Crowd sourcing Energy Poverty Data in South African Informal Settlements: The opportunity of Mobile Phone Technology

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Declaration of authenticity

I, Kimenthrie Pillay, hereby declare that the above thesis is my original and unaided work and that apart from appropriate guidance from my supervisor, I have received no assistance. The above thesis has not been submitted in the past or been submitted at any other university.

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Abstract

Energy poverty undermines development at a large scale. It is most overtly experienced in informal settlements, where the use of fuels like paraffin, charcoal and wood prove hazardous and harmful to health and wellbeing. The expenditure on and use of energy services in informal settlements are largely undefined, which severely undermines the success of energy access and safety initiatives. Despite the poverty of informal settlements, mobile phone ownership is high in these areas. This research aims to explore the potential and applicability of a digital data collecting systems using a mobile application that is accessible on entry-level mobile phones with basic internet access to collect information about energy access, affordability and multiple fuel use in these areas. As part of this research, a mobile application platform and data collection platform was developed which enables survey design and data collection in real time. The platform allows for creation of weekly surveys that question energy use, expenditure and affordability; it also offers other functions that are designed to increase awareness of fuel safety and efficiency. The application was piloted in Imizamo Yethu in Cape Town. Six weeks of continuous data was extracted from 200 users using airtime incentives with an overall reach of 306 households. The quality and quantity of data received was of high calibre. The results indicate that the potential for using this system and mobile phones as a data-collecting tool in Africa is high.

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1. Executive Summary

Energy poverty is a simple concept with complex causes and dire repercussions for the poor. A key gap in addressing energy poverty is understanding the extent and impact it has on the daily lives of the global poor. The lack of contextually relevant knowledge for rural and informal urban (slum) populations over long periods is a knowledge gap that has only been filled with fleeting snapshots of contextual energy poverty that lack consistency in the area and timeframe covered. The use of technology to extend the limits of traditional survey outcomes has been well demonstrated for the developed world with applications and web pages conducting surveys on computers, high end tablets and smartphones (Bastawrous, 2013; Tomlinson *et al.* 2009). However, the application of technology has not been adapted to access the poor populations, whose access to basic internet services is rapidly increasing, especially in Africa.

Mobile phones have penetrated Africa at an exponential rate over the past few years through to the poorest in Africa. It is common to find expensive and advanced smartphones in an informal settlement in South Africa. The advent of mobile applications and devices to collect information from its users has been growing consistently over the last few years with internet connectivity becoming faster and further reaching than ever. This research employed mobile phones as the primary survey materials used to gather information about household energy use from a member of the household. The possibility of creating an automated survey that can be accessed on any internet-enabled phone has potential for filling the information gap, both in terms of energy poverty data and in other research fields. This research project developed such an application and explored the potential and applicability of a digital data collecting system in the informal settlement context.

A mobile application platform and data collection platform was developed to design surveys and collect data in real time while using mobile network credit rewards for the submission of each survey as an incentive for participation from the local community. This application is accessible on entry-level mobile phones with basic internet access, to collect information about energy access, affordability and multiple fuel use in the informal settlement context. A long and detailed survey was compiled and broken up into smaller questionnaires that were administered through the application once a week and available in three different languages. The design of the application and management platform had to allow for maximum accessibility and user friendliness.

The target demographic for this project have significantly lower incomes and are often unable to access smartphone platforms, thus more basic and widely available platforms were considered. Although USSD and Java based applications were considered for this function, a mobi webpage was chosen as the best platform for this application, functioning as a web page optimized for use on mobile phones and devices. This platform allows for the hosting of (i) a fully functional digital survey and additional functions and (ii) an integrated data and webpage management system both of which are only limited by web design parameters. The use of a web hosted application allows for real time changes to be made to the functioning of the survey and management of the system.

The management system is responsible for the design of the survey questions, the order in which they are asked, the pay-out of airtime vouchers, the content of the application as well as a platform to collect, view and store the responses collected from the survey as well as the details of the users involved in the study. Since the survey is hosted on a mobi website, the administration functions can also be hosted on the same domain. The centralization and digitization of the entire data collection process, from survey design to data collection and analysis, can have great benefits on the research process allowing for bigger sample groups to be surveyed over shorter periods. This allows any administrator user to access the survey design, questions, user information and incentive payments from any device that has access to the internet. From this platform admin users can add, change or delete survey questions in all languages at any time with immediate effect. A schematic of the different functions of the platform is provided in Figure 1. Data can be exported at any time in Comma Separated Values (CSV) format, to be analysed in Microsoft Excel or any other data analysis program. The data can also be viewed in the form of graphs on the website. The results can be selected by variable and is represented in bar chart format for quick general analysis of specific variables. The data can also be visualized in the form of a map, where the location of users, determined by the given address, is plotted.

The data collected had varying levels of statistical relevance as each question was answered by a different number of participants due to varying dates of registration and inconsistencies in participation. With a lengthened study period it is likely that the rates of participation will increase as it did during the short study period used for the

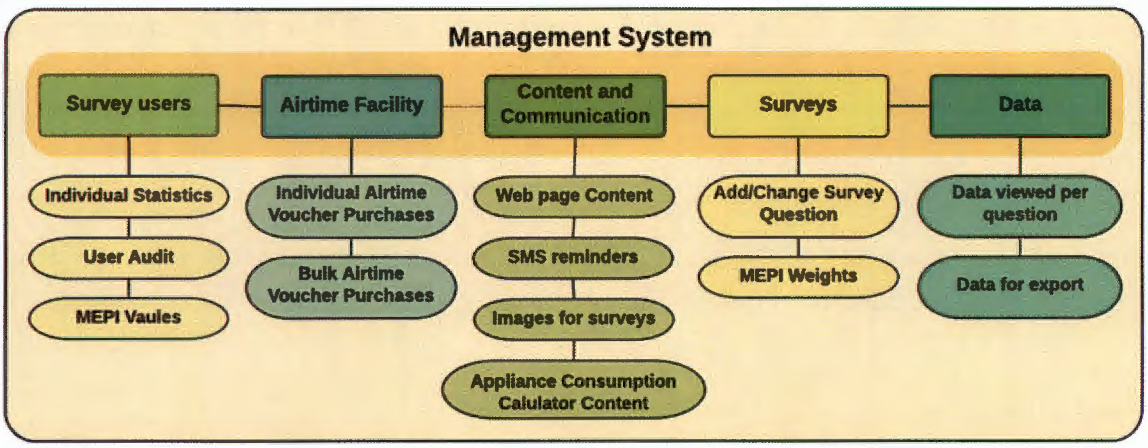

Figure 1 Schematic of Management System Functions

The application was piloted in Imizamo Yethu, an informal settlement in Cape Town. Six weeks of continuous data was extracted from 200 users. Two key factors in the success of this method is the participation in the survey, in terms of numbers of household reached, and data quality, in terms of the accuracy of the data collected. The use of mobile phones enforced selection bias on the sample population as one requires a mobile phone to participate. The use of single respondents as independent data contributors to this project was both beneficial and limiting. The information flow was only limited by the number and types of questions asked per week and not by the respondent. However, the accuracy of this information can only be verified by follow up surveys, the process of which is time consuming considering the size of the population to be verified. A small sample of the responses was verified by acquiring photographs of prepaid electricity receipts to confirm that there were no major discrepancies in the data collected.

The benefits of this method are clear in the amount and quality of data, the timeframe during which it was collected and the reach of the survey within the community as well as the reduced cost of this system compared to traditional means. Aside from administrative issues that needed to be undertaken with the developers and the WhatsApp helpline, which was made available for users to express any issues with the survey or any questions they might have, there was little input required from the researcher given that the survey was designed and compiled prior to implementation of the project. To have procured 200 household surveys within a two-month period would be challenging and resource intensive using traditional means such as household interviews. The digital data collection platform also succeeded in acquiring expenditure patterns over long periods of time, which would be more time consuming to achieve using traditional survey methods. A cost effective analysis was conducted as part of the exploration of the capabilities of this method. Standard costs associated with the running of a traditional survey were used to project long term costs for large populations. The digital data collection method derived in this study was deemed more cost effective for 2000 surveys or more.

A major disadvantage of this method identified is that participation and responses to questions are variable, and there is no guarantee that every user that has registered will participate in the full survey. To compensate for this the reach of the project must be far enough to attract enough interest to engage an adequate proportion of the population in order to reach valid conclusions or theories about the extent and level of energy poverty in an area. This needs to be assessed and addressed in future research to gain not just the interest of the public but also their long term and consistent participation to the project. The key to the success of this research method is proper community engagement, as it is through this that interest and participation in the project is promoted and sustained. The interest and participation of the community facilitates large scale data collection. Sustaining participation is necessary for large populations and different mechanism and means can be employed to achieve this. Currently the SMS reminders, WhatsApp helpline and mobile network credit incentives are the main mechanisms to promote long term participation however, with better community engagement, a more direct approach can be employed by using local events or rallies to promote participation in the project.

The quality and quantity of data received during the pilot of this data collection platform was of sufficient caliber, indicating that the potential for using this system and mobile phones as a data-collecting tool in Africa is high.

2. Introduction

Energy access - the availability, affordability, accessibility and acceptability of clean energy services as defined by the International Energy Agency, is a crucial element of modern life and an enabler of social and economic development (IEA, 2011). Energy poverty is a concept complex to define but can be briefly understood as a lack of access to modern energy services. It substantially undermines development at a large scale by reducing the means to enable education, reduce disease, promote safe public spaces and to provide a clean and sustainable environment that is not harmful to health (Fall *et al.*, 2008). Despite this substantial problem, understanding the extent and nature of energy poverty is challenging; eradicating the condition thus proves difficult without sufficient understanding of the concept and the problem (Sovacool, 2012). Because energy poverty is a subjective condition based on contextual relevance, it is an issue that is experienced differently by the individual or household (Nussbaumer *et al.*, 2013; Bazilian *et al.*, 2010). As such, there are numerous definitions for the concept and thus multiple ways of measuring energy poverty such as the Energy Development Index (EDI) (IEA, 2014) or the Multidimensional Energy Poverty Index (MEPI) (Nussbaumer *et al.*, 2013) or other means such as the poverty line or the Minimum Living Level (MLL) (Martins, 2003) which aims to define energy poverty at large scales in many different contexts. However, when energy poverty is assessed in a single context, it can be understood better since a single definition is required - as in the South African context. There is also a lack of contextually relevant definitions for energy poverty in South Africa, which are imperative to understanding, quantifying and relaying the extent and nature of energy poverty and how it is experienced.

In South Africa, energy poverty affects a large proportion of the population due to the high levels of income inequality, population growth, high levels of informal urbanisation and insufficient intervention strategies to resolve these issues (Eberhard & Van Horen, 1995). Energy poverty is most overtly experienced in informal settlements, which are urban and peri-urban communities that have been built informally on land that occupants have no legal claim to. It is in these communities in South Africa that the use of fuels such as paraffin and wood are common and prove hazardous and harmful to the health and wellbeing of their populations (Swart & Bredenkamp, 2012). There is an information gap where the expenditure and use of energy services in areas such as these are poorly understood. This can severely undermine the success of energy access and safety initiatives (Swart & Bredenkamp, 2012).

The issue of data paucity is a universal problem when it comes to understanding the extent and structure of energy poverty (Nussbaumer *et al.*, 2013; Bazilian *et al.*, 2010). Methods of collecting detailed information about energy use and affordability remain survey-based, which has drawbacks and barriers concerning accurate and in-depth data collection over long periods (Tomlinson *et al.*, 2009). These methods follow conventional means, which mostly involve door-to-door interviews or standard paper surveys (Tomlinson *et al.*, 2009). The technological revolution has modernised many forms of research such as marketing, geography, meteorology, engineering, medicine and microbiology, to name a few, and the case is no different in survey-based research, where the limitations of this method can be reduced and the benefits can be expanded. With the advance of technology, access to devices such as mobile phones and services such as the internet have increased, while prices have decreased, allowing for low income households to be a part of the digital revolution (GSMA, 2014; Porter, 2012; Eagle, 2010). The potential for this technology to gather information is high (Tomlinson *et al.*, 2009) and will be tested in this research project with regard to energy poverty in informal settlements in South Africa.

3. Aims and Objectives

This research project aims to contribute to overcoming one of key issues in addressing energy poverty from the research perspective, which is gathering reliable, long-term information about energy expenditure and use for the most inaccessible populations in South Africa: informal settlements. This study explores the potential of a new method of data collection utilising mobile phone technology as this technology has increasing rates of ownership in informal areas (GSMA, 2014; Porter, 2012). This project will assess the feasibility of moving the traditional energy survey into the modern digital age, using the internet as the primary means, by using mobile phones to submit surveys.

To assess the potential of a digital data-collecting platform in an informal settlement in South Africa, the two main research aims are to:

- Explore the most appropriate digital platform for this purpose
- Investigate household energy use

The former will be achieved through the following objectives:

- Design an appropriate management system and user interface for frequent energy data collection
- Assess the type of community engagement required for this method to be successful
- Test the capabilities of this method to determine energy poverty at a household level
- Assess the community engagement, interest and participation using this method
- Explore the types of incentives necessary for large scale participation

The primary objectives of this research are to test the applicability of the digital data collection platform in the field of energy poverty research as listed above. A secondary set of guidelines inform the scope of the data collecting process and questionnaire which will focus on determining:

- Patterns of energy consumption

- Levels of economic poverty
- Types of appliances commonly used
- Impact of energy poverty on the household,

and quantify it using an Energy Poverty Index relevant for use in the South African informal settlement.

Structure of thesis

This document begins by explaining the current state of energy poverty research in South Arica, while critically assessing the gaps in the energy poverty literature, methods of defining energy poverty and gathering sufficient data in this field. The literature review also analyses multiple fuel use in formal settlements and comparing methods to define energy poverty considering the informal context. The review also analyses the use of mobile phones and digital technology to conduct surveys. Chapter 5 discusses the selection of the study area as well as the methods used for sampling methods, data analysis and survey design. Chapter 6 discusses the process undertaken to design the digital data collection platform as well as means of determining the feasibility of this method through a cost effective analysis. Chapter 7 discusses the experiences with the implementation of the platform including the community engagement process and feedback from users. Chapter 8 analyses the two types of data collected though-out the process which includes an analysis of the quality and quantity of the data and an analysis of the data collected to determine the state of household energy poverty in Imizamo Yethu. Chapter 9 summarises the main findings of the research project as well as the key lessons and research to be carried forward into the future. The Appendix contains information on the functioning of the application and the management system as well as screenshots of each component of the system and the posters used for community engagement purposes.

4. Literature Review

Energy poverty substantially undermines development at a large scale (IEA, 2011; Fall *et al.*, 2008; Karekezi, 2002). Yet, understanding the extent and nature of energy poverty is challenging. Consequently, eradicating energy poverty proves difficult without sufficient understanding of the concept and the problem (IEA, 2011). In South Africa, energy poverty affects almost 50% of the total number of households (DoE, 2013) due to the high rates of income inequality, population growth, high rates of informal urbanisation and inadequate energy access policies to resolve these issues (Eberhard & Van Horen, 1995). Policies such as Free Basic Electricity (FBE), that fails to reach the households in most need of this incentive due to inefficiencies in its administration and is a clear demonstration of the challenges faced by the government to fully grasp the extent of the problem and how to effectively resolve it. Energy poverty is most overtly experienced in informal settlements, where the use of fuels such as paraffin, charcoal and wood prove hazardous and harmful to the health and wellbeing of their populations (Swart & Bredenkamp, 2012; Eberhard & Van Horen, 1995). There is a serious information gap where the expenditure on energy services and the use of energy services in such areas as these are unknown (Swart & Bredenkamp, 2012). This lack of information can severely undermine the success of energy access and safety initiatives (Swart & Bredenkamp, 2012). Equally, there is lack of contextually relevant definitions for energy poverty in South Africa, which are imperative to understanding, quantifying and relaying the extent and nature of the problem to stakeholders and policy makers.

4.1 What is Energy Poverty, Energy Access, and why is it important?

Energy is central to the functioning of modern daily life as such access to energy services plays a vital role in the development of nations, and can be perceived as a platform for providing equal opportunity for all (IEA, 2011). It is central to sustainable development and poverty reduction efforts. Energy poverty can be described as the inverse of energy access, which is the lack of access to modern energy services (IEA, 2011). Considered a continuation of economic poverty, the lack of energy services can act as a barrier to employment opportunities as well as the restriction of basic rights such as education, better healthcare and adequate and affordable transportation (IEA, 2011; Fall *et al.*, 2008).

Energy poverty is a multidimensional concept that can be defined in multiple ways; these are examined in more detail in section 3.2. However, its basic premise is defined as a lack of access to modern energy services (IEA, 2014). An estimated 1.3 billion people were living without electricity in 2011 worldwide and a further billion had access to only intermittent or unreliable electricity connections and networks (Sovacool *et al.* 2012).

4.1.1 What type of energy access is needed?

There is a growing concern that energy poverty will impede development worldwide if the world's energy supply remain unsustainable and inaccessible to poorer populations (Ha & Porcaro, 2005). Hence, the type of energy resources to which a population has access is a crucial element of energy access. Most international development and energy organisations worldwide agree that access to energy services needs to be sustainable, accessible, affordable, acceptable, and available in sufficient quantities (IEA, 2014). The increase in energy access, through making electricity more affordable in informal settlements or notoriously poor areas such as Khayelitsha, have had positive impacts on the lives of people, allowing for sustainable growth and decreased the levels of poverty in this community, while also contributing to greater social upliftment (Lloyd *et al.*,2004). Energy access can be a catalyst for sustainable development, granted the energy source meets at least one of the requirements outlined by the International Energy Agency (Misturelli & Heffernan, 2010; Martínez & Ebenhack, 2008; Ha & Porcaro, 2005; Eberhard, 1990). Access to sustainable energy can have significant positive impacts on societies and communities, however, these impacts are primarily rooted in energy access for the household unit. For the purposes of this research, only household energy poverty is analysed.

4.1.2 Household energy poverty

The energy used in households needs to provide a number of services for all household members. Cooking is one of the most essential household services, it is also the most energy intensive (Kanitkar & Sreekumar, 2008; Ha & Porcaro, 2005). It qualifies as a basic subsistence need, which is essential for a minimal level of human comfort (Kanitkar & Sreekumar, 2008; Ha & Porcaro, 2005). Other services that belong in this category include lighting, space heating and the operation of household appliances and devices. The ability to light the home sufficiently to conduct activities at night and to heat or cool your home are basic functions that contribute further to human existence and increasing productivity at home. The advantages of owning and running certain appliances are more specific to the functions each appliance performs. The advantages of owning and running a fridge, for example, can have beneficial effects on the amount of food waste produced or increase the amount of time and money saved on collecting or buying fresh food every day. The varied availability and advantages of certain energy services adds to the complexity of understanding the extent and level of energy poverty in a household (Ha & Porcaro, 2005). Thus defining or quantifying energy poverty is difficult to achieve.

4.2 Key challenges in addressing the problem

The need to define or quantify energy poverty is twofold, (i) by identifying the type of energy poverty experienced by a population, more effective mechanisms to improve energy access can be identified and implemented (Swart & Bredenkamp, 2012), (ii) quantifying this allows analysts and policy makers to understand the extent of this poverty (Swart & Bredenkamp, 2012; Eberhard & Van Horen, 1995). Defining energy poverty in many cases becomes increasingly difficult due to the complexity of the problem and the diversity of clean energy sources available (Nussbaumer *et al.*, 2013; Bazilian *et al.*, 2010; Karekezi, 2002). A binary approach to defining household energy poverty, the presence or absence of a certain fuel or appliance as the defining factor of household energy poverty, is an example of this complexity. For example, while in some studies, a household is defined as energy poor if their cooking energy is sourced from any fuel other than electricity, whereas households using alternative fuels that are clean and sustainable (modern energy access) they can still be defined as energy poor for not using electricity (Ha & Porcaro, 2005). This is evident in China, where it is not unusual to find households utilising solar cookers, biogas rings and both coal and residue-burning stoves in villages that are 97% electrified (Ha & Porcaro, 2005).

The difficulties in defining energy poverty lie in the complexity of poverty itself. The definition and quantification of energy poverty remains elusive under a quantitative analysis because of the complex dynamic between social, economic and political circumstances and changes (Nussbaumer *et al.*, 2013; Bazilian *et al.*, 2010). The South African Department of Energy has four approaches to defining energy poverty, wchih is a testament to the complexity of defining this condition. These include an expenditure-based approach, a subjective approach, a thermal efficiency and a low income and thermal efficiency approach (DoE, 2012).

Attempts at qualitative analysis of energy poverty are likely to yield equally uncertain results due to the insecure nature of living conditions. These are mostly dynamic and because of this instability, these conditions are often generalised when reduced to numeric data (Bazilian *et al.*, 2010). However, the reduction of this data to generalised numerical terms can assist in translating the extent of the problem to analysts and policy makers to inform future decisions and initiatives to combat energy poverty (Swart & Bredenkamp, 2012).

4.2.1 Methods employed to assess energy poverty

There are wide varieties of methods employed to measure energy poverty, which can be categorized as economic-based, engineering-based and access-based approaches (Pachauri *et al.*, 2004).

