and impoverished households.

How does electricity consumption in low-income households compare to the consumption in high income households? Our analysis showed that low-income households consume significantly more electricity than high-income households despite the trend towards a decreased

consumption in low-income households over several years. This may largely be attributable to factors unique to low-income households, for instance the continual dependence on old energy inefficient appliances and provision of space for renting in backyard rooms or shacks in premises (Makonese *et al.* 2012) – as compared to energy efficient buildings and appliances used by high income households. A study conducted by Parker (2003) reported that because of *inter alia* less efficient appliances, older homes consumed greater electrical energy for space heating and cooling. Furthermore, low-income households are also characterised by backyard dwellings that are put on rent, thus contributing to additional electricity consumption.

In contrast, high income households comprise in general only 2 employed persons in the households (StatsSA, 2011). This household category receives an annual income of more than R307 201 (about R26 000 per month). The household is characterised by dwelling solely dependent on electricity and gas as the main source of energy for cooking, lighting and heating. Electricity appliances found in households in this income group include radio, television, computer, refrigerator and cell phone. The household category is considered broadly energy efficient and can afford energy efficient electrical appliances, thus justifying the lower electricity consumption in comparison to low-income households. Several other factors not explicitly explored in the present study may also account for the differences observed. These include household expenditure patterns, education level, household and dwelling size, location of the household, factors that are recently identified as determinant of energy poverty in South Africa (Ismail and Khembo 2015). Based on our simple linear model, we identified that low-income households may have reached the same consumption level as high-income households since 2015. Unfortunately, we do not yet have consumption dataset beyond 2014 to confirm this

prediction, and this also precludes us from verifying whether the general decreasing trend since 2007 is maintained beyond 2014.

Conclusion

The White Energy Paper in South Africa clearly indicated that "energy security for low-income households can help reduce poverty, increase livelihoods and improve living standards" (RSA, 1998). Our trend analysis reveals that low-income households are consuming lesser electricity over time owing to prepaid meters, and this is positive development in support of the prepaid meter policy established since 2007. However, as more than 60% of the income in indigent households is spent on electricity consumption, way above the energy poverty expenditure threshold, estimated to be 10-15% (Ismail and Khembo 2015). We recommend to policy makers to review and monitor the prepaid meter programme; formulate tools (e.g. laws) protecting such energy vulnerable and impoverished households. Furthermore, we conclude that, though there is this decrease, low-income households continue to consume more electricity than high-income households. We therefore propose that in the midst of current electricity crisis in South Africa, there is an urgent need for the government to subsidize the installation of renewable energy technologies in low-income households. We also recommend that since the FBE policy is currently the main document providing an incentive to poor households, this policy needs to be evaluated and updated according to the socio-economic and energy poverty realities facing a majority of low income households in Soweto.