Economic based approaches utilize an energy poverty line or a fuel poverty line. Calculations to formulate this line are made according to the average level of energy consumption of people that are defined as being poor or living below the poverty line or Minimum Level of Living (MML) (Eberhard & Van Horen, 1995). Other methods include the assessment of the energy consumption at the aggregate national level and relating these to other poverty measures such as the Human Development Index (HDI) and the Physical Quality of Life index (PQLI) (McGillivray, 1991). However, these measures result in only a single energy or fuel line that generalizes data. Energy poverty can also be defined in terms of energy budget shares: that is if the percentage of income required to meet energy needs exceeds a certain level, that household is defined as energy poor (Pachauri *et al.*, 2004). Other means of economically identifying energy poverty is through energy expenditure (Eberhard & Van Horen, 1995). Because energy consumption usually comprises a large portion of household expenditure, a certain ratio of income-energy expenditure can be set. A household that spends greater than this ratio is deemed energy poor. This has been implemented in the United Kingdom, where a household is defined as energy poor if they spend more than 10% of their monthly income on space heating for their home (Kaygusuz, 2011).

Engineering-based approaches assess the type of energy being accessed by determining the direct energy required to meet basic needs. Thus, any household that does not have access to the amount of energy is defined as energy poor. This has been undertaken a few times with different results according to different climates and countries. However, this approach is problematic in that it generalizes the basic needs of many when the basic needs of individuals or households are quite specific. Equally, in order for these calculations to work there are a number of assumptions that need to be made about the type of appliances utilized for basic needs and their efficiencies (Pachauri *et al.*, 2004).

Access-based approaches are utilized as a means to quantify the potential energy access or energy availability, such as connection of a household to the grid, the accessibility and affordability of appliances. Another key factor lies in the type of fuel use and the health impacts of each fuel. While considering these factors allows for a comprehensive outlook of energy poverty, it is labour intensive and cumbersome to achieve for large populations. Equally, the standard of living for the poor is in infinite flux, making static results less applicable to real time issues.

4.2.2 Use of proxies for measuring energy poverty

There are other access-based approaches of measuring energy poverty at a household level, besides the presence of a grid connection. These involve the use of proxies as indicators of energy poverty. Utilising the presence of certain technologies in the household can be representative of clean energy access, such as the use of solar or electric powered lighting which indicates the household has access to clean, sustainable and affordable energy for lighting. However, the use of proxies presents a completely new range of challenges in identifying the proxies to be used in defining energy poverty. A proxy needs to be closely related to the service that is to be quantified, thus a normative judgement needs to be made for the selection of each proxy (Bazilian *et al.*, 2010). Proxies have the potential to yield large amounts of relevant information to decipher deprivation trends and patterns, and target the energy services required by the energy poor. Some of the most common proxy indicators include access to clean cooking, lighting and mechanical power (Hailu, 2012; Bazilian *et al.*, 2010; McGillivray, 1991). The following part of the review discusses these indicators briefly before moving on to indicators constructed intentionally for defining energy poverty.

Cooking is perceived as one of the most basic needs required by a household. *There is an urgent need for clean cooking in South Africa, as traditional biomass- and coal- open fire cooking methods have significant negative impacts on health and wellbeing.* The use of traditional biomass and coal indicates a deprivation of modern fuels such as liquid petroleum gas (LPG) and is thus a form of energy poverty (Andadari *et al.*, 2014; Owen *et al.*, 2013; Kaygusuz, 2011).

Lighting is a service that has variable efficiencies according to the type of energy utilised (Andadari *et al.*, 2014; Afrane & Ntiamoah, 2012). Candles and kerosene lamps are the most common alternatives to electric lighting, although the cost of the kerosene fuel far exceeds the cost of the electricity required to power lights and the quality of light produced is inferior to that of electric lighting (Kaygusuz, 2011; Eberhard, 1990). The presence of kerosene lamps is thus an indication of lighting energy deprivation and thus a form of energy poverty.

Mechanical power is a term used for functions and services that require physical motion and power. The type of mechanical power required by the household are unique according to the needs of the household (Kaygusuz, 2011; Bazilian *et al.*, 2010). In many cases, this is associated with agriculture, where services such as irrigation and ploughing are lacking due to the lack of electricity or modern fuels required to perform these functions. Affordable supplies of fuel represent an opportunity to transport surplus produce to a market-place providing opportunity to become more than a subsistence farmer (Kaygusuz, 2011). As a consequence, the lack of affordability of modern fuels such as petroleum and diesel marks a barrier for economic development and can be considered a form of energy poverty.

4.3 Indicators for energy poverty

To measure energy poverty there are a few key attributes that need to be defined or assumed beforehand. This includes defining what qualifies as a set of basic needs (Nussbaumer *et al.*, 2012). The most common household energy demand consists of cooking, space heating and cooling, lighting and entertainment. Other demands are imposed by other large appliances such as refrigerators, washing machines and geysers. In order to measure energy poverty it is important to define which of these needs qualifies as basic and whether a household should be deemed energy poor if deprived of these basic services. Equally, a normative measure of energy use needs to be established. Energy poverty can be measured as a deprivation of services or as availability or accessibility of services. While these measures query the availability of the energy services, the affordability, accessibility and acceptability of these services are not considered when using these measures of energy poverty. In other measures, only affordability of energy is isolated in order to determine energy poverty by a single indicator.

Measuring energy poverty is a means of defining the concept quantitatively. Indicators are the most widespread means of quantifying and analysing the progress of poverty alleviation methods (Sovacool, 2012; Giannini Pereira *et al.*, 2011; Bazilian *et al.*, 2010). They do not directly quantify the issue but rather quantify a factor that is likely to strongly influence the severity and extent of the issue. Indicators do not simply reduce the density and detail of the data into a single datum but extends beyond the basic quantification. They imply a deeper understanding of the principle issues and highlight the underlying problems and relations of these issues (Nussbaumer *et al.*, 2012). Indicators are also instrumental in communicating issues to decision-makers and the wider public. There are a few general indicators of poverty, which include measures of income, such as GNP and the minimum financial requirement, which is measured using Minimum Living Level (MLL). MLL is defined as the lowest sum possible on which a specific household size can live in the existing social set-up (Martins, 2003). The MLL definition is by far and large a loose definition of poverty. Unfortunately, the disparity between rich and poor in South Africa makes many of the single value indicators, such as a poverty line, irrelevant.

The Energy Development Index (EDI), formulated by the International Energy Agency, measures energy poverty based on the per capita electricity consumption in the commercial and residential sector, the share of modern fuels in the total residential sector energy use and finally the share of the population with access to electricity. The Multidimensional Energy Poverty Index (MEPI) measures energy poverty using the deprivation approach, thus the resultant values are defined by the number of people or households that are deprived of particular energy services (Nussbaumer *et al.*, 2012).

The Multidimensional Energy Poverty Index (MEPI) developed by Nussbaumer *et al.* (2010) provides a definition of energy poverty based on the type of fuels a household has access to and the appliances utilised to procure certain energy services. It is a comprehensive indicator as it accounts for the energy services received by the household, the health and environmental impacts as well as the quality of the fuels utilised to provide these energy services. The MEPI outputs detailed analysis that provides valuable information on energy poverty in a country or region as well as identifying the structure of energy poverty and how it is experienced. This is particularly useful for regions that have hidden energy access problems, for example in areas that are defined as electrified but where residents do not have access to appliances to utilise this energy service.

Different types of indicators can be distinguished for energy poverty. An attempted measurement of energy poverty, being a complex and ever-evolving issue, can be comprised of a number of single indicators or multidimensional ones. Because energy poverty is multidimensional by nature, it can be assumed that the use of many indicators or an indicator dashboard, as described by (Nussbaumer *et al.*, 2012). Single indicator and dashboard measures are much simpler in condensing relevant information into a meaningful index. While these measures are time and cost effective, there is a risk in cross comparing performance across areas that have different sets of challenges (Hailu, 2012). Conversely, composite indices offer a comprehensive and effective means of monitoring progress although, due to their complexity, they can be difficult to compute and implement. Equally as it requires intensive technical analysis, there needs to be a substantial amount of data available (Hailu, 2012).

4.4 Energy Poverty in South Africa

While energy poverty is widely understood to be a product of poverty (Hailu, 2012; Kaygusuz, 2011; Bazilian *et al.*, 2010; Martins, 2003) and is largely defined by the political and economic environments in which people live (Sovacool, 2012; Eberhard and Van Horen, 1995), the South African experience of energy poverty is largely defined by the political legacy of the Apartheid era. The result is that electricity is mainly limited to energy intensive commercial and industrial applications and high-income households. The electrification of the urban and rural poor has been inadequate (Mainali, 2014; Manyah, 2010; Winkler, 2007).

In South Africa, the patterns found in household energy poverty mirror those of the wider inequalities of the country, where cooking fuels and appliances as well as the type of dwelling poor households are constricted to result in the poor health of its occupants, the cause of which is rooted in income inequality and poor residential accommodation facilitated by Apartheid policies (Winkler, 2007; Eberhard and Van Horen, 1995). Poverty has been strongly influenced and exacerbated by Apartheid policies through uneven income and wealth distribution as well income inequality through racial and class discrimination. These issues of energy, poverty and development are strikingly evident in South Africa with the existence of a developed energy intensive industrial economy dependent on fossil fuels and distribution infrastructure that was prioritised mainly in white areas (Winkler, 2007). South Africa is comprised of a minority population at a high standard of living alongside many underdeveloped areas where the majority of the population live in poverty and are dependent on diminishing fuelwood resources or harmful and unsustainable fuels (Winkler, 2007; Prasad *et* *al.*, 2006; Eberhard & Gandar, 1984). Addressing energy poverty poses a variety of challenges to the state and involved parties as the extent of energy poverty needs to be understood and appropriate and effective means of alleviating energy poverty need to be developed as a response to this (Swart & Bredenkamp, 2012; Giannini Pereira *et al.*, 2011). Currently the main issue in energy poverty research and alleviation is the difficulty in understanding the impact of a myriad of social, economic, environmental, and political factors that cause energy poverty and further exacerbate general poverty (Swart & Bredenkamp, 2012).

There are a number of policies that have been put into place to rectify the energy disparity between the rich and the poor in South Africa, the largest of these include the Integrated National Electrification Program (INEP), which was a program designed to provide universal access to electricity in the country by the year 2025 (DoE, 2013). The number of households with access to electricity has doubled since 1990, a decade after the implementation of the INEP, and presently continues to grow. However, due to natural population growth and other factors there have been consistent backlogs, with the national backlog standing at 3.4 million household in March 2012. When disaggregated, this represents 1.2 million households in informal settlements which are urban and peri-urban communities that have been built informally on land that occupants have no legal claim to, and 2.2 million households in formal settlements. For legal matters that concern backyard dwellers and informal settlements on private land, solutions have been derived by the residents of these communities which include informal connections and agreements between those who are connected and those who are not. The most common solution is the lease of an extension cord from an electrified home to a non-electrified home. Due to the variable levels of development in areas such as informal settlements and low-basic housing developments nationwide, there is a diverse mix of energy provision methods across the country. However, the rate of illegal connections and sharing of connections through extension cords remain high in informal settlements across the country.

There are many facets to the energy access problem in South Africa. A key facet is that there is a divide in how poverty is experienced in both the urban and the rural context, and each setting provides unique challenges to ensuring energy access (Winkler, 2007; Prasad *et al.*, 2006; Eberhard and Van Horen, 1995). A second issue is the way in which energy is utilised; multiple fuel use is common in South Africa and diversifies the challenges of promoting sustainable energy resources to a large percentage of the population (Tait *et al.*, 2012). The latter will be further discussed in Section 3.5. These issues increase the complexity of assessing energy access and understanding the extent of energy poverty. The remainder of this section discusses the energy poverty across the urban-rural divide.

One of the most observable differences between urban and rural energy poverty is the access to electricity, which is far limited in rural areas than in urban areas (Bouzarovski & Petrova, 2015). A second feature is that rural households tend to rely more heavily on biomass resources for their basic energy needs (Owen, der Plas & Sepp, 2013; Karekezi *et al.*, 2006). Biomass used in rural areas also tends to be more diverse than the biomass options in urban areas. Rural households have a variety of biomass options to utilize, including cow dung and crop residues, which are never, if rarely, used in urban areas (Fall *et al.*, 2008). It is clear that the geographic location of households dictates the types of energy resources available, thus energy poverty in urban and rural areas are different. Urban households have a wider variety of modern fuels available to them whereas rural households are limited in their access to modern fuels (Prasad *et al.*, 2006; Martins, 2005).

Urban energy poverty is also a growing problem globally as the world's urban population now comprises half of the total world population and is increasing at a rapid rate (Visagie, 2008). In South Africa, this is particularly important as a significant proportion of urban populations live in densely packed informal settlements. The problems experienced in informal settlements in South Africa are derived from issues involving energy poverty. The number of shack fires, paraffin poisoning incidents and explosions in these areas have been attributed to improper use of dangerous fuels such as paraffin (Tait *et al.*, 2012; Swart & Bredenkamp, 2012; Visagie, 2008). There are a number of factors that have led to the levels of energy poverty observed in informal settlements. One of the consequences and perpetuating factors of household energy poverty is the prevalence of multiple fuel use.

There are a number of factors that define how poverty is experienced regardless of location. Poverty is often stimulated by isolation, be it geographical, social, economic or cultural isolation. The lack of income and a lack of energy are two defining factors that cause and perpetuate poverty (Li *et al.*, 2014; Ha & Porcaro, 2005; Eberhard, 1990). Vulnerability to natural disasters or social unrest can be catalysts or causes of poverty and is often accompanied by a lack of opportunity or resources as well as physical weakness in the form of poor healthcare, nutrition and incapacity (Eberhard & Van Horen, 1995). While these factors play a defining role in how poverty is experienced, it is the difference in these factors in the rural and urban context that defines the unique challenges faced when combating energy poverty.

4.5 Multiple Fuel Use in the Urban Environment

Multiple fuel use has been associated with energy poverty globally and is observable in South Africa (Afrane & Ntiamoah, 2012; Heltberg, 2004; Barnes & Qian, 1992). The association of multiple fuel use with energy poverty lies in the unsafe and improper use of certain fuels as well as the harmful effects on health and well-being (Afrane & Ntiamoah, 2012; Heltberg, 2004). Multiple fuel use has been a popular method of meeting energy requirements for decades, until the advent of the electrical grid and the introduction of electrical appliances (Heltberg, 2004). However, the use of multiple fuels to fulfil household needs currently has proven to be dangerous, particularly in informal or semi-formal settlements in South Africa's urban centres (Heltberg, 2004). This is largely due to the improper use of fuels and their associated appliances or hardware required for their utilisation. However, another issue is that the pollutants produced from combusting these fuels can be detrimental to the health of people in the vicinity and contribute to environmental degradation (Afrane & Ntiamoah, 2012; Heltberg, 2004).

4.5.1 What drives multiple fuel use?

The literature on what drives multiple fuel use is divided. It is assumed that multiple fuels are utilized when no electrification is available or the household is unable to afford electricity and was thus considered an indicator of energy poverty (Heltberg, 2004; Eberhard & Van Horen, 1995). However, studies show that multiple fuel use is driven by the cost of the fuel and the energy service provided by the fuel (Andadari *et al.*, 2014; van der Kroon *et al.*, 2013; Eberhard & Van Horen, 1995). Numerous examples demonstrate that there are specific uses for certain fuels that out-perform other fuels in terms of cost, convenience and efficiency as well as the number of services derived from a single use (Barnes & Qian, 1992). For example, paraffin stove/heaters are preferred appliances for informal homes in the winter as the burning of paraffin for cooking also produces sufficient heating for the home simultaneously. The theory of modernization foresees a fuel transition to more modern fuels and a move to electrification (van der Kroon *et al.*, 2013; Sovacool, 2012; Nussbaumer *et al.*, 2012). It is expected that households will move up the energy ladder to more sustainable and appropriate fuels. However, it is evident through some of the benefits of multiple fuel use, that energy poverty cannot be identified through electrification alone (Li *et al.*, 2014; Nussbaumer *et al.*, 2012; Barnes & Qian, 1992).

Numerous factors could influence a household to utilise certain fuels over others. The price and availability of the fuels are a large determinant, which has greater influence if the household income is low (Tait *et al.*, 2012; Eberhard & Van Horen, 1995). Household income can also influence the use of certain fuel due to the cost of the appliances needed to utilise those fuels, such an electric appliances for an electrical connection. The time and effort collecting fuel is another determining factor defined by the size of the household and their ability to collect fuel (Tait *et al.*, 2012). Other determinants include the climate, which dictates the energy services required for the household, such as heat or cooling as well as the availability of certain fuels such as wood or biomass (Barnes & Qian, 1992). The location can also be a major determinant of fuel use in terms of what fuels are physically available. Equally, cultural factors have an underestimated effect on the types of fuels utilised by a household (Matinga, 2010; Eberhard & Van Horen, 1995). This is particularly true for cooking, where certain dishes are best prepared using a certain method or fuel (Matinga, 2010).Equally, the ability to moderate the consumption of certain fuels by buying it in small quantities, such as paraffin, is advantageous for poor households where disposable income is limited (Tait *et al.*, 2012).

The benefits of multiple fuel use are not yet known for large populations (Heltberg, 2004). At a household level, the advantages are that the fuels most appropriate for each energy service is used to increase efficiency and reduce costs (Visagie, 2008; Eberhard & Van Horen, 1995). However, it is unknown whether this method is used in all households or whether there are other factors influencing the use of certain fuels over others. While surveys and assessments are performed regularly, there are numerous flaws and shortcomings of this approach, which are analysed in section 3.7. Past and current research that seeks to reveal the types of fuels people use and the reasons behind this have been illuminating but not altogether revealing about current and future household energy use trends (Afrane & Ntiamoah, 2012; Heltberg, 2004; Eberhard & Van Horen, 1995; Barnes & Qian, 1992).

4.6 Energy Poverty as experienced in informal settlements

The most commonly used fuels, used as alternatives to electricity, are found in the informal settlement and rural context is paraffin (or kerosene), charcoal, wood and candles (Visagie, 2008; Eberhard & Van Horen, 1995). These fuels are problematic due to the pollutants they generate when combusted as they are harmful to health and cause a number of serious respiratory problems when utilised in a poorly ventilated area. Another problem caused by the use of these fuels is the introduction of an open flame for cooking, heating and lighting (Afrane & Ntiamoah, 2012). The use of an open flame in a household is a primary cause of shack fires in informal settlements, a problem that has dire implications for people living in these areas (Pelling & Wisner, 2012; Eberhard & Van Horen, 1995). The emergence of multiple fuel use in urban environments - not only in South Africa but also throughout the world - poses a further challenge to defining and quantifying energy poverty. Multiple fuel use adds another dimension of complexity to the informal settlement context, where informality is uniquely complex and challenging

Informal settlements are expanding across the country (Visagie, 2008). This is largely due to the increase in rural to urban migration and an increase in overall population, but it is also due to the housing backlogs and the failure of housing policy to keep up with population growth and migration rates (Pharoah, 2009). The number of people living in these settlements in Cape Town alone, has increased from just over 28 000 in 1992 to over 100 000 in 2006 (Pharoah, 2009). Along with the size of informal settlements growing, the number of these settlements is growing at an even higher rate, with an increase from 50 informal settlements in 1993 to over 200 in 2005, with some government officials claiming this has gone up to 250 in 2009 (StatsSA, 2011, Pharoah, 2009). These settlements are densely populated with an average occupancy of between 350 to 450 people per hectare; this is clearly observable in Figure 1. The increasing rate of population growth and migration have increased the size and density of informal settlements in South Africa and has made its populations more vulnerable to risk as a result. Settlements such as Langa, Gugulethu and Khayelitsha have populations that have grown exponentially as people seek homes closer to jobs, schools and other facilities

(Swart & Bredenkamp, 2012). The expansion of these settlements makes the definition between informal and formal even more blurred as the previously informal dwelling become more formal and permanent while remaining in an informal context and typically poor neighbourhood. Another factor that contributes further to this is the occupancy of dwellings in the backyard of formal homes or established dwellings. Often these dwellings share an electrical connection with the formal home through an extension cord or are illegally connected to a municipal power supply, which poses a serious fire risk.

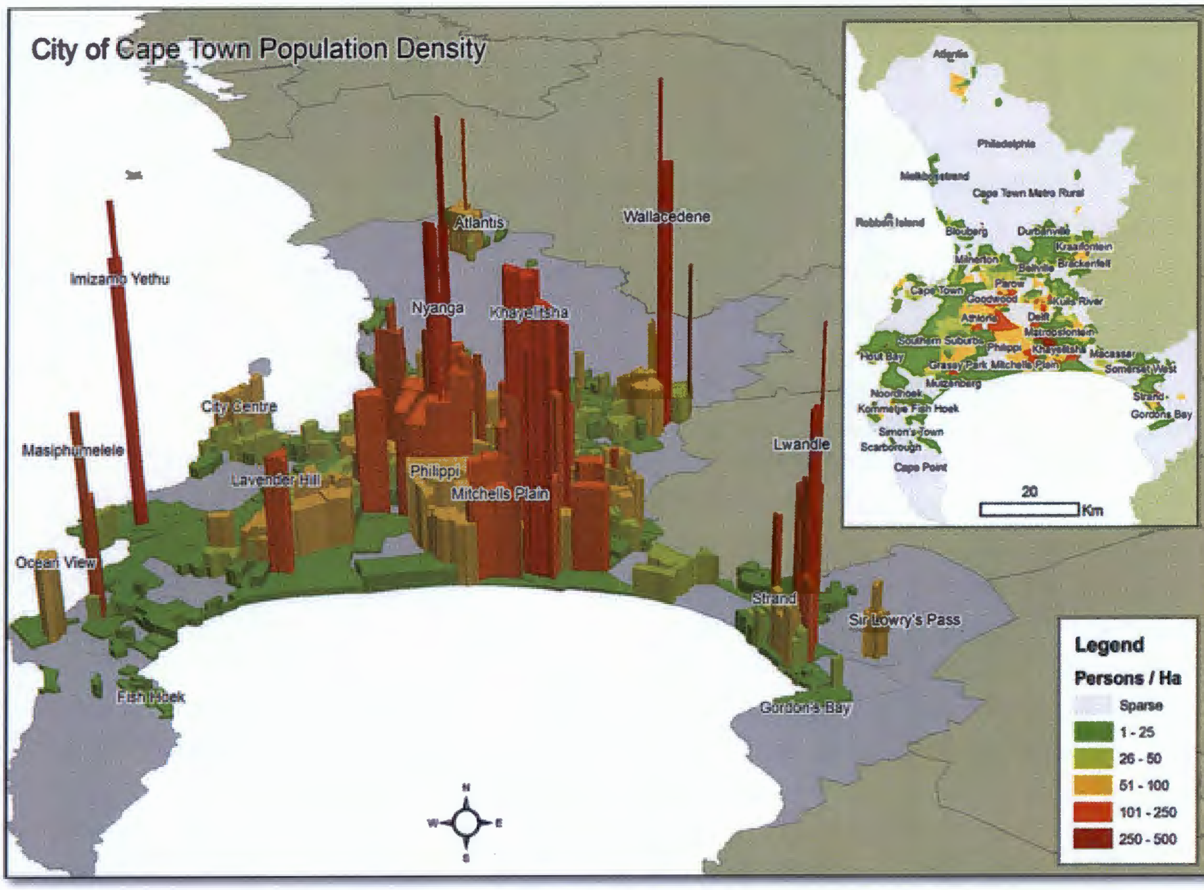

Figure 2 City of Cape Town Population Density (Turok. *et al.* 2011)

Informal settlement fires are a serious problem in South Africa and in Cape Town in particular, as they destroy houses and shacks on a weekly basis. Fires are particularly problematic as the households that are the most vulnerable and have the most fragile livelihoods are being affected the worst and have no means to recover from such serious damage. These disasters are moving into more formal areas with the increase in the number of backyard shacks (Pharoah, 2009). The materials used to construct many of these dwellings often act as catalysts for fire, with cheap and readily available plastics, untreated wood and cardboard which are highly flammable materials. Thus, a densely populated informal area constructed of cheap and flammable materials coupled with open flame appliances, highly flammable fuels and the strong Cape winds results in thousands of homes affected by fire on a yearly basis (Pharoah, 2009).

The type of fuels utilised by informal settlement dwellers as well as the level and quality of illegal connections plays a substantial role in the starting of fires and adds a new dimension to energy poverty (Swart & Bredenkamp, 2012). Fuels such as paraffin and wood are not just toxic and dangerous but when used with illegal and cheap appliances the danger and risk of fire, explosions and poisoning increases (Thurber *et al.*, 2013; Bates *et al.*, 2005; Barnes *et al.*, 1993; Barnes & Qian, 1992). The dangers of these fuels far outweigh the benefits of using them (Jeuland & Pattanayak, 2012; Barnes *et al.*, 1994). It is also common for children to ingest paraffin accidentally as the fuel is often not labelled or stored in drinking bottles and can easily be mistaken for water. The use of paraffin cannot be justified when the rate of fires, injury and poisoning are so high (Tait *et al.*, 2012); thus it can be deduced that the use of fuels such as paraffin are an indicator of energy poverty.

4.7 The data gap

The lack of continuous and current data on energy consumption in urban and rural areas leads to speculation about consumption trends. This type of speculation can have a negative effect on the prediction of future trends. If policies were shaped around these assumptions, the result would be inefficient energy policies that do not target the correct issues. This problem is not only specific to informal settlements in South Africa, but to the entire field of energy poverty research. One of the main barriers to applying an indicator to a population is the lack of information surrounding the supply, use and expenditure of low-income households on energy services. The complexities of multiple fuel use, illegal connections and shared meters for a population that is densely concentrated in a small area provide a number of challenges for accessing information about energy use in informal settlements. Data paucity is problematic, specifically for informal areas in South Africa as the informality acts as a barrier to data collection (Nussbaumer *et al.*, 2012; Giannini Pereira *et al.*, 2011).

The most common method of acquiring data about income and expenditure and use of energy services is with the use of a traditional survey (Swart & Bredenkamp, 2012). While there are numerous ways of collecting data, in terms of sample size, survey design, time scale and logistical approaches, such as door-to-door surveys, these factors differ according to the type of study being performed. Data is usually captured for specific survey needs which generally tend to span a month or less, providing a short snapshot of energy behaviour patterns rather than a broader perspective (Tait *et al.*, 2012; Eberhard & Van Horen, 1995). Traditional surveys tend to be resource intensive in that they require a significant amount of time and money to conduct (Tomlinson *et al.*, 2009). The research area needs to be relatively accessible in terms of logistics and location. The size of the population and sample group are dependent on the financial capacity and timescale of the research as the cost to employ surveyors can be high, depending on how many people need to be surveyed and how long they need to be active in the field. This is also an important factor to consider when designing the survey as the number of questions or the type of questions can be more laborious and time consuming to conduct. Equally important to consider in survey design is the reliability of recall based information, which is often inaccurate (Swart & Bredenkamp, 2012; Wright, 2005). These factors inhibit the true potential of surveys as method of data collection. There are different types of surveys that aim to compensate for some of these shortcomings, such as longitudinal surveys, which aim to gather information at intervals over long periods. The traditional survey method is a source of a number of gaps and shortfalls in terms of costs, time dimensions and the quality of data in terms of participant recall. The gaps produced by this method, in that data is not acquired frequently with identical aims or study areas, the result can often be shallow and uninformative when conducted at a small scale over short periods. The type of information required to have a rich understanding of energy use and expenditure in informal settlements is to have a continuous stream of data that allows for multiple fuel use to be expressed over different seasons and changes to the form of energy transmission.

4.8 The Potential of Mobile Phone Technology

Two key issues in alleviating energy poverty are defining energy poverty, with the use of an Index of indicator, and understanding and quantifying its extent and evolution over time with frequent and continuous surveys (González-Eguino, 2015; Li *et al.*, 2014; Nussbaumer *et al.*, 2012). This can be made possible with the use of an independent survey tool that allows the researcher to reach populations that are challenging to survey, through mobile phone technology. Mobile phones have penetrated Africa at an exponential rate over the past few years: the technology has penetrated even the poorest in Africa (GSMA, 2014; Tomlinson *et al.*, 2009). It is common to find expensive and advanced smartphones in an informal settlement in South Africa (Tomlinson *et al.*, 2009). The rate of penetration is explained in more detail in the Research Methods section.

The advent of mobile applications and devices to collect information from its users has been growing consistently over the last few years with internet connectivity becoming faster and further reaching than before (GSMA, 2014; Peyper, 2013; Porter, 2012). The research aims to use mobile phones as the primary survey tools used to gather information about household energy use from a member of the household. The possibility of creating an automated survey that can be accessed on any internet-enabled phone has immense potential for filling the information gap, both in terms of energy poverty data and in other research fields. This research project aims to develop such an application to fill this gap.

The prevalence of mobile phones amongst the South African population presents a platform from which an entire population can participate in social and economic activities. The adoption of mobile phone technology over a single year spanning 2012-2013 is given in Figure 2. In this Figure, not only have the number of countries with mobile phone access increased, but also countries that have had moderate rates of mobile phone penetration previously, such as Libya and Mali, have increased to 100% in the space of a year.

Globally, mobile phones are rapidly replacing functions that were previously only available on computer, allowing more diverse populations at lower incomes access to more advanced functions (Peyper, 2013). In Africa, only 0.3% of the total population has access to broadband internet; however, the access to mobile broadband has increased internet usage by 500% in just three years (GSMA, 2014). Mobile technology is democratizing social change throughout Africa. South Africa, in particular, has almost a 100% subscriber level as well as high mobile penetration.[1] A key use of mobile phones is for mobile internet access, the need for which is driven by social media. The most notably successful mobile application in Africa is Facebook Zero, which is the product of a collaboration between Facebook and mobile phone based internet providers that do not charge for bandwidth used when accessing Facebook as a text-only version of its webpage (Heuler, 2015). The success of Facebook Zero in Africa is a testament to the power of mobile phone technology in developing countries, increasing the number of African Facebook users by 114% in the first 8 months after its release in 2010 (Heuler, 2015). The opportunity this widespread access and ownership offers is immense as mobile phones can now be considered a gateway for communicating with populations that may have been previously inaccessible for research purposes due to geographic location or complexity, as in informal settlements.

[1] These figures do not mean that every individual owns a mobile phone but rather that the number of mobile network subscribers exceeds the total population of South Africa

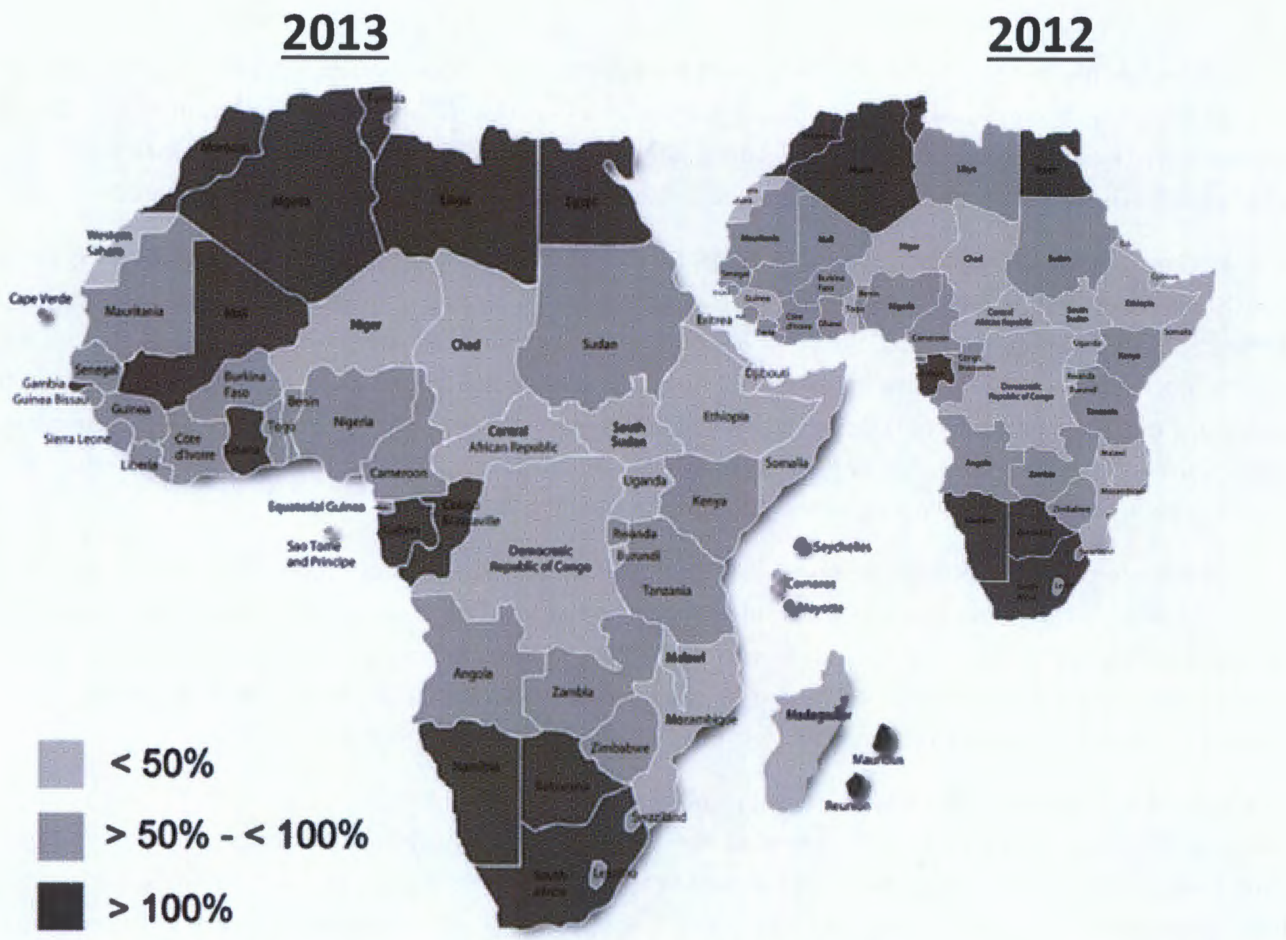

Figure 3 Africa mobile phone penetration in 2013 and 2012 (inset) as a percentage of the population that owns a mobile phone (GSMA,2014)

4.8.1 Mobile phone use in Informal Settlements

The use of mobile phones in informal settlements is high, which offers a unique opportunity to access people who live in these areas where the informality can act as a barrier for data collection (Swart & Bredenkamp, 2012). The use of mobile phones in informal settlements has proven to be an integral part of life for its inhabitants allowing for residents to communicate and interact cheaply on a regular basis through prepaid SIM contracts with local networks. As airtime, which is the common term for mobile network credit, is a commodity that is in high demand in these areas and is bought regularly in small quantities as needed. This important attribute can be used to add incentives to the data collection process when utilising mobile phone technology to collect survey data in informal settlements.

The application of mobile phone technology in research provides an opportunity to keep in contact with the user on a regular basis over long periods on a continuous basis (Tomlinson *et al.*, 2009). This can be hugely beneficial in simplifying the data collection process. A system that fully exploits this opportunity would be set up to communicate with the user on a regular basis. It is designed in a manner that makes data collection quick and easy. It is also important to make the collection method repeatable and easily accessible to reduce the input required from the researcher (Wright, 2005).

Data collection can be undertaken in a few ways when using mobile phone technology (Aranda-Jan *et al.*, 2014). Some methods include siphoning metadata from smart phones to gather information about cell phone or data use for each individual. This requires passive input from the cell phone user and only allows for certain types of cell phone use related data to be captured (Tomlinson *et al.*, 2009; Wright, 2005) . An active approach would be for the user to submit information voluntarily. This would require some sort of incentive to encourage users to actively volunteer their information on a regular basis. Airtime vouchers, as discussed previously, provide a neat and cheap solution to this problem; the implementation of this is discussed later in this document.

For the purposes of this project, an ideal design would include a central database on which all data is stored and is easily accessible to a controlled number of users. The survey would be designed before implementation and would include a detailed account of household information such as the number of occupants, the homeowner or breadwinners' employment record, a brief but detailed account of monthly income and expenditure patterns as well as regular energy use and expenditure patterns. Additional research is required to determine the best platform for such an application and a well-structured incentive schedule, as well as a well-designed survey. Determining these characteristics are challenging due to the constantly changing mobile phone market.

4.8.2 Challenges to moving to a digital system for informal settlements

The challenges to employ mobile phone technology in energy poverty data collection include a lack of knowledge surrounding the types of phones that people use in these areas as well as the primary uses of mobile phones for this population group. Developing a method of data collection using mobile phones without this knowledge becomes difficult as there are numerous platforms for which applications can be developed and it is unclear which method or platform would perform best without insight into common types and uses of cell phones in low-income households. This is made increasingly difficult with the high rate of technological advancement, as the standard of mobile phones used by even low-income households is advancing rapidly (GSMA, 2014; Porter, 2012; Tomlinson *et al.*, 2009). Another factor that increases the complexity of planning and implementing a mobile phone orientated survey system is that it is difficult to incentivise independent survey submissions without having knowledge of what drives mobile phone use. Despite these challenges, there are numerous studies that have successfully utilised mobile phone and tablet based technology for data collection. Equally, this information can and will be gathered in order to conduct meaningful and appropriate research conditions under which to test this method.

4.8.3 Use of digital survey methods in the field

The majority of studies undertaken using mobile phones or tablets as a data collection tool are rooted in the healthcare or health sciences field (Aranda-Jan *et al.*, 2014; Bastawrous & Armstrong, 2013; Leon *et al.* , 2012). These all involve agents that are assigned a device and move through a community to collect data on the digital system. These studies have largely focused on health related studies that utilise the Mobenzi Researcher platform at some point in the platform's evolution (Aranda-Jan *et al.*, 2014). The first study to utilise this technology, used a Java based application that could run on standard energy level cell phones. It involved the training of existing healthcare workers to use the application, troubleshoot the software and learn the interview protocols (Tomlinson *et al.*, 2009). Households were interviewed directly by these trained healthcare workers allowing them to verify data as it was collected and ensuring that the most senior member of the household responded to the interview questions. The survey information is stored on the phone, with up to 50 completed surveys storage space on the phone. The cost of this method has been stated as $0.30 per survey, which equates to roughly R3,89[2] (Tomlinson *et al.*, 2009). It is not entirely clear whether this is a cost

[2]Exchange rates as of August 2015, $1 = R12,95

defined by the developers of the application or whether these include total costs for hardware, software development, training and labour.

The most successful research utilizing mobile phone technology to gather survey data in South Africa was conducted by Tomlinson *et al.* (2009) where a mobile phone was utilized as the main apparatus of survey data collection by trained surveyors. This research has proved to be effective in meeting the end goals of the research and is revolutionary in the health research field in South Africa. However, the concept can be improved and modified to create a digital data collection platform that functions independently and would work for large populations. This research was conducted without modification of the concept created by Tomlinson *et al.* (2009), but was rather designed and implemented independently according to the needs of the energy poverty research field.

4.8.4 Crowdsourcing

Crowdsourcing has become a popular trend amongst marketers, mappers, meteorologists and civil society to determine consumption trends, traffic patterns, accidents and infrastructure malfunctions as well as weather changes and crime watch (Yuen *et al.*, 2011; Behrend *et al.*, 2011). This type of data collection can either be (i) passive, where smartphones transmit usage information to a database where this information is stored and analysed, or (ii) active, where users are actively submitting information to a central site or application for others to view and modify (Behrend *et al.*, 2011). The type of crowd sourcing used in this project is active participation, which requires users to have active interest and participation in the data collection process. While other digital surveys have used mobile phones or devices as a means of collecting data, this research differs in that it crowdsources this data instead of requesting this data from each household. This could potentially increase or decrease the number of households that would usually participate in such a survey depending on the types of people participating, the types of incentives offered for participating and the quality of the user experience (Behrend *et al.*, 2011).

In this chapter, the complexities of energy poverty have been defined as a major determinant of the challenges facing researchers trying to define energy poverty and understand the extent of this issue. In South African informal settlements a different set of challenges are imposed on the energy researcher, with the added challenge of informality, multiple fuel use and a perpetually changing population. Collectively, attempting to define energy poverty in the South African informal settlement context is difficult. However, the advent and increasing adoption of mobile phone technology in these areas offer a unique opportunity to integrate this flexible technology with the dynamic nature of household energy poverty. The evidence that a digital data-collecting platform will be successful in South African informal settlements is non-existent, a gap this research aims to fill. However, the use and ownership of mobile phones across Africa and in the poor areas of South Africa is evident, providing a potential indicator of success for such a method. The next chapter will examine the methods and conditions required to conduct this study.

5. Research Methodology

This chapter will outline the study design such as the sampling method used, the duration of the study the process of selecting an appropriate community in which to test the application as well as the process of designing the questionnaire that was featured in the application as well as the type of application that was used. In conjunction with the aims and objectives of this study, the experiment has been designed to test the feasibility and functioning of a data collecting digital application on Mobile phones in informal settlements in South Africa.

5.1 Selecting a study area

The area used for this study was selected based on a number of criteria needed to make the data relevant for the objectives of this study. These included having a cohesive community in which there were strong community leaders to drive the project internally. One of the original aims to determine energy use changes caused by electricity tariff increase at the beginning of April 2015 was later abandoned but set the criteria for the location of the study community. The increase was set to occur in April 2015 for Eskom supplied areas whereas Municipal supplied area tariffs were to be increased in July 2015. Because of the deadline for thesis submission, an Eskom area needed to be used for the study and the township of Enkanini in Khayelitsha was identified and pursued as a potential study area. Thus, the original timeline for data collection was over March and April 2015. There were a number of problems that were encountered in Enkanini. These are described in further detail in Chapter 6. However, despite the best efforts of the community leaders and the researcher driving the project, another area had to be found within the Municipal supply area and the original aim had to be abandoned. Imizamo Yethu was then identified as a viable community with a strong cohesive community and a number of dedicated social development workers who were impressed with and supportive of the project.

5.1.1 Study Area Background

Imizamo Yethu was established in 1991 on forest reserve land in Hout Bay, a town near Cape Town, South Africa situated in a valley on the Atlantic seaboard of the Cape Peninsula, South Africa (Visagie, 2008). It was a designated settlement scheme for black South Africans who mostly worked as domestic workers and in the fishing industry in the Hout Bay area (MacGregor *et al.*, 2005). The plan was to relocate 455 squatter households from Hout Bay. Since its establishment, the township has expanded to house over 16000 people. Electricity is frequently accessed informally by households by using extension cords to connect to other households with an electricity supply. The key domestic energy source is paraffin fuel, which is used within shacks for heating and cooking, often on defective stoves. Housing is dominated by self-constructed shacks with 76.7% of the structures in Imizamo Yethu made from plywood, Masonite, timber boards, plastic sheeting, advertising boards and corrugated iron. While the land was originally planned to accommodate brick houses on individual serviced sites, Imizamo Yethu received a significant increase in the number of new squatter residents from early in its establishment. This has exacerbated disadvantage and poverty in the community despite the 450 brick houses that were constructed between 2002 and 2005 and the proportion of formal dwellings rising to 23.3% in 2011(StatsSA 2011; Informal Housing Sector, 2005). These houses were provided with electricity connections and most of the informal dwellings were also electrified over the years. Despite the progress made in the community and the gradual improvement of living conditions and employment in the area this community is still regarded as being a poor area where households struggle to provide for themselves (Franks, 2014).