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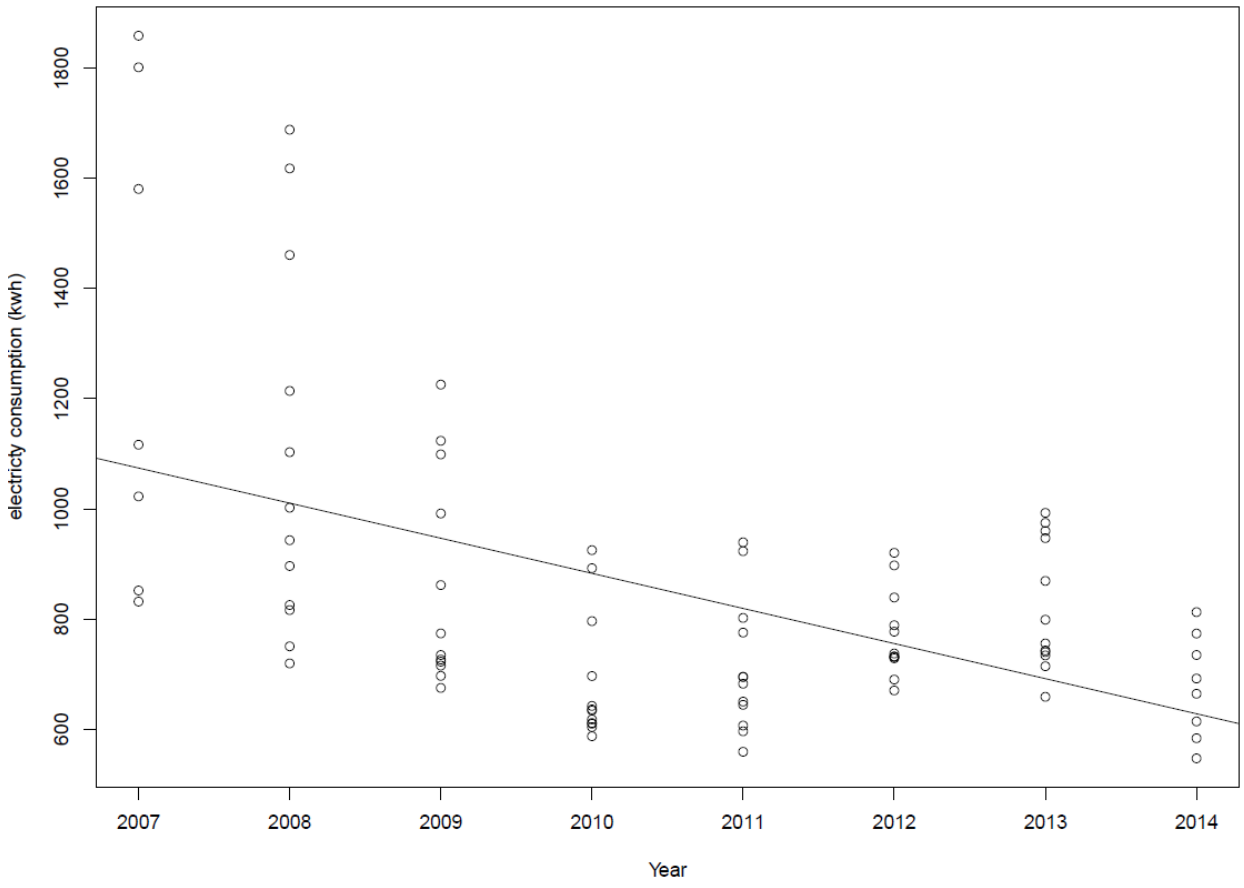

Figure 1: Trend of yearly electricity consumption in low-income households since the introduction of prepaid meters in 2007 (2007-2014).