Figure 4 Satellite Photograph of Imizamo Yethu (Google Earth)

5.2 Sampling Methods and Duration

A reasonable sample size for a population (Kotrlik & Higgins, 2001) can be regarded as 5% of the overall population. This is a significantly larger sample group than used in previous studies in this area, such as Visagie (2008), which only sampled 2.6% of the households in Imizamo Yethu. Imizamo Yethu has 15 538 occupants in 6 009 households according to the 2011 National Census (StatsSA, 2011). To adjust this for 2015 it is assumed annual population growth rate at 2.8% derived from the annual population growth rate for the City of Cape Town in the Regional Development Profile from the City of Cape Town (Western Cape Provincial Treasury, 2012); accordingly it can be estimated that there are currently 15 973 people in 6 177 households in Imizamo Yethu. This estimate is likely to be low due to variable and unpredictable migration rates from the Eastern Cape to the township. Locals estimate nearly double these figures. The optimal sample size for this population would be 308 households. Due to funding and time limitations, a target was set for at least 250 households to participate in the survey representing 4.08% of the estimated total population.

A random sampling technique was initially employed through the use of posters and pamphlets around the residential area, see Appendix. This allowed for a self-selection bias for owners of mobile phones within the community to participate, resulting in a stratified sample group. This stratification allows for better insights on the type of individual to which the application appeals. However, the short time span for promoting the project required the use of large formal social hubs, such as high schools, to promote participation in the project in a short period as, initially, rates of participation were very low. However, the use of high schools as the primary means of disseminating information about the project may have influenced the sample group to consist of more high school students than would usually occur in a randomly selected sample group. This would have resulted in a more focused and less random sampling group. Because the participation in this project was voluntary the self-selection basis of the sample group defines the sampling method as stratified.

The original date to start the study was the 1st of March 2015 until the 30th of April 2015, which spans 8 weeks. However, after complications with the community of Enkanini, the start date was adjusted to allow time to find a new community in which to develop a relationship and presence. Once Imizamo Yethu was identified as a feasible area in which to conduct this research, a new start date of the 13th of April was announced to the community within two weeks from the first contact. Because this date was significantly later in the year as previously planned, the study time needed to be reduced to allow for data analysis and project writing to meet deadlines for dissertation submissions. Thus, the initial eight-week period was reduced to six weeks, with the data collection ending on the 24th of May.

5.3 Data Analysis

The data collected in this study was analysed using basic statistical methods including averages and modes. Further or more analytical statistics and methods were not used as the data created by the survey is not the primary objective and rather the process of designing, implementing and managing the application and management system as well as the quality and quantity of the data are the results this study aims to isolate and analyse.

5.4 Survey Design

While the actual data created by this survey was not the primary objective of the study, the quality and diversity of information that can be derived from using a digital data collection tool needed to be demonstrated in order to fully explore the potential of the tools as well as prove the feasibility of such a system. As such the survey questions were designed to acquire information that demonstrates the:

- Patterns of energy consumption
- Levels of economic poverty
- Types of appliances commonly used
- Impact of energy poverty on the household.

The other component of this project aims to utilise an adapted version of the Multidimensional Energy Poverty Indicator (MEPI), see Section 4.3, which requires certain characteristics of household energy use to be known. Thus, the questionnaire was also designed with these characteristics in mind and to address the feasibility of the survey system and test its capabilities. Thus a number of different questions engaging the topics outlined above were asked, using two different types of responses, text and multiple choice, where appropriate. The type of data used to contextualise energy poverty were also carefully considered when designing the questionnaire, as such only a general overview of the income and costs of users while more specific questions are asked in order to determine specific energy poverty characteristics needed to define the MEPI value for each household.

The design of the full survey was complex and difficult to outline, as there are numerous examples of good household income, household expenditure and energy access surveys to collate into a simple and comprehensive survey spanning six weeks. The Household and Fuel Use and Supply Questionnaire developed by the Energy Research Centre at the University of Cape Town for the Energy Sector Management Assistance Program was used as a template from which the Sabela Sokwazi survey was designed. This survey was conducted in Botswana, Ghana, Senegal and ERC/ESMAP surveys in Botswana, Ghana, Senegal and Honduras as part of a study to determine use and transition in poor Fuel use and transition in poor households and can be found in the appendix (Prasad, 2008)

There were two challenges in adapting this survey for use on a mobile phone: (i) to include only questions that required closed answers or very short open answers (ii) to include questions that can be repeated, the responses of which can be used to derive patterns in energy consumption and expenditure on energy services. The completed survey instrument can be observed in the Appendix.

There were three different categories of questions that were included in the survey: (i) Household (ii) Energy Consumption (iii) Economic Indicators. Questions to acquire household information, such as the number of occupants, level of education, occupation, type of occupation, income, major expenses and expenditure on fuels were asked incrementally over the six weeks. This does not particularly reduce the time taken for an individual to answer the entire survey but it does make answering the survey much easier when answered in segments. The household questions listed in the ERC ESMAP Household survey were complex and numerous. These questions could have been adapted and used in the Sabela Sokwazi Survey, however the timeline for the completion of this project did not allow for more than basic household questions to be asked. Lengthening the time required to fill in a weekly survey would have allowed for these questions but it would significantly reduce the usability of the application and possibly the participation as a result of this. Thus, questions that summarised the estimates of basic income and expenses for the household were used.

The energy consumption and energy services questions were largely defined by the categories of the adapted MEPI. The ownership of certain appliances, the types of fuels used for cooking, heating and lighting as well as the legality and safety of the electrical connection of a household are important factors to define in order to categorise the household in terms of energy poverty using the adapted MEPI.

The Economic Indicator questions are centred on appliance ownership, living conditions and comfort. Some of these questions interrogate a number of research questions asked by researchers in the field such as the average period a household spends without electricity and the reasons behind this. These questions have been adapted to be contextually relevant to the South African informal settlement. The final weeks' questions incorporate some marketing questions to help streamline the community involvement and implementation for following studies using this method.

5.4.1.1 Testing for feasibility

The main aim of this study is to test the feasibility of using the digital data collecting platform for energy poverty research in informal settlements. This will be achieved by assessing the quality and quantity of data received as well as the viability of collected responses at the end of the study period. This will also be achieved by evaluating the cost effectiveness of the approach, where the costs associated with traditional surveys are compared to the cost of a digital data collection platform. Feasibility can be assessed by comparing these results to those of traditional surveys. If the quality, quantity and viability of responses and cost of implementing a digital data collection platform are competitive with that of a traditional survey the system can be deemed feasible.

5.5 Developing a Relevant Energy Poverty Indicator

The Multidimensional Energy Poverty Indicator (MEPI) developed by Nussbaumer *et al.* (2010) define energy poverty based on the type of fuels a household has access to and the appliances utilised to procure certain energy services. It is a comprehensive indicator as it accounts for the energy services received by the household as well as the health and environmental impacts including the quality of the fuels utilised to provide these energy services. The MEPI provides detailed analysis that provides valuable information on energy poverty in a country or region as well as identifying the structure of energy poverty and how it is experienced. This is particularly useful for regions that have hidden energy access problems; for example in areas that are defined as electrified but where residents do not have access to appliances to utilise this utility. Defining the structure of energy access in areas is key to identifying the success of interventions and energy access strategies aimed at resolving this issue.

The MEPI was constructed by defining energy access as a measure of deprivation of certain energy services. This energy access definition, and the resultant Index, was guided by data made available through various projects and organisations such as the International Energy Agency (IEA), which has been compiling energy access data at a national level for ten years, as well as datasets made available through the public domain. An important source that influenced the variables selected for this index is the Demographic and Health Surveys Project (MEASURE DHS) which was financed by the United States Agency for International Development (USAID). The index was formulated around the data that was readily available, which contributes to some of its shortcomings discussed later.

The MEPI is unique compared to other indices in many ways, one of which is that it focuses on energy services that people want and need. The indicator thus measures the energy service deprivations experienced by a household. It is relevant for effective policy formulation and the energy access interventions to bridge the energy access gap (Nussbaumer *et al.*, 2013). Energy services are defined as the application of useful energy to end uses required by the consumer. These can extend to transportation, cooking, lighting, space heating and communication. These services can be categorised into primary and secondary needs; however, this categorisation is often subjective and is thus contextually defined. Another factor that defines an energy service is the convenience of receiving that service (Bazilian *et al.*, 2010). This definition has shaped the categories and their respective options for the MEPI but have left some gaps that inhibit thorough and comprehensive definition.

4.5.1 Need for adaptation

While this indicator is useful it only considers energy poverty through the lens of energy services. As noted by (Nussbaumer *et al.*, 2012) limited attention has been paid to the quality of these services. This is because the primary measure of access to energy services is binary, whether a service is provided or not. For the purposes of investigating multiple fuel use, the energy services perspective, while illuminating, is insufficient to illustrate the extent and complexity of energy poverty at this level. A major shortcoming of the MEPI for the South African informal settlement context is that the type of stove being utilised is not considered. Neither is there an allowance for multiple fuel use for cooking. This shortcoming is caused by the fact that this indicator is applied only once to a single household for the duration of a survey as different fuels are often utilised seasonally or are dependent on fuel prices.

The MEPI, in its current state, does not account for the affordability of fuels, even if it is utilised in conjunction with a household income and expenditure survey. Analysing the relative quantities and costs of the fuels utilised by a household contributes to defining whether that household is experiencing energy poverty or is susceptible to energy poverty in the future. For the purposes of this research project, a number of additional parameters for defining energy poverty can be included, as the type of data collected can be easily changed or manipulated immediately and at a large scale. These parameters are aimed at improving on the shortcomings of the original MEPI, which includes increasing the data richness in terms of detailed energy use and health and safety impacts of this use.

4.5.2 Adapting the MEPI to the study aims

Each major category was broken down into components that were major determinants of affordability, health, safety and efficiency. These standards are maintained as they are common requirements for energy access as defined by the International Energy Agency (IEA), the United Nations Development Program (UNDP) and the World Resources Institute (WRI) (IEA, 2011). The original index, as outlined in Table 1 below, was comprised of categories that had certain weights relative to the importance and ability of each category to determine energy access. The issue of weight as well as the definition of categories for multidimensional indices is somewhat controversial. One can argue that all criteria considered in an index need not necessarily have the same relative importance or symmetrical importance. The criteria included in an index need not have the same relative value as certain characteristics of energy access play more important roles than others (Bazilian *et al.*, 2010). However, it is difficult to assign rational and unbiased weightings to certain categories, as the importance of each is highly subjective. Thus, assigning weights can be very challenging and is an arbitrary and value-driven process. As such the categories and their respective weighting for this research project has been determined by the context in which it will be used, i.e. South African informal settlements.

Table 1 Dimensions of The Multidimensional Energy Poverty Indicator developed by Nussbaumer *et al.* 2013

Dimension	Indicator (weight)	Variable	Deprivation cut-off (poor if...)
Cooking	Modern cooking fuel (0.2)	Type of cooking fuel	Use any fuel beside electricity, LPG, kerosene, natural gas, or biogas
	Indoor pollution (0.2)	Food cooked on stove or open fire (no hood/chimney) if using any fuel beside electricity, LPG, natural gas, or biogas	True
Lighting	Electricity access (0.2)	Has access to electricity	False
Services provided by means of household appliances	Household appliance ownership (0.13)	Has a fridge	False
Entertainment/education	Entertainment/education appliance ownership (0.13)	Has a radio OR television	False
Communication	Telecommunication means (0.13)	Has a phone land line OR a mobile phone	False

The options for each category have been expanded with a wider variety of options that are contextually relevant to the research area. The weighting for each of these options are explained in detail below. One major addition to the categories was the inclusion of the type of stove used. The lifespan of stoves were considered to be an important component of stove safety as this contributes to the condition and overall functioning of the stove. However, based on how the stove is utilised, how it was initially purchased and the quality and durability of the stove the condition of the stove was considered a more important parameter that directly affects the safety of the energy service and thus the extent of energy poverty for cooking (Shankar *et al.*, 2014; Jeuland & Pattanayak, 2012).

4.5.3 Application to the Study

While the MEPI has largely been used as an indicator for large areas, regions and countries, it will be applied per household and per area for the purposes of this project. The index has been adapted to reflect significant changes in energy consumption behaviour, such as the type of primary fuel being utilised, the acquisition of any new appliances as well as the condition of the stove currently in use. Thus, the MEPI will be applied to the household continuously as different components that the MEPI is comprised of are determined throughout the six to eight week study period.

The MEPI was developed for international application, which means that there is a significant amount of simplification and generalisation of the categories and the variables of the index. This does not allow for the consideration of contextual or cultural differences in energy consumption behaviour and omits large amounts of detailed and insightful data to be included in the index to make it more comprehensive. This omission has been rectified in this adapted version with the addition of relevant energy consumption behaviours in the index. Despite this, using an indicator still reduces detail rich qualitative data to quantitative data. However, the benefit of this indicator is the added depth of understanding gained by acknowledging relative uses of common fuels and appliances in the informal context and assigning those weights for consideration in overall energy access.

The changes to the MEPI have been alterations to the main categories to allow for a more detailed and wider variety of end use options that help to determine the type energy access or level of health and safety deprivation experienced by the household. The methods used to determine the categories and weighting of each option are similar to those used for the original MEPI, in which they were determined by utilising available research to prioritise each factor according to its contribution to energy deprivation. While a focus group may have been an effective means of determining the relative importance of each category, the aims of this project are to test the feasibility of the application and its effectiveness in enriching data for researchers to develop better methods and strategies to combat energy poverty. The category weightings are thus defined from the researchers' perspective in terms of identifying problems that can be resolved with policy changes and initiatives.

4.5.4 Category Changes

The adapted MEPI is presented in Table 2 . The main categories were kept more or less constant with changes in category weighting in the indoor pollution and household appliance ownership categories as well as the inclusion of safety in the indoor pollution category. Safety was included with indoor pollution as it falls under the health and safety of the fuel and its associated appliance (Shankar *et al.*, 2014; Barnes *et al.*, 1993). This change was due to the inclusion of stove type and condition in the indoor pollution and safety category. This category is especially important to consider due to the history of stove use in informal settlements in South Africa. Stoves that are common and popular in informal settlements tend to be illegal and unregulated resulting in uncontrollable shack fires from exploding or malfunctioning stoves caused by improper use, damage or stove defects. Equally, the number of injuries and fatalities associated with improper stove use or illegal stove use is high (Kulati, 2014). As such, this category is afforded the highest weighting as it considers both the type of stove being used and its condition - that potentially contributes to health and safety associated with alternative fuel use. The additional weighting afforded to this category was expended from the household appliance ownership category as the indoor pollution category accounts for more appliance ownership, appliance type and condition.

4.5.4.1 Cooking

Cooking is a primary need for energy in any household and has been proven one of the most energy intensive tasks in the household (Shankar *et al.*, 2014; Barnes *et al.*, 1993). The cooking category remains a heavy contributor to the overall index with a 20% weighting overall. The fuels utilised for cooking are weighed according to efficiency and convenience, which were determined through analysis of studies investigating these properties (Andadari *et al.*, 2014; Afrane & Ntiamoah, 2012; Tait *et al.*, 2012).

Electricity is perceived to be the most efficient and convenient fuel to use for cooking, while LPG can be equally as efficient, for use in an informal settlement the convenience of this fuel is likely to be low. Equally, the efficiency and convenience of LPG is highly dependent on the stove type (Tait *et al.*, 2012). The use of LPG in informal settlements has had a history of negative health and safety issues with explosions, leaks and fire and thus has a significantly lower weighting compared to electricity (Kulati, 2014; Tait *et al.*, 2012) Similarly, biogas has been included in the index with LPG as it has similar properties to LPG but is assumed to be more sustainably and safely generated and transmitted (Tait *et al.*, 2012).

The use of paraffin in informal settlements has been met with similar issues of health and safety. The impact of paraffin use on health is significantly worse than LPG, with particulate matter and poisonous fumes becoming the leading cause of respiratory disease in informal households(Tait *et al.*, 2012; Afrane & Ntiamoah, 2012; Fall *et al.*, 2008).

Wood was included in the index as they are commonly used fuels in the Western Cape (Swart & Bredenkamp, 2012). They were assigned low scores due to the high levels of pollution created when either of these fuels is combusted (Afrane & Ntiamoah, 2012).

4.5.4.2 Indoor pollution and Safety

Two extra categories were added to the indoor pollution and safety category. These include the consideration of the fuel type, the type of stove with which the fuel is utilised as well as the condition of the stove. In these cases if the stove is illegal it is highly unlikely it is safe as the conditions and functioning of these stoves is unregulated (Kulati, 2014). As such, a zero weighting has been assigned to any illegal stove.

4.5.4.3 Lighting

In this context, lighting has been included as a proxy for an electricity connection. While having a grid connection can be an indicator of energy access, the affordability of the electricity provided can be an inhibitor of energy use and thus an inhibitor of energy access (Swart & Bredenkamp, 2012). As such, the amount of electricity used by the household can be considered an indicator for energy access. A threshold level of 50kWh has been used to meet the requirements of the Free Basic Electricity (FBE) initiative which was undertaken to address energy poverty and improve energy access (Swart & Bredenkamp, 2012). As such, there is an additional weighting for households who benefit from FBE. Access to Free Basic Electricity is a reduction of energy poverty and is thus awarded a higher score if a household benefits from it.

4.5.4.4 Household appliances

The ownership and use of a fridge is an indicator of the use of an electricity supply and the level of use. The fridge, being a large and relatively expensive household appliance, is an indicator of the standards of living of the household (Swart & Bredenkamp, 2012; Louw *et al.*, 2008).

4.5.4.5 Entertainment and Education

The only changes to this category are the inclusion of laptops and tablets as an option for this category. The reason for this inclusion is that the penetration of laptops and in particular budget tablets has risen at a remarkable rate in lower income populations in Africa (Porter, 2012).

This Chapter has outlined the selection of Imizamo Yethu as an appropriate community in which to test the functioning of the method and use of the application. The study period and the sample size of the study was also determined to be 250 households over a period of six weeks, while the sampling method was defined as random initially but with the participation of the high schools this evolved to more selective sampling. This Chapter also interrogated the methods used to adapt the Multidimensional Energy Poverty Index to a more contextually relevant index for use in South Africa Informal settlements by adding categories that measure a household's level of access to certain energy services that are specific to the lifestyles of informal settlement dwellers.

Table 2 Adapted Multidimensional Energy Poverty Indicator and weighting

Dimension	Indicator	Variable	Options			Score
Cooking	Modern Cooking Fuel (0.2)	Type of cooking fuel	Electricity			0.2
			LPG			0.1
			Paraffin			0.08
			Charcoal			0.06
			Biogas			0.1
			Modified Wood			0.06
			Wood			0.03
	Indoor pollution and safety(0.33)	Type of stove (0.3)	Electricity	Stove		0.3
			LPG (0.20)	Legal	Like new	0.20
					Used, decent condition	
					Damaged	0.05
					Damaged	0.00
					Needs replacement	
				Illegal		0.0
			Biogas			0.15
			Paraffin (0.12)	Legal	Like new	0.12
					Used, decent condition	
					Damaged	0.05
					Needs replacement	0.0
				Illegal		0.0
			Charcoal	Improved cook-stove		0.1
				Traditional stove		0.5
				Open fire		0.0
			Wood	Improved cook-stove		0.05
				Traditional stove		0.03
				Open fire		0.0

Dimension	Indicator	Variable	Options	Score
Lighting	Electricity Access (0.1)	Has access to own electricity	Grid connection	0,05
			Solar home system	0,1
			Free Basic Electricity	0,05
		Has shared meter or extension cord agreement		0,05
	Lighting (0,1)	Solar lighting		0.1
		Electric lighting		0.1
		Paraffin lamp		0.05
		Candles		0.03
		Battery operated lights		0.07
Services provided by household appliances	Household appliance ownership (0.03)	Has fridge	TRUE	0.03
Entertainment/education	Entertainment/education appliance ownership (0.13)	Owns entertainment/ education appliance	Television	0.10
			Computer/tablet	0.03
Communication	Telecommunication means (0.13)	Has a phone land line or a mobile phone		0,065
		Charges cell phone at home		0,065

6. Design and Development of the Digital Data Collection Platform

This chapter will outline the process of designing the mobile application, starting with the advantages and disadvantages of this method and how these can be maximised and minimised respectively. The general concept for the application is then outlined along with the research process employed to select an appropriate platform on which to develop the application and management system. The designing of the complete system is then described starting with the design and functioning of the: (i) Management System, which is used to generate surveys as well as collect and store data acquired from these surveys, (ii) the User Interface, which is the actual application through which the survey is administered which will be used on mobile phones and (iii) the execution of the development of the managements system and application. The Chapter will then outlines the manner in which the research will be conducted in order to minimize any shortcomings that may be experienced. This includes ensuring the accuracy of the data, verifying the data and conducting follow up surveys to achieve this. The implementation of the project in the community of Imizamo Yethu is then outlined and different methods of community engagement and participant recruitment are described. The Chapter ends with a Cost Effective Analysis of the costs of traditional survey methods, pen and paper interviews, versus the costs of the digital data collection platform developed as part of this study. It is important to note that the methods defined in this chapter are a result of different feedback from attempting to implement the project in both Enkanini and Imizamo Yethu.

6.1. The Prospect of Mobile Application-based Data Collection

The move away from traditional paper surveys, as demonstrated in a few health related studies, to digital platforms for collecting survey data have been motivated by the time and cost benefits of this method. The time and cost for conducting a survey using mobile phone technology compared to traditional surveys is greatly reduced, see Section 5.6 (Tomlinson *et al.*, 2009). However, by eliminating the need for survey agents who are responsible for data collection on a single device, there is the opportunity for an even more efficient system to thrive. The use of individuals' mobile phones to determine energy poverty or to acquire energy related data is unique and untested. In this case, the trained surveyor can be excluded, removing the limitations of travelling time, wages and a limited number of surveys per day per surveyor. The benefits of a digital survey system can be significantly increased, as start-up costs are constant regardless of the size of the sample group.

Digital solutions for gathering data have multiple benefits for the data collector and the research, including: (i) access to participants in distant areas or areas where physical communication is not possible; (ii) automated data collection reduces the amount of time and effort required from the researchers in terms of capturing and storing data in a database; and (iii) a digital interface also adds an element of flexibility and quick adaptation to the entire system.

The use of a digital data collection platform releases the control of a number of factors when sampling a population. These include (i) a self-selection bias based on the need to have access to a mobile phone in order to participate (ii) the respondent is not always representative of the household in that there is no assurance that it is always the head of household responding which leads to (iii) the non-verifiable nature of the system and the data collected and (iv) the risk of exploitation of the system in terms of registering more than once or submitting a survey more than once for the airtime incentive.

The shortcomings created by moving to a digital system have been minimised with the system design and functioning as much as possible. The first of these is that only one person can submit surveys for their household. While this allows more households to be surveyed using the same budget for airtime incentives, it needs to be controlled in order to reduce the rate of repeated data. The researcher cannot control who in the household submits the survey or determine whether this is the same person each week or the accuracy of their knowledge of household income and expenditure. The former issue has been reduced by allowing only one user per address to submit surveys. An easy way around this is to use a false address; however, users are not informed on how survey users are verified and this acts as a potential barrier to exploitation. Another major shortfall of this method is the self-selection bias imposed on the sample population. Unfortunately, this cannot be remedied, largely because not every individual owns his or her own mobile phone and that participation is voluntary. However, this shortcoming can only become less relevant in the future, as mobile phone use and ownership will only increase with time while participation in any self-selected or voluntary survey will result in a biased sample population whose responses in effect would generalise and be non-representative of the target population. There will always be a bias when using this platform, based on who uses the mobile phones, but also a self-selection bias of who decides to fill in a survey.

6.2 System Design

For the purposes of this project, basic information on energy use and expenditure on energy services needs to be acquired from individuals on a regular and long-term basis dependent on the nature and extent of the study. Considering this, a number of specifications need to be set for the design of the mobile application in order for it to be affordable, accessible and available to all. These specifications lie in the design of the application, the type of user input and additional features that can be implemented in the future. Because the mobile phone survey requires active input from the user, the application needs to be easy to use and understand as well as quick and convenient to use and manage in the long term. This would require the survey being no longer than 10-15 questions taking no longer than 10 minutes to complete. This is to promote participation in the study and to ensure participants do not lose interest. The design would involve the use of multiple language options as well as simple and intuitive menu options, to minimise the effort and input required by the end user.

6.2.1 Selecting a platform for development

Mobile applications are often developed for more technologically advanced software platforms such as Android, iOS, Blackberry or Windows Phone. However, when considering these platforms for the data collecting tool it must be noted that each platform requires its own unique coding which requires a significant amount of development time and resources. Equally, because the target demographic for this project have significantly lower incomes and are often unable to access these platforms, more basic and widely available platforms need to be considered. Equally, while there are a number of survey software and services that could be used for this type of research, they are only available on computers, tablets or smart phones and exclude the mobile phone users from a lower-income bracket. Instead, the development of a unique application with special functionality is available on a few platforms that are more accessible for the target population.

Unstructured Supplementary Services Data, or USSD, is the most basic form of a mobile application that can run on all mobile phones. This session-based protocol utilises GSM [3] signalling channels, which is available on all mobile phones and requires no credit or particular network subscription to work. USSD is not a store and forward protocol like SMS; rather, the communication is hosted on a remote server. It creates a real-time data session that interacts with a remote application handling service and thus needs no application software to be loaded onto the device. This technology is commonly used for checking airtime balances and for topping-up prepaid accounts. The typical use of this technology involves entering codes in the following format:

[3] Short for Global System for Mobile Communications, one of the leading digital cellular systems (GSMA, 2014)

*\emph{*shortcode\#command\#\#}* and pressing send (Eagle, 2010). The potential barriers to implementing mobile solutions using this platform include the need for collaboration with a network operator. However, if an operator were to cooperate there would be immediate access to virtually all four billion GSM subscribers globally (Eagle, 2010).

Java applications, involving the use of Java computer language and coding conventions, while requiring a slightly more complex system, were also considered for this project. These applications require java plugin support, a feature offered on all mobile phones with WAP/GPRS[4] access in South Africa. The success and popularity of java applications can be demonstrated by the popularisation of an instant messaging application called MXit. Any changes made to the application on this platform requires specialised coding or design and has a certain lead time depending on the pace of the developers.

Mobi webpages, which are webpages enhanced for viewing on mobile devices such as cell phones or tablets, are an alternative to these platforms and have similar functions to a mobile application, in which each page presents a different stage of the survey. Mobi webpages have been optimised for use on handheld devices such as mobile phones. Because the functionality of this platform is limited by only web design parameters, a fully functional digital survey hosted on the site and any additional functions would be supported and embedded easily. Equally, this platform allows real time changes to be made to the functioning of the survey.

The simplicity of USSD is inefficient for the type of survey that needs to be administered as multiple responses need to be captured including text, which cannot be sent though USSD. The use of a Java application would be easy to develop, however this involves the user downloading the application, which can be data intensive and costly for the user. The mobi-webpage platform provides the most flexibility for the design of the survey application and any additional functions without using a significant amount of data or network credit on the submission of surveys.

6.3 Designing the system

Designing a digital system that minimises error and data loss while ensuring that the experience is beneficial for both the researcher and the participant requires a number of standards for functionality on both ends of the system. On the researcher end, the system would be required to provide a database that is easily accessible and understandable as well as flexible in order to effectively analyse that data without extraneous input required. It also needs to provide a functional platform from which to design the survey.

6.3.1 Management System

The managements system is responsible for the design of the survey questions, the order in which they are asked, the pay-out of airtime vouchers, the content of the application as well as a platform to collect, view and store the responses collected from the survey as well as the details of the users involved in the study. An overview of the management system and its components are depicted in Figure 4. Since the survey is hosted on a mobi website, the administration functions can also be hosted on the same domain. This allows any administrator user to access the survey design, questions, user information and incentive payments from any device that has access to the internet. From this platform admin users can add, change or delete survey questions in all languages at any time with immediate effect. This method also allows questions to be assigned a condition, priority and week, dictating whether the question is asked independently or dependently on the outcome of a previous question, in what order and in which week of the survey. Data can be exported at any

[4] Short for Wireless Application Protocol (WAP) and General packet radio service (GPRS) are types of internet connections commonly used on mobile phones (GSMA, 2014)

time in Comma Separated Values (CSV) format, to be analysed in Microsoft Excel or any other data analysis program. The data can also be viewed in the form of graphs on the website. The results can be selected by variable and is represented in bar chart format. This is particularly useful for quick general analysis of specific variables. Other ways the data can be visualised are in the form of a map, where the location of users, determined by the given address, is plotted.

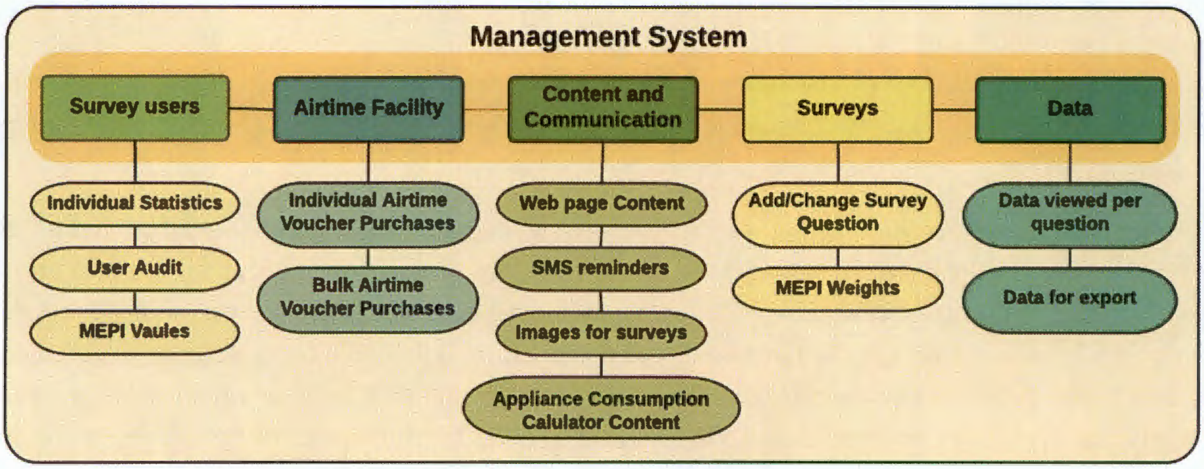

Figure 5 Schematic of Management System Functions

6.3.2 User Interface

On the user end, the interface needs to be simple and easy to use. The user needs to register in order to opt-in to participate in the survey. In order to control the number of users and to ensure some form of identification is captured, the system requires the user to register once at the start of the project. They will need to supply basic information such as a name, address, phone number and the mobile network they are supplied by in order to ensure they receive the correct type of airtime. As a precautionary measure, to ensure that the phone number supplied is legitimate and functioning, a login code is sent to the user via SMS upon registration. The user is required to login to complete each survey. Once logged in, the user will be able to select the language they would like to use. The survey will be available in English, Afrikaans and isiXhosa.

All questions asked in the survey should require only closed answers or very short open answers to reduce the amount of time and effort required from the user. This can be accomplished by using radio buttons, buttons that can either be switched on or off by the user, and dropdown menus. Other basic functions include automated SMS reminders to each user based on the time and date of the completion of their first survey as well as an airtime voucher function that dispenses network appropriate airtime to the user upon completion of the survey. Surveys are limited to one a week to allow for continuous data to be collected with appropriate time intervals.

There are a number of other functionalities that were considered in the design of this system to improve the experience and maximise the benefit of using the application. The need for this application to benefit the community has been motivated by community leaders and development workers from both Enkanini and Imizamo Yethu. This was suggested in order to persuade community members to participate in the survey and allow for an opportunity to improve energy safety knowledge. In order to educate the user on their own energy use and energy safety, an energy feedback report is sent to the user upon completion of the weekly survey and can be accessed from the website at any time. This report contains a brief summary of the user's expenditure on all the fuels they have used to date. The report also contains safety and efficiency tips that are presented according to the responses provided in the survey. For example, paraffin users will be reminded to store their fuel in an airtight container that is clearly labelled and kept out of reach from children. The report can also contain information about local stores selling energy related products such as stoves or solar lamps. This is integrated with the vendor version of the application which allows local vendors of energy related products to advertise their products to survey users. This advertising is geographically-targeted, so users within a certain geographical range will receive prices from the vendor.

In addition to these functions, it is also important that users become more aware of their electricity consumption and ways of reducing this. The Appliance Consumption Calculator is an additional function that allows users to calculate how many kWh an appliance uses for certain periods of time and how much it costs to run for each of these periods. This is accomplished by setting the ratings of common appliances in the management system and creating equations that calculate the consumption for 5 minutes, 30 minutes, 1 hour and 1 day. The user selects a single appliance or all appliances they use in a day and the calculator outputs a kWh value and a rand value for the selection. This allows users to have a comprehensive overview of their consumption and observe which appliances cost the most to run. It has the potential to be an effective tool to reduce electricity consumption. While the feedback reports and appliance consumption calculator are tools that are designed to improve the efficiency and safety of energy use, this may affect the results of the survey if they are effective, making the energy consumption of the household seem more efficient or less energy poor compared to the patterns of energy consumption prior to the start of the survey.

With the onset of load shedding at the time of design and implementation of this project, a load shedding schedule was created in addition to these functions. This is a very simple function that can be observed on the homepage of the site and is manually updated by an administrator. This feature was added to inform community members of the times the electricity was scheduled to be put off to promote the use of the application and participation in the project. This feature was a requested feature from community leaders in Enkanini.

6.3.3 Execution of Development

Due to the complexity of the development and coding required for this system, platform development was outsourced to a private company. The airtime voucher function was further outsourced to a third party that specialises in this function. The project was named Sabela Sokwazi which means "to answer the call with knowledge" in isiXhosa. The database and application is hosted on www.sabelasokwazi.co.za. The cost of development totalled R66 050 and was developed by Deep Current eMarketing Solutions cc based in Durban. The development of this unique system had some challenges and shortcomings in terms of undertaking research in an academic setting as there were a number of compromises that had to be made in order to move to a digital system that may have compromised the integrity of the research. The following section outlines these and how the study design has compensated for this.

6.4 Maintaining Research Integrity

There are a few ways in which the integrity of the research is partially compromised in the move to a digital data collection tool. The sample size can only be controlled to a certain extent by limiting the number of people able to fill in the survey. However, as mentioned previously there are no means of controlling or knowing who in the household is submitting responses or how accurate their knowledge is. Equally, the use of mobile phones as the primary requirement for participation automatically excludes poor households unable to afford a mobile phone for any inhabitants. However, this problem is perceived as a minor and temporary problem as the rate of mobile phone use and the standard of mobile phones is predicted to increase in the future.

The aims of this project seek to develop and test an appropriate mobile phone survey system as well as formulate a relevant energy poverty indicator to be used in informal settlements in South Africa. The development of a relevant energy poverty indicator builds on research undertaken from academics globally (Aranda-Jan *et al.*, 2014; Leon *et al.* , 2012; Tomlinson *et al.*, 2009).

6.4.1 Accuracy of Data

The accuracy of the data supplied cannot be tested for each household. However, some features of digital survey design can be used to improve the accuracy of the data procured. One of the simplest methods to improve accuracy is to employ a simple interface that displays simple questions in a user-friendly format. These questions should be accompanied by a user-friendly answer input, such as multiple-choice answers in the form of single options or multiple selections. Equally, questions that require approximate figures as responses should be limited to ranges of figures rather than the input of figures. Other features of using this technology is that questions deemed irrelevant by given responses can be skipped using skip logic. Equally, the respondent can view their progress with the use of a status bar, which motivates the respondent and gives an indication of how much time is required to fill out the survey. This method ensures that the survey is as easy as possible to fill out and requires minimum effort from the participant. This factor could potentially decrease the amount of falsification of information from the participants.

6.4.2 Verifying Data

For virtual survey data collection to be successful a number of important criteria and trade-offs need to be made. While the movement to this system is appealing, the removal of an objective authority physically administering the survey removes the simple and automatic auditing of survey responses by the surveyor. The reliability of data gathered using this method is compromised in ways that are unidentifiable without physical auditing of responses for validity. Measures to improve data reliability or decrease the potential for falsified information are difficult to implement. However, the benefits of acquiring large amounts of continuous data form large populations outweighs the disadvantages of falsified data or data that is difficult to verify as this type of data is difficult to verify by nature.

Surveys are customarily conducted by a third party or by the researchers themselves with face to face interaction that allows for a certain amount of legitimisation of the data to take place. The uncertainty created by using data that is unverified and sourced directly from the user, without verification by a second party, is one of the disadvantages of this method. Another party could potentially verify data but this is counterintuitive to the advantages of the method in terms of time and resources used to collect accurate data. In order to develop a baseline of uncertainty when using this method a number of visits to random households will be made in order to verify information and detect trends of uncertainty. Regardless of this verification, the very nature of the information being provided is inherently uncertain. Fluctuating cash flow in poor households for example is particularly difficult to verify, even if the survey is physically present and acquires some sort of verification of the data collected (Eberhard & Van Horen, 1995). The survey is designed to compensate for these kinds of fluctuations by using reliable indicators of wealth to improve the quality of data.

One method to verify the data collected suing this method is to conduct follow up surveys that determine whether any major discrepancies in the information gathered. This is discussed in the next subsection. An alternative method of verifying the data collected is by comparing the patterns and trends to studies conducted previously in the same community. In this case, a study conducted by Visagie (2008) was used to compare the main energy consumption and energy access trends in the community of Imizamo Yethu as well as data derived from the 2011 National Census conducted by StatsSA (2011).. A summary and discussion of this comparison is made in Section 8.1.7.

6.4.3 Follow up Surveys

Follow up surveys were conducted after the survey period ended. This date was largely dependent on the rate of completed surveys; however a threshold of 50 completed surveys was used as an indication of the end of the survey period. The aims of the follow up survey were to legitimize the data and determine reasons for dropout rates amongst users that did not complete the six week survey. Participants were randomly selected from two pools, one with users that have completed the six week survey and the other with users that have registered within the first week of the survey but did not complete the full survey. The data was legitimized by showing there are no major discrepancies in consumption behaviour between the automated survey and a one-on-one survey. The surveys were conducted telephonically, due to time constraints, with 10 participants. Evidence of consumption behaviour was to be acquired using photographs where possible. For future use there is potential for automated random verification questions to be asked, including the uploading of photos of electricity credit receipts.

6.5 Implementation

Because of the successful operations of the community development office in Imizamo Yethu the process for distributing information about the Sabela Sokwazi project were very simple. It was suggested by the community development workers that the youth be approached as representatives of the project to explain the concept to older members of the community. This approach was suggested, as the youth are the most common population group to utilise the necessary technology to take part in the project.

6.5.1Recruitment of research participants

A top down approach was used to delegate knowledge dispersing roles to leaders or organisers of various groups, organisations and societies that are popular in the community. There were a number of meetings with the leaders of the youth clubs and associations in the area. Information about the Sabela Sokwazi Project was passed on within these groups in their weekly and monthly meetings. To supplement this at least 100 A3 colour posters (see Appendix 11.5) were posted on public buildings and shops in the area for the duration of the study.

There were three types of paper materials used for the promotion of the Sabela Sokwazi Project, these included A3 colour posters, A4 colour posters and A5 black and white pamphlets, see Appendix. The smaller pamphlets were distributed throughout the area with the help of a community development worker and the shop owners. The A4 colour posters were posted in the 80 Hout Bay taxis, with permission from the Hout Bay Taxi Association, who supported the project based on the positive impact it would have on the community. These posters were less successful as the drivers, who were not personally informed of the project and its objectives, removed them from the taxis. Unfortunately, there was no opportunity to address this issue and the strategy was dropped.

In addition to reaching out to the community at large, special focus was given to targeting high school students, who tend to be better informed of technology than the general population with regards to mobile phone use. There are two high schools in the area that educated most of the population of Imizamo Yethu at high school age. Hout Bay High School was approached within the first week of the project with the project outline and objectives. It was suggested by the vice principal that the members of the Environmental Club were ambassadors for the project. The 25 students were supplied with posters and pamphlets and distributed these materials within the school for each class and outside of school in their communities, reaching over 600 students. Silikamva High School is more closely situated to Imizamo Yethu, and was approached in the first week of the project to announce the general outline of the project and the objectives at school assembly. Three grade assemblies were attended in the third week of the project where this was achieved. Pamphlets were distributed at the end of the school day to each student, reaching approximately 500 students while posters were posted in and around the school.

6.6 Cost Effective analysis

Cost is one of the factors that can greatly influence the feasibility of implementing this data collecting system on a wider scale. General costs for traditional surveys in urban and rural areas were used to compare total costs and costs per survey with those of a digital survey. The costs used for the traditional surveys were estimates but the digital survey costs are real costs that were incurred to produce the survey data discussed.

It is estimated that an enumerator can fill in 10 surveys in a day. The daily pay for this is R110, the average rate for interns at the University of Cape Town. Because the enumerators are university students it is assumed there is no cost for training the enumerators. The number of enumerators needed per day is determined by the number of surveys that need to be completed, 1 enumerator per 10 surveys required. This determined the period for data collection. Transportation costs were calculated using the AA Vehicle Rates Calculator using a 2006 model Tata Indica LSi. This produced a cost of R4.67 per km. It was assumed that the average travel distance for urban surveys would be 20km return and 75km return for rural surveys. The material costs for traditional surveys account for the costs of paper and stationery per survey at R5 per survey for both urban and rural. Data Capturing, Data Cleaning and Analysis were assumed to take 3 hours per day for 10 surveys at an hourly rate of R100. See Appendix 11.6 for a Table of all the cost used for this analysis. Costs were added for a student to undertake school visits and put up posters while posters were costed at 50c per expected survey. Costs for managing the WhatsApp helpline are negligible it is free to use WhatsApp.

The costs for the digital survey are mostly comprised of the start-up costs, which is Web Development, Web Management, Web Support and Project Management which totalled R66051.60. There are no enumerators required, transport costs, materials or data cleaning, analysis, and data capture required as this is all built into the system.

For short-term surveys with a total sample size of less than 2000 participants, traditional surveys are more cost effective per survey and total costs. However, if the sample size exceeds 2000 the digital data collection system is a more cost effective method. In terms of longitudinal surveys, which this platform was designed for, the number of surveys to be conducted for a household or individual are variable and will amount to at least two to an unlimited number of surveys over the entire study period.