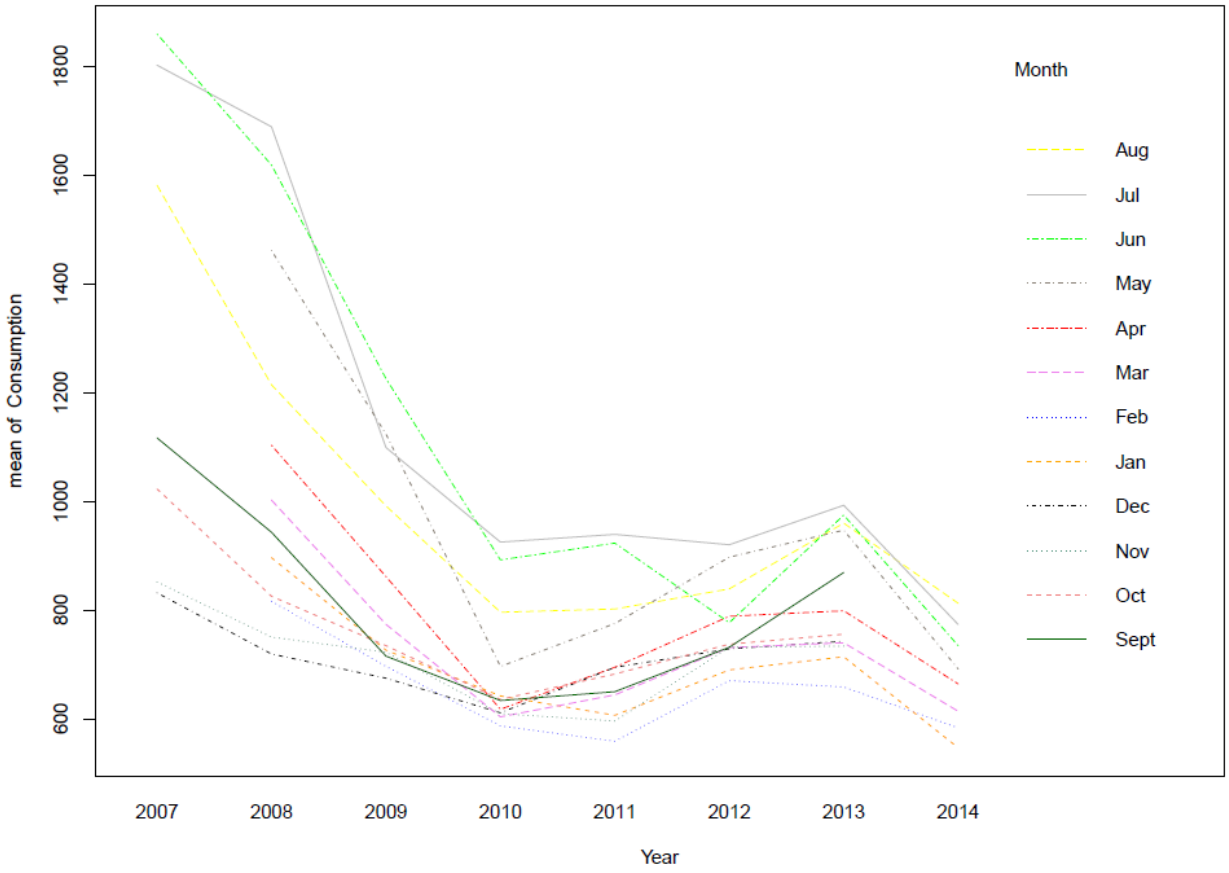

Figure 2: Trend of yearly electricity consumption in low income households highlighting the monthly patterns