The Figure 5 below illustrates the total cost of conducting a survey for increasing number of surveys. From this figure it can be observed that the total cost of conducting digital surveys does not fluctuate or increase at a high rate, even over a range of 50-15000 surveys. The cost of conducting rural and urban traditional surveys however, rapidly increase between 50 and 2000 surveys. Digital surveys become increasingly more cost effective compared to traditional surveys after the 2000 survey threshold has been reached. In Figure 6 the cost per survey for digital and traditional surveys are plotted against the number of surveys conducted. This graph indicates a similar result for Figure 5 where the cost per survey greatly for digital surveys decreases with an increasing sample size, whereas the cost for traditional surveys, while rural surveys are initially higher that urban surveys, stays constant even with increasing sample size. These figures illustrate that studies that involve large sample groups or repeated surveys, studies that require more than one survey per participant, would benefit from using a digital survey tool as opposed to a traditional survey as the costs of this decrease as the sample size increases. Even with studies with smaller sample groups and a non-repetitive nature, many of these studies can be conducted using the same tool, which can be adapted for the specific needs of each study. Considering these conditions the digital data-collecting platform is financially feasible compared to traditional surveys

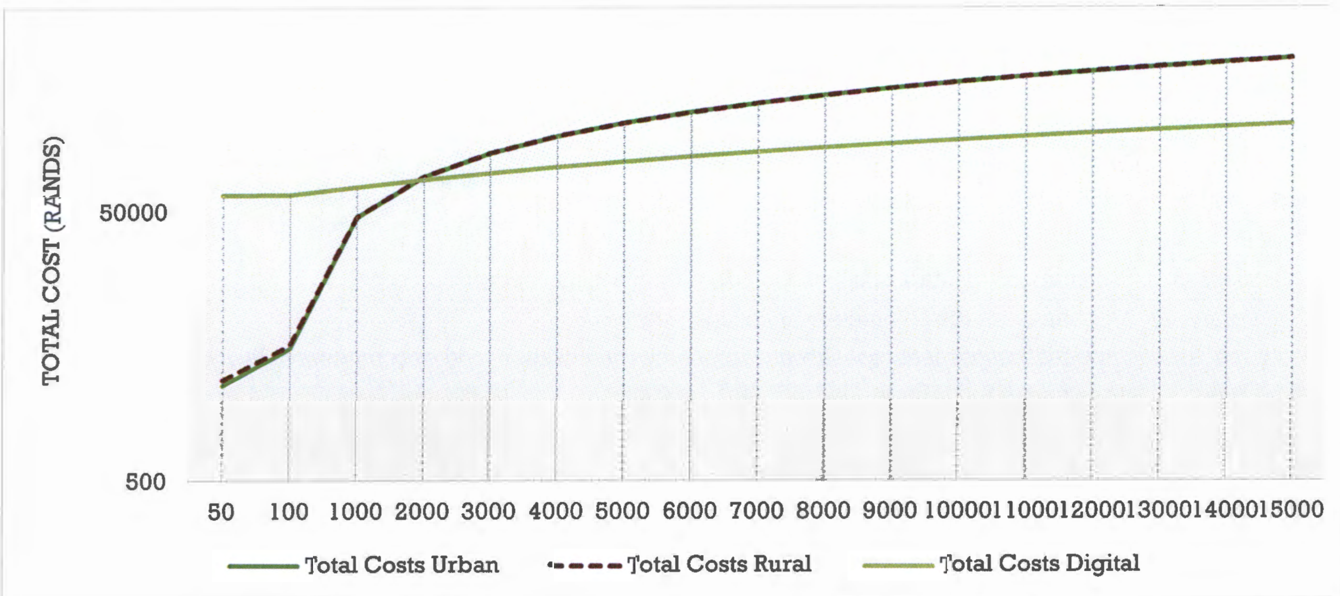

Figure 6 Total Costs of Surveys versus the Size of the Survey

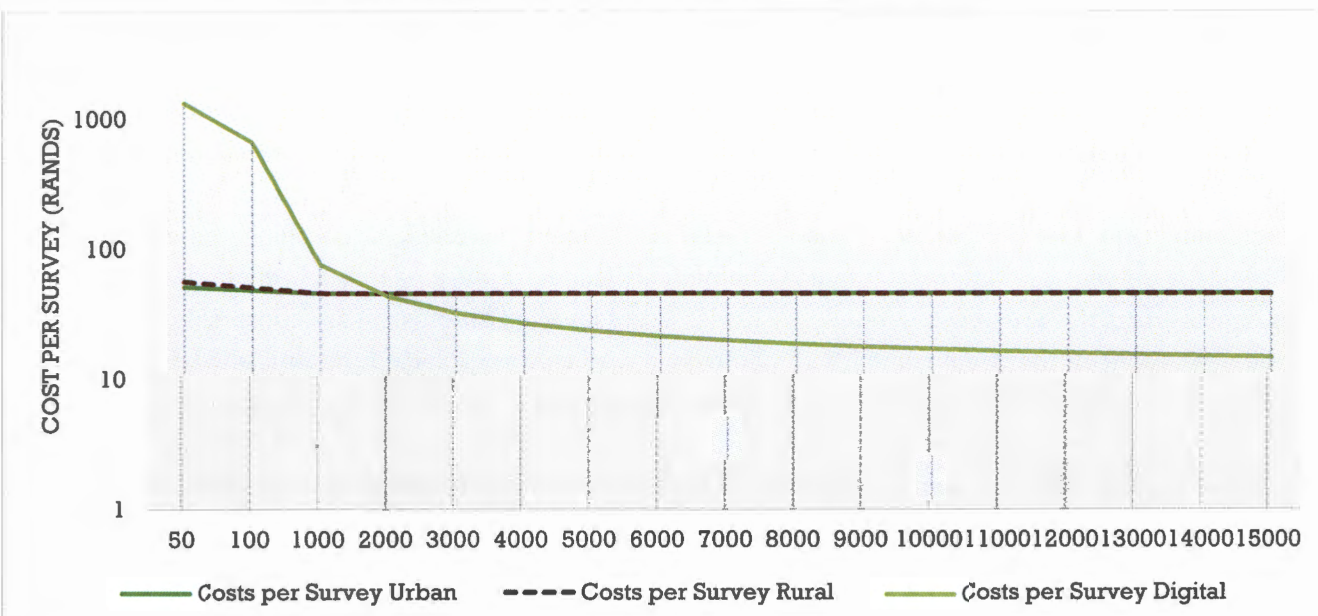

Figure 7 Costs per survey versus the Size of the Survey

7. Local implementation of the digital data collection platform and community engagement

In order to determine the feasibility and functioning of this digital data collection platform for future use, the implementation, maintenance and costs associated with this method of data collection also need to be analysed. This section discusses the local implementation of the digital collection platform, and analyses the problems encountered with community engagement, community response, development and maintenance of the web page, as well as a cost efficiency analysis of this system versus traditional survey methods. The series of events that occurred while undertaking community engagement are numerous and detailed as these involved two different communities at different times. The detailed descriptions of these events is described in Section 6.1. Table 3 summarises the major events that occurred during this period.

Table 3 Timeline of major events during implementation

2014	
October	First meeting with community development workers in Imizamo Yethu, First meeting with Deep Current (Application Developers)
November	Application Brief submitted to Deep Current
2015	
January	Preparations for start of application development, payment processed
February	Meetings with the community of Enkanini started
March	Continuation of meetings with the community of Enkanini, end of community engagement in Enkanini at the end of the month
April	Meeting and planning of community engagement with the community development workers in Imizamo Yethu, Start of the survey mid-month
May	Survey continuation, Issues with the survey experienced
June	Informal continuation of survey

7.1 Experiences with community engagement

The implementation of this project in a relevant community was challenging; the first attempt to introduce the project to the community of Enkanini was unsuccessful, largely due to community engagement problems. There was no specific method for finding a community in which to test the functionality of the mobile application. However, a community with an electricity supply sourced directly from Eskom was required due to previous aims to determine changes over a major electricity tariff change that was expected to happen in April in Eskom supplied zones. Thus a list of potential informal settlements in Eskom supplied zones was compiled, and a community was selected based on the ability of the researcher to contact community leaders in each area, Enkanini was selected. Eskom was used as a platform from which to engage and select a community. On Friday the 20th of February a meter auditing team working in Enkanini, an informal part of Khayelitsha, served as facilitators for finding a community leader for the area through whom the project could be conveyed to the greater community. A leader was identified through many conversations with local residents. As one of the street committee[5] members, a woman was explained the aims and basic operations of the project. This street committee representative was enlisted to disseminate information about the project to the broader community. Additional features of the app were suggested at this meeting including an appliance consumption calculator, which calculates the kWh and Rand value used by an appliance for any amount of time. It was agreed that a door-to-door approach would be commenced the following Monday.

[5] A street committee is a group of residents elected by the local community, within a 2-5km radius, to deal with issues such as conflicts, changes in utility supply or developments arising in the community

Figure 8 Satellite photograph of Enkanini (Google Earth)

On Monday the 23rd of February as agreed, materials for communicating the basics of the project, which included posters and pamphlets, were brought to the community. There was confusion and slight animosity about the implementation of the project in the community as the previous visit with the Eskom group seemed to have suggested a problematic working relationship with Eskom[6]. This had a negative effect on the perception of the project as the meter auditors were mainly disconnecting tampered meters in this community and there was already a significant amount of animosity towards Eskom and this particular team of meter auditors. So much so that the team was evacuated from the area that Friday after two men were spotted following the team around with rocks in hand. From this point onwards, it was strongly suggested that in order for the project to be taken any further the community leaders would have to be consulted. It was also very important to make very clear that the project was purely academic and has no association with Eskom or Telkom, another company that appeared to be a source of animosity in the community.

Following this unfortunate misunderstanding, a meeting was set up with the community committee chairperson on Monday the 2nd of March. This meeting involved an explanation of the concept of the project as well as what would be required of the committee in order to successfully implement the project. While the concept and the benefits of the project were understood and accepted, there were reservations as to the response of the broader community. Equally, additional features were suggested, such as a daily electricity use calculator, where appliances used for the day are selected as well as the period of use for each appliance to output a kWh value and Rand value for the electricity expenditure for the day.

7.1.1 Community consultation and local gatekeepers

The community leaders that were addressed at this meeting continued to consult other members of the leadership and gather opinions about the project. A further two weeks followed before another meeting could

[6] Eskom's relationship with this community has deteriorated, as Eskom's main activity in this community has been to disconnect electricity meters where account holders have not been paying for their electricity or where households have been tampering with the meter box. Equally, complaints about the electricity supply from the community have gone unheard by Eskom's office, situated just 2km from the community.

be held on the 17th of March. At this meeting, posters and pamphlets were distributed and a method of disseminating information about the project was discussed. It was discussed that the best methods for getting the message to a large enough population to take part in the project would be a door-to-door approach was suggested by leadership; however, for the purposes of the project this approach would be counterproductive to its aims which seeks to be less demanding on human resources and more reliant on the digital interface to prove how far the digital interface can substitute human labour. It was suggested that a community meeting be called in the coming days to announce the project concept and benefits and to seek out interested parties. Following this, if there was enough interest in the project, pamphlets and posters would be distributed and a start date would be announced.

A community meeting was scheduled for the evening of Friday the 20th of March. The project organiser was only aware that this was to be a public meeting upon arrival. The project concept was announced to the public through the project organiser in English and was translated by the community leader in isiXhosa. Unfortunately, after the brief explanation, there was no interest in participating in the project and it was suggested by the community leader that the pursuit of involvement from this particular community would not have a successful outcome.

Unfortunately, because of various service delivery failures on account of Eskom, which include load shedding and lack of information surrounding electricity use in the area, as well as the nature of the activities performed by the Meter Auditing team that was accompanied, the project was associated with Eskom. These promoted a sense of animosity towards Eskom and by association, the Sabela Sokwazi project. While it was thought that the local woman that was consulted was a significant member of the local leadership, it appeared that she did not hold enough power to persuade the wider community and leadership that the project was beneficial and not associated with Eskom. However, after the confusion of being associated with Eskom, it was made clear that the best means of reaching out to the community would be through the chairperson of the community leadership.

There was also an issue with assuming the community would stick to the project deadlines and not allowing enough time to gain the trust of the community leaders and the community at large. This was a risky assumption to make, as the amount of time required to effectively implement the project in the community is relative to the interests of the community. It is also expected that if the community had a sense of ownership of the app there would be more interest and participation. This would involve consulting the community before developing the app. However, this defeats the purpose of having an application that can be applied to multiple studies in different communities.

Once it was agreed upon with the community leaders that Enkanini would not be a viable sample population for the project, another community was selected and contacted. The community of Imizamo Yethu was initially approached in October 2014 to conduct this research in March/April 2016. The social cohesion and setup of Imizamo Yethu was much more favourable for conducting research, as there is a clear leadership structure and community structure in place. Equally, the community is familiar with academic research projects as the University of Cape Town has conducted numerous studies in this area before and continue to do so. These two factors were missing in Enkanini, and if they were present the application of this type of survey to an impoverished community such as Enkanini, the project might have been successful. It was also advised by the Enkanini community leaders that the community has maintained a low level of education, which impeded understanding and interest in the project.

Imizamo Yethu is governed by the African National Congress, which funds a community development office. This factor could have potentially affected the rates of participation and the number of participants in the project, as the project could be perceived to be associated with or supportive of the ANC which would deter non-ANC supporters to participate. This does not seem to have been the case as the community development office was only used to meet with the leaders of local groups and societies and much of the promotion of the project was achieved independently.

The community of Imizamo Yethu was mainly consulted through the community development workers, who have a deep-rooted sense of authority amongst residents, as they have been consulting representatives of the community since its establishment in the 1980s. The community development workers facilitated all the meetings with local community groups and societies as well as the local high schools. Any engagement with the community was facilitated by the community development workers, which facilitated interest and participation in the project in the community. This supervision is likely to be the reason behind successful community engagement from the projects perspective.

7.2 Community Response/Willingness to participate?

There were a significant number of registrations over the first 4 weeks (13 April – 4 May 2015) as observable in Figure 8 below; however, out of 306 registered users, only 170 submitted their first survey, with a 69% success rate over this period. It is likely that if this project had no time limit and the study was continuous there will likely be an increase in the number of registrations and submitted surveys over a longer period. The initial response to the project, within the first week of the survey, was mostly negative from the wider community when explanations about the project were done one-on-one in the streets of Imizamo Yethu, and mostly by an English-speaking person that was relatively unknown in the community. However, the engagement with the local high schools and the promotion of the project by students within the community seem to have increased participation and interest.

Figure 8 displays the number of participants that had registered over the April-June 2015 period. This graph also shows the number of survey submissions for each week of the survey over the study period. Each blue bar represents an SMS reminder that was sent out. The red bars represent school visits. Hout Bay High School was approached on the 20th of April to campaign on behalf of the project and Silikamva High School was approached on the 24th of April in grade assemblies, the number of registrations after these two dates increased significantly. There are a few instances where the SMS reminders appear to have an impact on the number of submissions made; this is particularly notable for the 29th of May 2015 and the 13th of June 2015. This is most likely because they were sent on Friday and Saturday at 5pm and 11am respectively, indicating that these are better days and times to ensure a higher number of responses. The periods during which there were no SMS reminders, most notably, between the 12th to the 21st of May and the 29th of May and the 12th of June, were periods when the survey was not functioning correctly and participants could not submit their surveys.

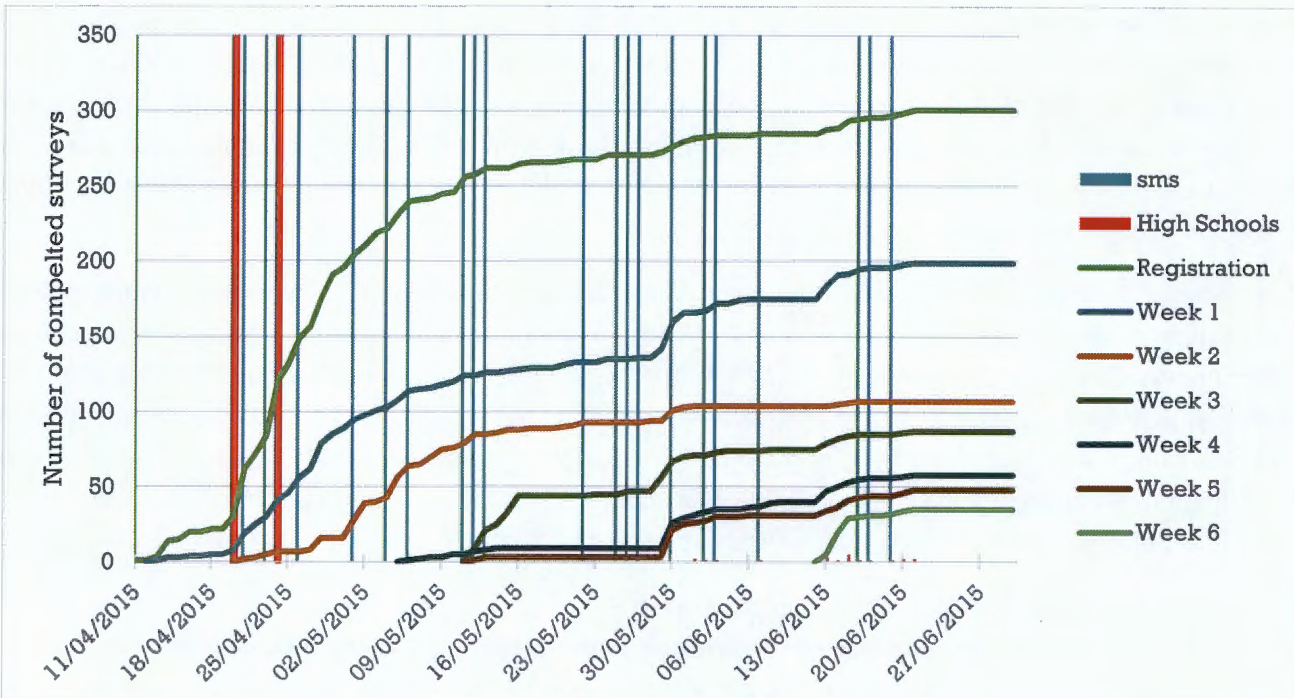

Figure 9 Surveys Submitted April-June 2016

7.3 Maintenance of the System

Throughout the survey period, there were a number of questions and issues that were expressed by participants. To manage these inquiries and issues, a WhatsApp[7] helpline was created and managed by the project manager. Most of the inquiries were from people who had heard about the project and wanted to know what it was about. In the early weeks, there were many users that required step-by-step assistance to complete a survey. This decreased throughout the duration of the project. A large proportion of the queries were for lost login codes. These codes are sent to the users as soon as they register and act as a password along with their cell phone number as a username, to submit their surveys. It was assumed that the login codes, which were sent by SMS, would be retained by the user, but the several requests by the same users for their login codes indicated that this was not so.

7.3.1 Helpline Functioning

The helpline was open on WhatsApp from 8am to 8pm every day. The number for the helpline was advertised on the pamphlets distributed in the community and reminder SMSs. This helpline was fairly successful as many participants were part of the Cell C Network which allows customers to utilise WhatsApp free of charge. Participants did not abide by the open hours of the helpline and the most frequent complaints were for the survey malfunctioning experienced from the third week of the project. There were also numerous requests

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7 "WhatsApp Messenger is a cross-platform mobile messaging app, which allows you to exchange messages without having to pay for SMS. WhatsApp Messenger is available for iPhone, BlackBerry, Android, Windows Phone and Nokia and yes, those phones can all message each other! Because WhatsApp Messenger uses the same internet data plan that you use for email and web browsing, there is no cost to message and stay in touch with your friends besides the network cost of data for running the application, of which Cell C users are exempt In addition to basic messaging WhatsApp users can create groups, send each other unlimited images, video and audio media messages." (Whatsapp, 2015)

for airtime vouchers to be paid out as well as requests from user to resupply their login codes. While the helpline was helpful to many users the amount of complaints that needed to be addressed due to the system malfunctioning were too high to be managed by one person on a daily basis. With a maximum of 20 complaints on a day in the peak of the malfunctioning period, this was felt manageable but requiring time and effort to respond to these complaints.

Other inquiries were for the estimated time for the pay out of airtime. At the start of the project, this had become an issue due to several bugs in the functioning of the management system and the airtime utility, which were shortly rectified. Despite this, there were still a large number of requests when the airtime distribution was working smoothly. This could be largely due to the delay from the time the user completes a survey until an administrator pays out airtime to users that have completed certain surveys. The developers planned this delay and the project administrator as the application had not been used previously and it was unknown whether there were bugs or inefficiencies in the system that would allow users to exploit the system for airtime vouchers. This delay also allowed the administrator to check that the users had completed the survey and were living within the sample area/community. There were many lessons learned during the first implementation of this project. Several changes were made to the way the application and the management system functions so future surveys can be enabled with automatic airtime pay-outs with each survey.

7.3.2 Operation Issues

The most important issues arose when problems occurred within the survey management system. The users issued many complaints that surveys asked only one or two questions and then ended without completing the rest of the week's questions. This was due to two changes in data and question management. Previously the system calculated and assigned a week to the user depending on how many surveys they had submitted. Questions that were automatically repeated weekly were disabled after the first batch of data was analysed and the responses for weekly questions were indistinguishable from week to week, since weekly questions assigned the same variable name for each response received, regardless of the week. This prevented weekly or long-term patterns in responses to be observed. As a response to this problem, different variable names were given to separate questions that asked the same question every week, allowing the responses to be ordered by user over time, making patterns over the weeks visible. Once the weekly questions were removed, the system malfunctioned and prevented users from completing a weekly survey. Unfortunately, during this three week period the survey system was down and most users were unable to submit surveys. The resultant decline in the number of responses can be observed in Figure 8. The WhatsApp helpline was another form of communication used to inform participants of the downtime experienced as a result of this problem. Another bug occurred during this period caused by adding new questions assigned to earlier weeks that had been previously completed by some users. As questions were added retrospectively to earlier weeks, the system counter-acted this by asking only the additional questions added to previous weeks while excluding the current week's questions. Both of these issues were rectified, unfortunately, weeks after the problem was reported. This was the result of an internal issue with the developers.

7.4 Recruitment of application developer and system functioning

The tender process for selecting an application developer to code the application was simple. An application brief was sent out to a range of South African IT Development firms in October 2014. There were 3 quotes from this, of which the most comprehensive and financially efficient company was chosen. Unfortunately, the development firm selected, Deep Current E-Marketing Solutions cc, was situated in Durban which is a disadvantage as the project would be conducted in Cape Town. However, this challenge was overcome with the use of Skype calls and emails, with 3 visits to the developer for the entire duration of the project. There were some issues with receiving timeous responses to bug issues or changes to the system as the project wore on. The initial brief for this project was to have the entire system and application fully functioning by the end of February. Unfortunately, this was not achieved and the maintenance following this experienced similar problems. The root of this problem was an internal issue within the web development company where the primary programmer and digital manager for the Sabela Sokwazi project was a freelancer the company had employed, while the company itself was being asked for detailed assistance of the project with little or no knowledge of the project. The delay between these two actors was disappointing and uncontrollable. With correct and reliable services, this project could have potentially produced better results as the periods when the survey was inoperable and the airtime facility was faulty damaged the reputation of the project and could have potentially prevented people from registering and or continuing with the survey. There were at least 60 participants that expressed, on the WhatsApp helpline, their dissatisfaction in the functioning of the survey during this period. In the follow-up surveys, discussed in later sections it was determined that this was the primary cause for participants to stop completing surveys.

There were a number of issues that were derived from poor communication and delayed response time for changes, fixes and queries. These are summarised in Table 4.

Table 4 Summary of the issues experienced with the Application Developers

Date issue raised	Issue	Problems with resolving the issue	Date issue resolved	Outcome	Time to resolve
28 February 2015	Automated SMS reminders as specified in original brief	Delayed response, adapted solution to send out SMSs manually in bulk according to week, unable to automate process, unable to select multiple users to receive SMSs	Not resolved	Not Resolved, No automated SMS feature as specified in original brief	Not resolved
9 March 2015	Airtime Credits and functionality not up and running	Payment from University delayed, no credits added to account to begin project	8 April 2015	Money was transferred in the next week, airtime function only working from the 8th April	4 weeks
16 March 2015	Appliance consumption calculator functioning not yet added to web page	Delay in money transfers between UCT and Deep Current	31 March 2015	Resolved	15 days
16 March 2015	Load Shedding Schedule function no yet added to web page	Delayed response	31 March 2015	Resolved	15 days
16 March 2015	Map of given addresses not yet added to web page	Delayed response	23 April 2015	Resolved	5 weeks
16 March 2015	Statistics of appliance consumption calculator use	Not addressed	Not resolved	Not Resolved	Not resolved
16 March	Reporting visualisations per household on the admin system	Delayed response	1 May 2015	Resolved	7 weeks
20 March 2015	Duplicate data being submitted by users reloading and resubmitting the same question	Advised to remove duplicate data in a data processor, revisited problem in June 2015, no action taken	28 July 2015	Resolved	17 weeks
20 April 2015	Airtime function not operating	Fault in the system	21 April 2015	Resolved	1 day
23 April 2015	Airtime payment system faulty	Delayed response to fault	1 May 2015	Resolved	2 weeks
23 April 2015	Unable to export data from system		1 May 2015	Resolved	2 weeks
30 May 2015	Repeating surveys and premature ending of surveys	Delayed response to fault	7 June 2015	Resolved, with the use of the User Audit tool that was added to handle this error	1 week
4 July 2015	MEPI values not calculating correctly	Delayed response to fault	28 July 2015	Resolved	3 weeks

These issues affected the users' experience with the application and as such has discouraged use of the application resulting in higher dropout rates in the third week of the survey as depicted in Figure 8. The most realistic rates of data capturing for this project are thus the first two weeks of the survey where there were few, if any, complaints about the system's functioning. The issues experienced with the developers also contributed to functions remaining rudimental and unevolved as many additions and improvements were requested and were never addressed or invoiced as requested. The handing over of the development of this project to a more local firm or professional was suggested only in June when the survey period had ended. This transition to another developer would have been beneficial when the first issues arose; however, Deep Current was mandated to provide these services based on the invoice that was paid to them. With better maintenance and control over changes, improvements and troubleshooting, it is likely that this project would have produced better quality data at a larger quantity than the data that was collected over this period where these issues were handled perfunctorily.

7.5 Post project response

The final survey consisted of questions that would inform future project implementation and design through feedback on incentives, energy tools such as the Appliance Consumption Calculator and the Feedback Reports as well as identifying the motivation behind continuous participation and use of the application. At the time of writing only 52 users had completed the last survey. Their responses are represented in Figure 9 below. From this figure, it would appear that the combined incentive of airtime vouchers and energy education tools are effective in sustaining participation. This also promotes energy education through this application as a viable means of engaging the community. The integration of energy education tools with the survey is a producive means of alleviating energy poverty but it can also affect the data being collected as these tools are actively trying to change the energy use patterns in the households being surveyed. This element of accuracy is discussed in later sections. This information is useful for future use and cost estimates of this platform. These results suggest that if the survey is explained clearly through formal avenues within the community, such as schools and community meetings, the need for more costly incentives decreases as the understanding and awareness increases.

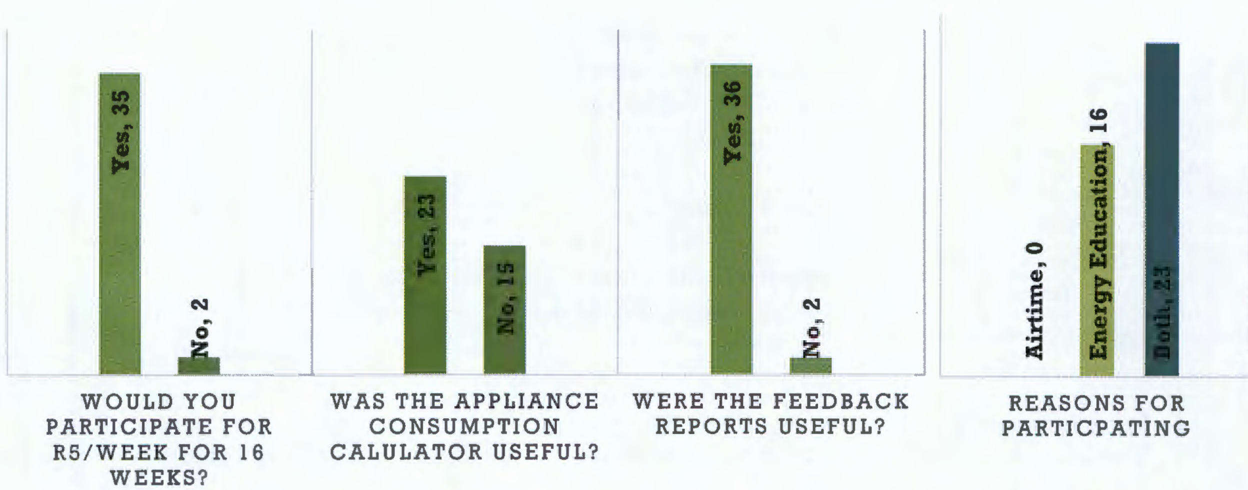


Figure 10 User experience and reasons for participating

Figure 9 also indicates that it is likely a lower airtime incentive would be sufficient for studies that are undertaken over longer periods. The suggested rate used in the question was R5 per week for 16 weeks which is half the weekly incentive and double the study period used in this survey. This could have signinficant impacts on the cost of conducting the survey as lower incentives allow for more households to be surveyed at the same cost or for the same number of households to be surveyed for longer, which would be more beneficial for longitudinal data studies. The usefulness of the Appliance Consumption Calulator is largely divided, this is likely because people did not know how to use it or there were a lack of relevent appliances listed. This can be refined with the addition of clearer instructions and more appliance options. The majority of particiapnts concluded that their feedback reports were useful as it gave them indication of how much they were using as the weeks progressed.

Figure 10 below lists the ways in which participants found out about the project. The majority of users that answered this question found about project through another person. Upon further questioning, as can be seen from the inset of Figure 10, the majority of these information agents were high school students. This result indicates that the use of high schools to recruit participants was highly successful and contributed the most to disseminating information about the project. The posters are also successful, the combination of both amounting to a similar number of participants recruited.

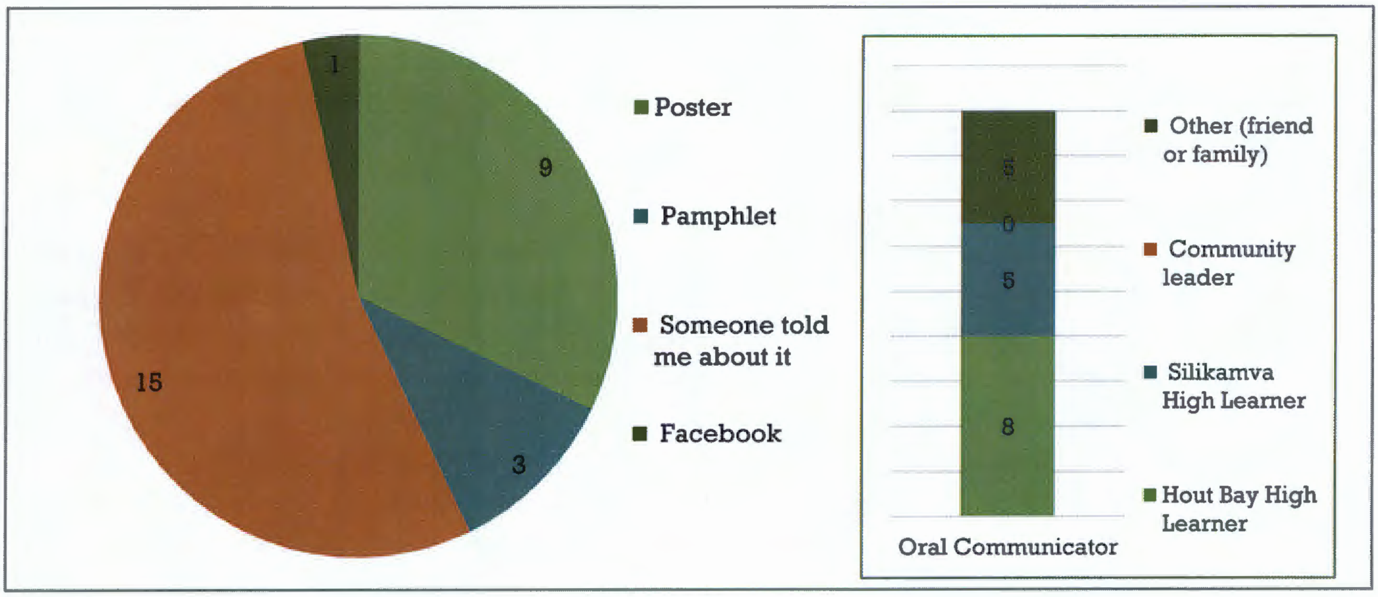


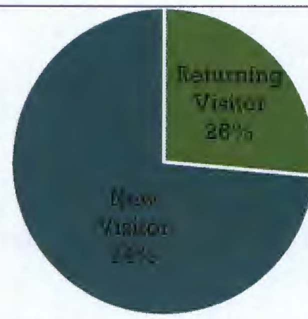
Figure 11 Information dissemination methods experienced by users and main distributors of information (inset)

7.6 Web Page Usage

Table 5 below summarises the usages statistics of the web page from the start of the project in April until June 2015. There was a relatively low number of sessions considering the high number of users visiting the page and the expected repeated use by each user. There are 88 more users visiting the site than those who registered for the survey, suggesting that many people were auditing the website while not participating. According to the low bounce rate, which is the percentage of users that navigate away from the site after viewing only one page, 81% of these users stay on the webpage to browse the site. This indicates that users are interested in the site but the low number of registrations relative to the total number of visitors to the site suggest there are factors that prevent their registration or participation in the project. These factors may include the use of the load-shedding schedule, which was in demand during this period. It could also be attributed to the use of the Appliance Consumption Calculator; however, statistics show that only 151 users used the Calculator 354 times over this period. This indicates that there is another reason users are staying on the website but not registering for the survey. Perhaps this is attributed to the lack of detailed information about the project and how the surveys and airtime incentives work. There could also be a language barrier as the language options were placed lower on the webpage and were not obvious options to the user.

Table 5 Web Page Usage Statistics

Sessions	1495
User	394
Page views	16257
Pages/session	10,87
Average Session Duration	6'05"
Bounce rate	18,19%
% New sessions	26.29%



The average pages per session relate to the average of 10 questions asked per week thus each page per session was a different question in the survey. The average duration is lower than expected, as a 10-minute target was set for each weekly survey. This is positive feedback for the project indicating that the user interface is quick and easy to use.

7.7 Maintaining participant involvement

The involvement of participants in this project has been inconsistent, leading to a database with a wide variety of information but with inconsistent confidence levels for each question. The method used to acquire this information is not uniform in its approach to each participant as not all questions are asked to all participants based on their given responses. Questions are also asked at different times depending on when the participant opts to submit a survey. The system was designed in this way to ensure that participants found the survey easy to use, without unnecessary questions with surveys that are available to submit at a time suitable for themselves, to promote regular participation. However, despite this the rates of participation decreased as the study progressed. The reasons behind this have been discussed previously and the declining rates of participation are largely attributed to the malfunctioning of the survey. This is also mentioned by the participants that were interviewed for the follow up surveys. In addition to decreasing rates in participation, there were a significant amount of registered users that did not submit a survey throughout the entire study period. This was likely due to people hearing about the project and the airtime incentives, but who lost interest or did not know enough about the project to continue. This was experienced a few times on the WhatsApp helpline, where users would ask what the project was about. Aside from this group of users that actively sought out additional information, it is assumed that the remainder of the users did not have the time or resources to do this or had lost interest in the project. Word of mouth is another factor that may have prevented users from becoming participants in the study. The mass registration for the project was largely promoted by word of mouth. Thus, it can be safely assumed that, with the large number of complaints received during the malfunctioning of the survey, there was communication of this fault to the rest of the community, which opted to not participate in the project because of this, despite having registered.

7.7.1 Follow up surveys

Six follow up surveys were conducted over a two-week period, two months after the conclusion of the study period. The participants selected for these surveys were selected at random within two pools of participants, one with participants that have completed the full six-week survey and the other from participants who had not completed the full survey. These surveys aimed to legitimise the data collected in the digital survey by determining that there were no major discrepancies between the responses give in the digital survey as opposed to the telephonic follow up survey. The responses for expenditure on electricity were inflated for all six participants in the follow up survey compared to their responses in the digital survey. This is likely because of the change of season that occurred between June and August, with households requiring more heating in the winter periods. From the group of participants that did not complete the six week survey all concluded their participation when the survey was malfunctioning. While Most of the interviewed participants tried multiple times to submit a survey while the survey was malfunctioning only one abandoned any further attempts to submit a survey after experiencing difficulties this first time.

The overall experience while conducting these surveys was the difficulty in reaching participants throughout the week. Initially it was intended for 12 participants to be interviewed for the follow up surveys, however, after trying continuously for two weeks only 6 participants were contactable and available to respond.

7.8 Conclusion

This Chapter has discussed the relevant outcomes of implementing, managing and maintaining the application and management system. Because there was a third party involved in the development of the system and the communication and response time for faults was slow the survey went through major faults that affected the user experience and participation in the project. Other data that was collected indicate that many unique visitors frequently visited prior to this malfunctioning the website, with a short and reasonable time taken to complete each survey. Equally, the means of notifying the community about this project and recruiting participants for the survey were largely due to the school visits and the combined effect of the posters and pamphlets distributed throughout the community.

8. Outputs and outcomes

This chapter is divided into two subsections: the first analyses the quality and quantity of results that contribute to assessing the feasibility and effectiveness of a mobile phone based survey platform to collect reliable information about energy use and expenditure on energy related services. The second analyses the data collected and the outcomes of the application of the Multidimensional Energy Poverty Indicator to the data.

8.1 Data Feasibility

In order to explore the potential of this method to conduct valid energy poverty research it is important the quality and quantity of the data collected is feasible to make logical and well-informed conclusions about energy use in the study area. The qualities include having a valid number of viable responses and ensuring that the data collected will inform the research aims. This section aims to determine the feasibility of the data. It includes an analysis of: (i) the quality of the data collected as well as the viability (in terms of useful information derived from responses) of responses collected (ii) the quantity of data collected and its significance to energy poverty research(iii) the questions and data suitability for longitudinal research (iv) an analysis of the type of audience that was engaged in this study and who the appropriate individuals are (v) the Multidimensional Energy Poverty Index values and the outcomes of applying this index to the data and (vi) the data range acquired.

8.1.1 Data Quality and Response Viability

In order to determine whether data is of an acceptable quality, the responses gathered must be analysed for viability. A non-viable answer includes responses that do not answer the question, this could mean that the answer is not in the correct format or units or that the answer is simply irrelevant for the question. While there were restrictions on the types of responses submitted through the survey system, such as multiple choice answers or limitations on text responses, there were still a few anomalies in the responses received for the duration of the project. The questions that did not have 100% viable answers are summarised in Table 6 below. The viability of the overall data set is comprised of over 6000 individual responses, of which, 98% were viable responses, with 2% being non-viable. The non-viable responses were largely due to administration fault, systems faults or inappropriate responses. These can be minimised by introducing counter measures for system bugs as they occur, implementing question input procedures to prevent the incorrect entry of certain questions and answers available. The need for data cleaning in this instance was minimal, no responses required alteration, and any inappropriate responses were not valid and were not used. A summary of viable and non-viable responses only for questions with non-viable responses can be observed in Table 6 below.

Table 6 Summary of viable and non-viable responses for questions with non-viable responses

Question	Type of Question	Total Number of responses	Number of Viable responses	Non-viable responses	Reasons for non-viability	Overall viability of data
How much did you pay for F02 this week? (week 6)	Multiple Choice	38	2	36	Answers were not loaded correctly on the management system	5%
How long does your household stay without electricity?	Multiple Choice	55	16	39	Blank responses were accepted for this question, System Fault	29%
How much do you pay per month for your extension cord lease?	Text	10	9	1	Response was for daily income instead of monthly income	90%
How much did you spend on F03 this week? (week 3)	Multiple Choice	52	47	5	Blank responses were accepted for this question, System Fault	90%
How much electricity do you use in a month?	Text	55	50	5	Incorrect/unknown units stated, "unknown" and blank responses	91%
How much do you spend on fuel in a month?	Text	81	76	5	Inappropriate responses	94%
How much do you spend on education in a month?	Text	84	82	2	Inappropriate responses	98%
Male or female?	Text	199	195	4	Participants using other languages had	98%
When were you born? (DD.MM.YYYY)	Text	79	78	1	Inappropriate responses	99%
How much do you spend on transport in a month?	Text	80	79	1	Inappropriate responses	99%
What is your monthly income?	Text	85	84	1	Inappropriate responses	99%

8.1.2 Data Quantity and Data Saturation

Data saturation is a point where no new or relevant data is being collected (Saumure & Given, 2008). There needs to be data saturation in order for any theories on the trends found using the data to be robust, with no gaps or unexplained phenomena (Saumure & Given, 2008). Figure 11 illustrates the number of responses per question, with each marker representing a single question, with each series representing a different weeks questions. While short-term results reflect low data saturation rates for the majority of questions posed to this particular community in this figure, the process of data collection using this digital data collection platform is continuous, thus the longer the survey is online the greater the number of responses per question. Since there is no standard largely agreed upon to qualify data saturation, it is determined by the researcher according to the type of data being analysed and the aims of the research. The unique capability of this data collection tool is that data can be accessed and analysed while data is still being added to the database, which allows data saturation to be defined and reached at any point throughout the survey. Because the number of responses per question are variable, the reliability of the results for each question is relative to the number of responses on which it is based. Throughout this document the number of respondents per question are referred to as the sample population. The total number of respondents in the sample population are variable according to the number of respondents that answered that question. The variable sample populations per question limit the use of these results to elucidate theories about the conditions influencing the levels of energy poverty experienced by the household.