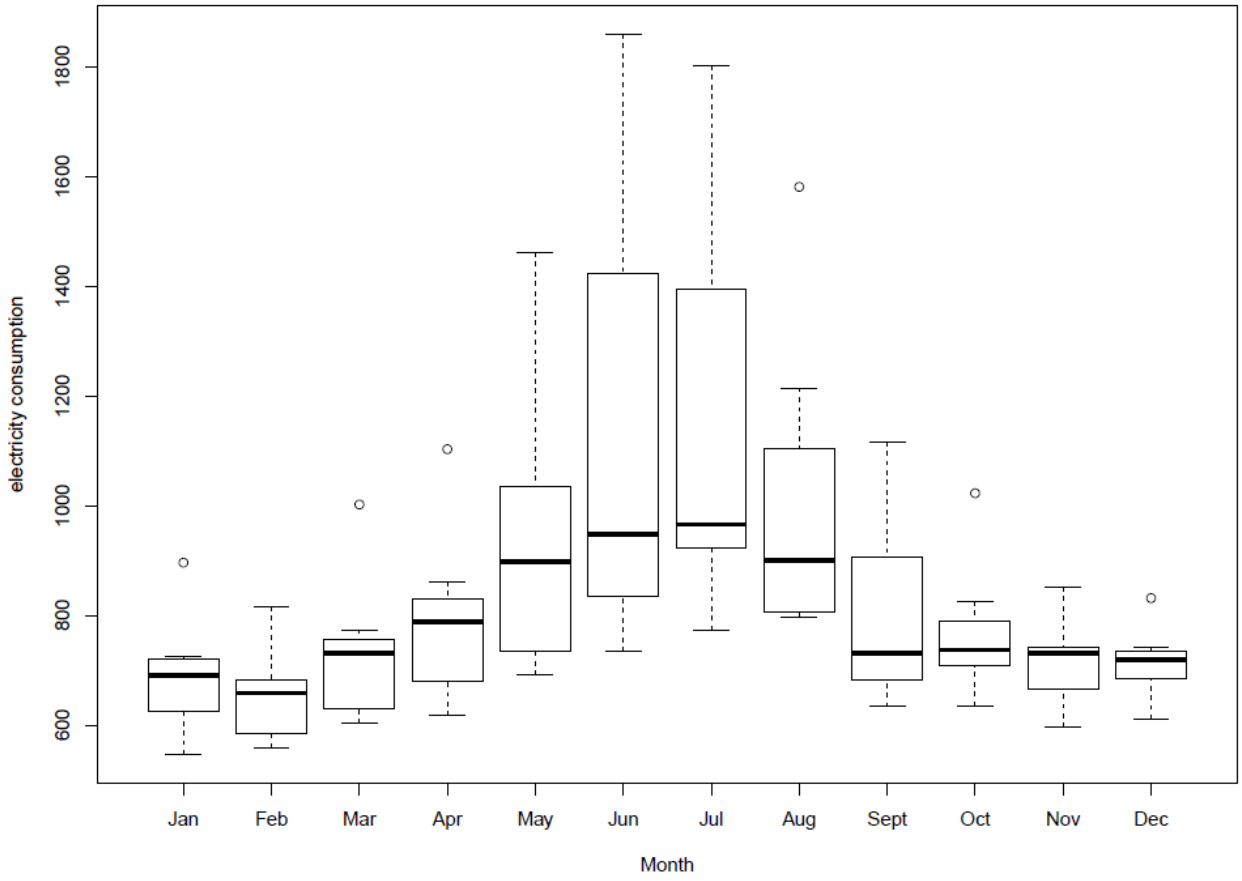

Figure 3: Boxplots depicting the monthly variation in electricity consumption

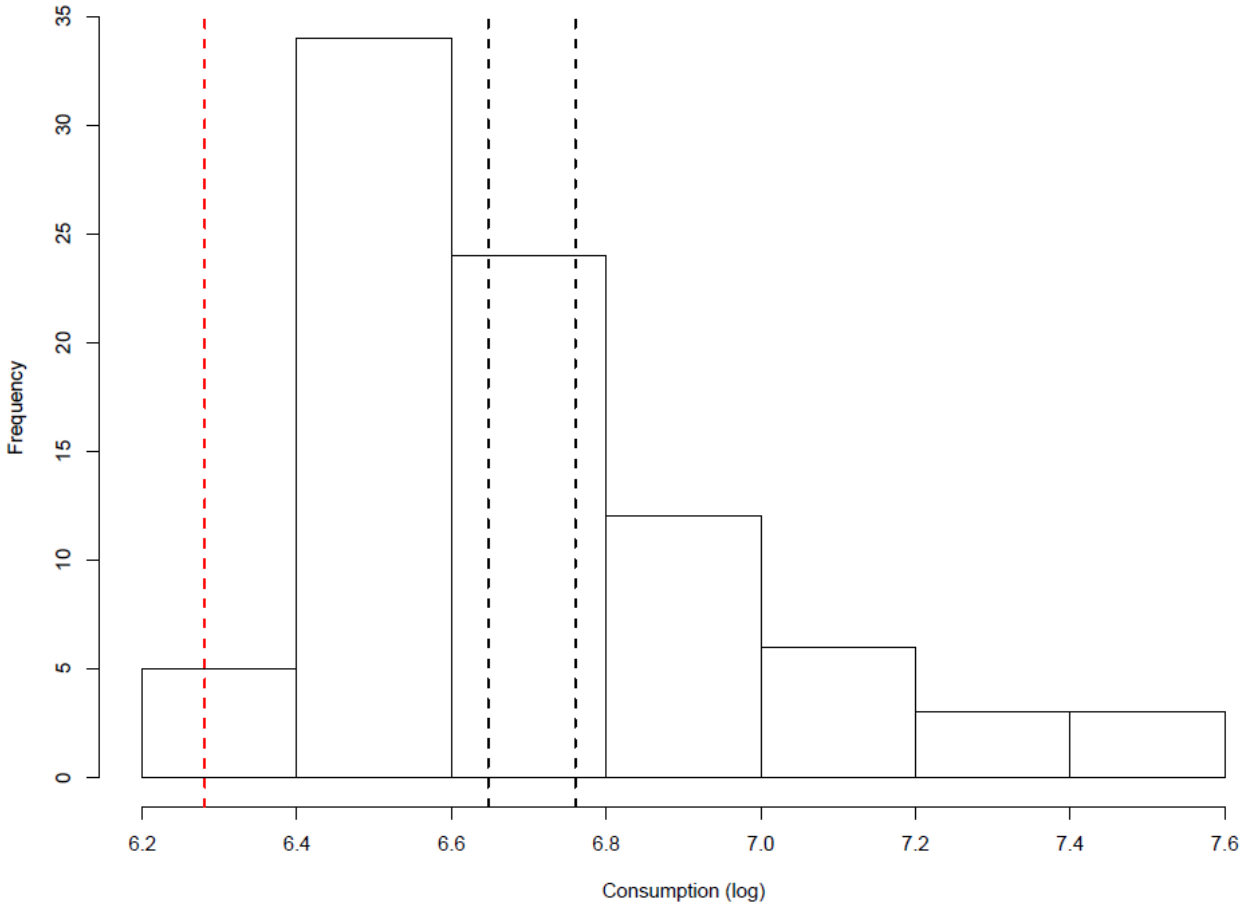

Figure 4: Comparison of electricity consumption between low- and high-income households form 2007 to 2014[1].

[1] The histogram indicate the average distribution of monthly electricity consumption in randomly selected years in low income households between 2007 and 2014. The bold dotted black lines indicate the confidence interval for the random consumption. The bold dotted red line indicates the actual monthly average consumption of high-income households. The dotted black and red vertical lines mean: 1) Black dotted line – confidence interval for consumption in low income household. 2) Red dotted line – average monthly consumption of high income households.