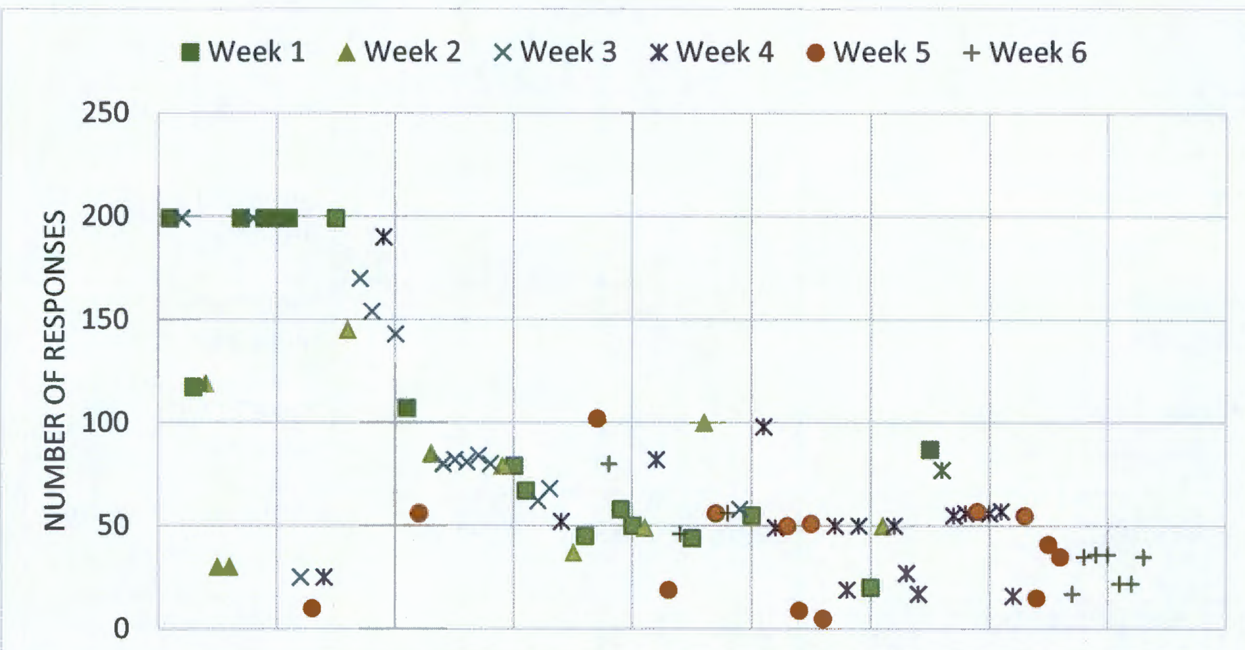


Figure 12 Number of responses per question

8.1.3 Questions and Data Suitability for Longitudinal Research

The types of data collected in this survey were selected for four reasons: (i) to gather a broad range of data to demonstrate the capabilities of the system, (ii) to address the categories listed in the Adapted Multidimensional Energy Poverty Index and (iii) to understand the perception and experience of energy poverty in the community (iv) to test the limitations of the tool. From the results listed in Table 8 and Figure 11 above, some inferences about the most appropriate and suitable types of questions and answer options can be made. The viability of responses to questions that require a text answer are compromised, as there are few means of ensuring that the participant enters a valid response using this method, the most common of these is the requirement of a minimum number of characters for a response before the user can continue to the next question. Some types of questions, such as the economic-based questions that aim to acquire accurate data, cannot be accommodated by multiple choice answers, a key mechanism that can be employed to reduce the input of non-viable responses . The use of multiple choice questions for questions where there are known options and ranges such as expenditure on energy reduces the input of non-viable responses as the respondent can only respond using given answers. To reduce the occurrence of non-viable answers for economic questions or questions that require unique responses, such as "reasons the participant feels their electricity supply is inadequate", it is best to conduct a pilot study such as this to formulate a range of common responses and an option to add a new unique response if none of these options is suitable. This will also aid the researcher in testing for data saturation.

While the data described above is illustrative of the experience of household energy access and indicative of characteristics of energy poverty, the time taken to acquire this information must be analysed. The dynamic nature of the state of poverty is acknowledged by using a system that tracks long-term changes in the state of energy poverty of a household, and thus does not reduce the data to general terms but applies a high level of detail to the data while still being able to communicate these changes in numerical terms. As observable in Figure 11 above, there are varying numbers of responses for questions in each week. While the potential reasons for this have been explained previously with the malfunctioning of the survey, the element of time as a determinant of the number of responses received can also be a contributing factor. This was tested informally after the study period concluded to test whether more responses were acquired with a longer study period, without SMS reminders. During this extended study period, from 1 -30 June 2015, 141 additional responses were acquired. It is likely that with additional time, minimal system malfunctioning and SMS reminders, the number of responses would increase as would the recurrence of responses form participants.

8.1.4 Audience Engagement

Due to the difficulties experienced with community engagement and implementation, there was a tight deadline to start collecting data in a short period of time. This deadline required more formal and radical approaches to be taken when promoting the project, as discussed in the previous sections. However, while successful in recruiting large number of participants for the survey, the use of high school students as respondents could have potentially made the data more inaccurate than if the heads of household were consulted. There are few effective means of ensuring that the heads of household, or at least an adult in the household with knowledge of the household expenses and income, would be the primary respondent for any survey. With knowledge that the use of high schools to promote this project was successful and that a large number of the respondents were high school students, a notice can be put up on the webpage to get the answers for the survey directly from the head of household. Alternatively, certain questions that require the accuracy of the head of household can be asked noting that the head of household should be consulted for this question. Some other practices that can be added on to ensure the accuracy of data collected would be to ask respondents to upload photographs of their electricity meter or electricity purchase receipts.

During the implementation of the project, it was found that not all participants were conscientious users, as surveys were most often not submitted every week. There were problems with the survey functioning and airtime payment scheme, which are discussed in detail in the research findings section, that were potentially large contributors to the curbed enthusiasm and participation of the users. Having surveys that could only be repeated every seven days may have also contributed to low rates of continuous use or long periods, greater than seven days, between consecutive surveys. SMS reminders were also sent out to remind users to submit their survey. It was intended that these reminders be sent out automatically twice a week but complication with the application developers and issues with the survey resulted in this service being used sporadically. As a result, completed surveys took longer than expected with only 52 people (17% of the total sample group) completing the entire six-week survey with the mismanaged survey issues. The diminished success of the platform could be due to a number of problems experienced with the survey and management platform functioning that was largely due to poor diligence on the developer's part.

Below in Table 7 is a summary of the age range for this group of participants. Unfortunately, because the question of birthdate was only asked in the third week and of the survey, as this question was not included in the initial import of survey questions done by the developers, and there were some issues with the formatting of the answers submitted, only 80 participants submitted this information. The large number of younger participants between 16 and 18 years old were potentially due to the targeting of high schools as part of the campaign to promote the project in the community. This could also be due to the common notion that teenagers have better technological knowledge with mobile phones than older members of the community do. While targeting the schools was a successful means of recruiting households to participate in the survey, the high amount of younger participants could potentially skew the data collected as well as introduce inaccuracies in the income and expenditure data, as students are not usually the breadwinners of the household.

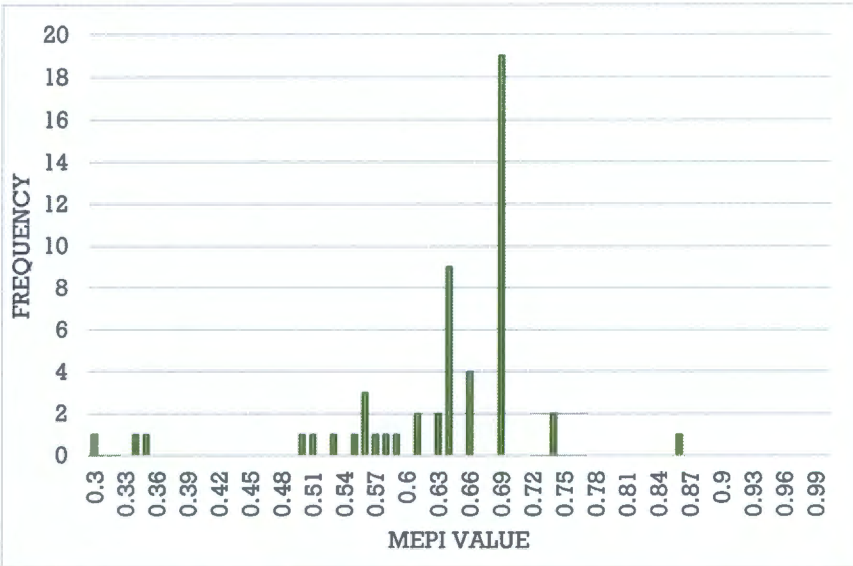
Table 7 Summary of ages of participants

Statistics			Age range	Percentage of total sample group
Average age	25		16-19	38%
Most common age	18		20-30	35%
Youngest	16		31-40	18%
Oldest	50		41-50	9%
Total sample Size	80			

8.1.5 Multidimensional Energy Poverty Indicator (MEPI) Values

Because the information required to calculate a full MEPI for a household was attained incrementally over the 6 week period, the only complete MEPI values acquired were from the 52 users who completed the 6 week survey.

Figure 13 shows the range of MEPI Values attained by participants that had completed the last week of the survey. Despite the fact that all participants answered the same number of questions there is a wide range of MEPI values for this sample group. This indicates that the levels of household energy poverty experienced in Imizamo Yethu is diverse. Despite most households being electrified the affordability of electricity and the the availably of electrical appliances is low. Equally there are a significant number of paraffin users in the community which is reflected in the MEPI values. a A 0 MEPI value indicates severe energy poverty while A value of 0.6 indicates adequate energy poverty and a value of 1 indicating access to all modern energy services.



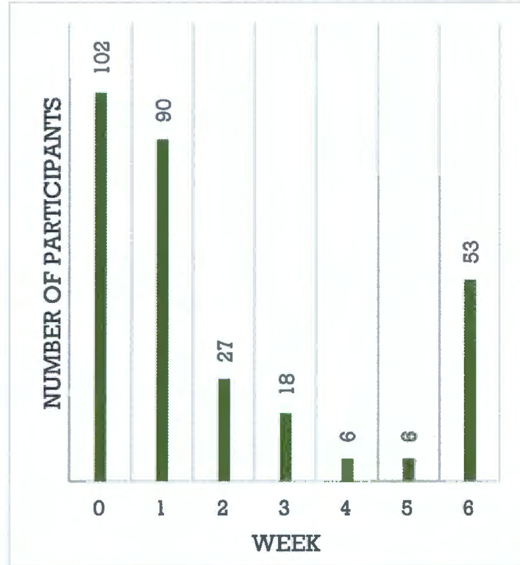


Figure 13 Completed MEPI values for participants in week 6 of the survey

Figure 14 Total Number of participants in each week of survey

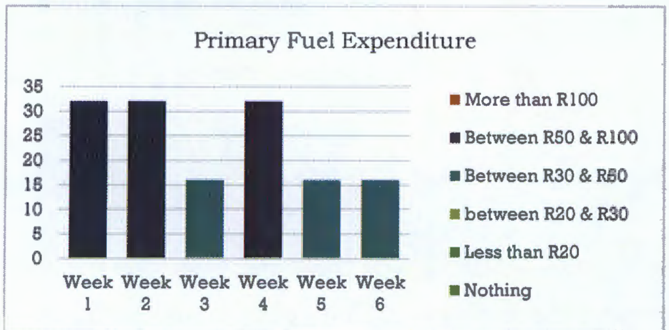
8.1.6 Data Range

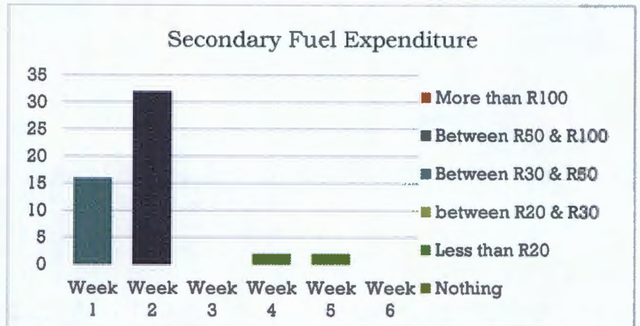
The data that was collected was intended to inform researchers about the expenditure patterns on electricity and other fuels for long periods of time. This was achieved in this project with the data of each household available for analysis in the format in Figure 14 below. This example of a user profile contains a brief overview of most responses given by the participant. It was generated in Microsoft Excel where the user number can be selected to display a profile for any participant. Anywhere #N/A appears indicates the user has not completed that question. The data range gives the researcher a good overview of household income expenditure, fuels used, appliances owned and other demographic information about the participant. The overall impression of the user profile can be illustrative of the priorities and needs of the household. For example, as depicted in figure 14 below, this household is able to afford electricity for the month, with access to their own electricity meter, Free Basic Electricity, frequent electricity purchases without periods of no electricity and with satisfactory energy supply for cooking, lighting, heating and cooling, this households energy access is adequate.

Weeks Completed	7
First Registration	01 May 2015

DEMOGRAPHICS	
Age	18
Gender	female
Employment	yes
Type of Employment	housekeeper
Education	matric
No# Hhold occupants	3

FUELS		Frequency of use
Primary Fuel	Electricity	
Secondary Fuel	Biogas	Not often
Tertiary Fuel	Biogas	





ELECTRICITY		
Monthly Electricity	500	Kwh
Electrical Connection	Yes	
FBE	No	
Own Meter	Yes	
Satisfaction of energy supply for:		
Cooking	Adequate	#N/A
Heating	Adequate	#N/A
Cooling	Adequate	#N/A
Lighting	Adequate	#N/A

APPLIANCE OWNERSHIP	
Stove type	Electric
Fridge	Yes
TV	Yes
Cell phone Type	Samsung
Laptop or tablet?	Yes laptop
Working appliances	Yes

EXPENSES	
Groceries	2000
Fuel	500
Education	0
Transport	100
Shared Connection	400
Cell phone Charging	100

Lighting Fuel	Electricity
Number of electricity purchases in a week	5
Number of electricity purchases in a month	8
Period for no electricity	Never
INCOME	6000

PROJECT FEEDBACK	
Awareness	Pamphlet
Incentive	I wanted to know more about saving energy
Lower incentive	Yes
Appliance consumption calculator use	No

Figure 15 Data Range for a single participant

8.1.7 Comparative Study Verification

The data collected using this method needs to be verified in order to make logical conclusions about Only one other study to determine household energy poverty has been conducted in Imizamo Yethu (Visagie, 2008). This study was undertaken in 2008 and involved 100 households. When comparing the results from the Visagie study and this study there were a number of trends that were identified to have evolved since 2008. Equally, the latest Census data for Imizamo Yethu also reflects similar patterns in demographic data collected with this platform. A comparison of these three datasets is presented in Table 8, where N/A indicates that the data was unavailable. The percentage of electrified households has increased from 74% in 2008 to 92.5% in this study. Equally, similar patterns of multiple fuel use were identified with high rates of electricity and paraffin use being apparent. The relative number of extension cord agreements has remained relatively constant with a decrease in the average price of these leases. While this study did not share the same objectives, the few common characteristics of energy use used in both studies provide evidence of a successful venture of data collection using this method. Overall the data suggests that the sample group is not overtly energy poor nor are any households living in abject poverty. However, the self-selection bias, requiring a mobile phone, appears to have prevented the poorer households from participating in the survey as Franks (2014) finds that there are in fact more energy poor households in Imizamo Yethu than this survey has identified.

Table 8 Comparative datasets for Imizamo Yethu

Data Type	Sabela Sokwazi Data	Visagie Data	2011 Census Data
% of population sampled	5	2.6	N/A
% of population electrified	91	74	80
% of electricity metered	87	46	N/A
Extension Cord Agreements: Average prices	R150 R500/pm	R171-R604/pm	N/A
Energy Expenditure (R/Month)			
Electricity	R200-R400	R108	N/A
Paraffin	R70	R65	N/A
Average Household Size	5.5	N/A	2.9
Education level % of population group			
None	3	N/A	4.1
Primary	1	N/A	12.1
Secondary	35	N/A	47.9
Matric	39	N/A	27.9
Tertiary	22	N/A	2.6

8.2 Data Analysis

8.2.1 Occupation, Education, Income and Size of Household

Seventy participants completed the income section of the survey at the time of writing. This information is represented in Figure 16 below.

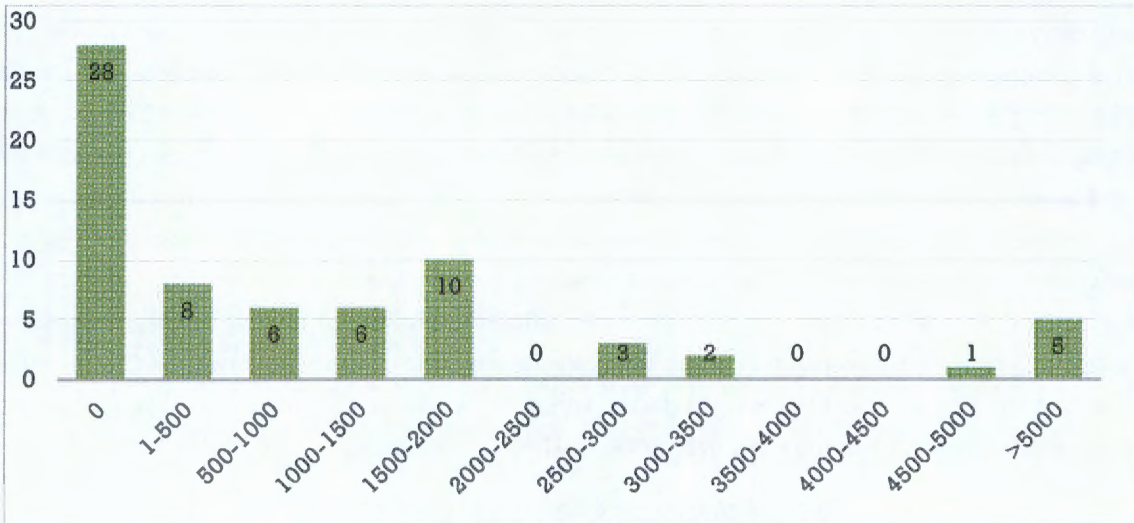


Figure 16 Frequency of Average Monthly Income per household

The results represented here tend to be biased with 49.1% of the total sample group being students, 23.6% are unemployed and only the remaining 28.3% are employed as depicted in Figure 17 below. As a result of this bias, 40% of the sample group has no income due to there being such a high number of student participants. This question could be rephrased to procure the total household income instead of individual income; however, the accuracy of this information when not derived from the breadwinner themselves is unknown. The alternative methods for increasing the accuracy or of this information or getting information that is more relevant for the entire household is described in previous sections. The level of education for the sample group is quite varied, with the largest percentage of the sample group having secondary school education and matric qualifications.

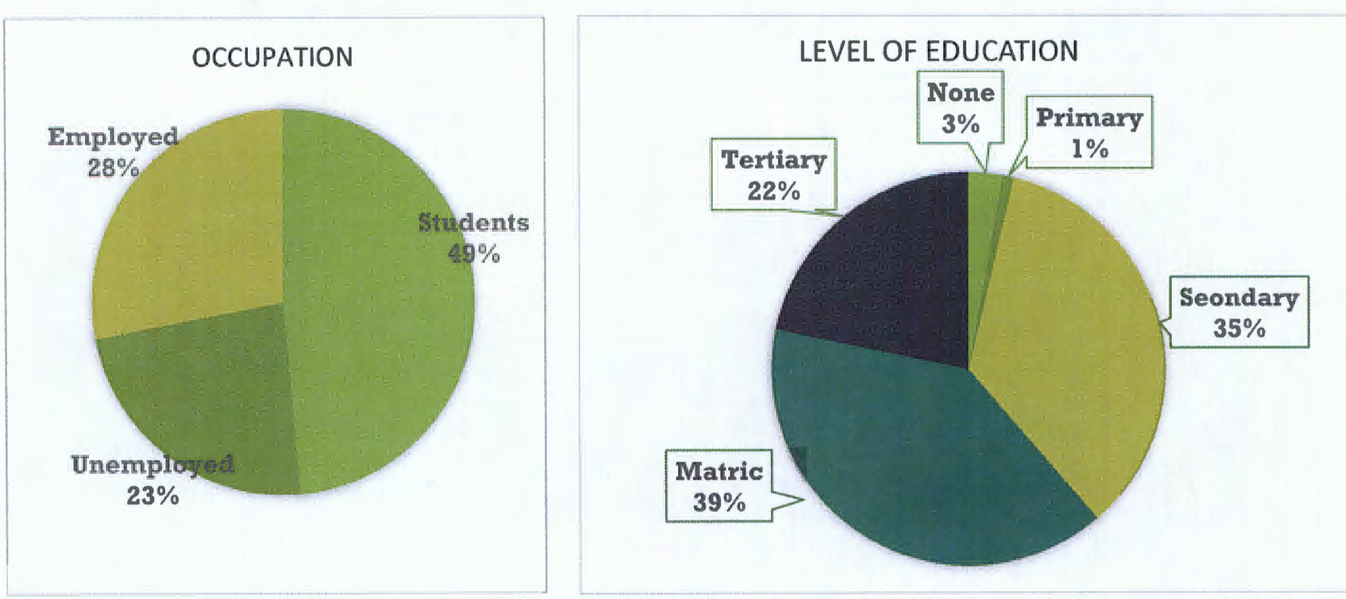


Figure 17 Occupations (left) and Level of Education (right) within the sample group

The size of households in the sample group, represented in Figure 21, vary greatly, with 3-7 occupants having the highest frequency. The total number of household members represented by the sample group is 1109 people that make up 199 households.

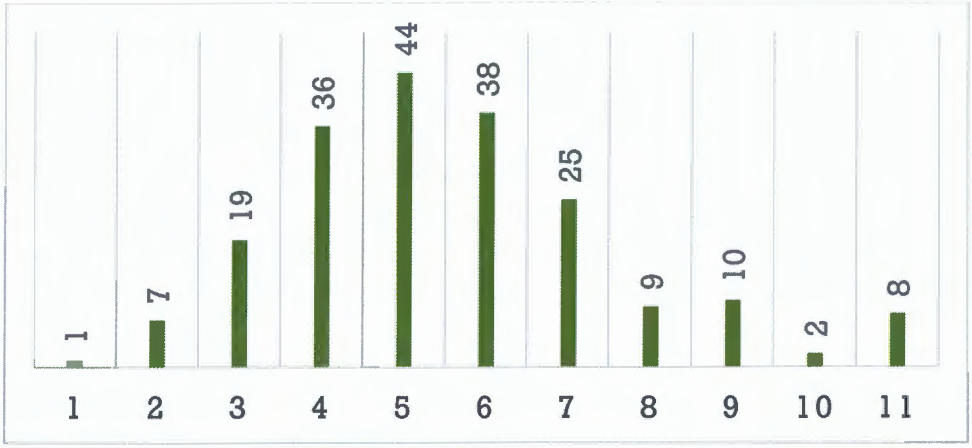


Figure 18 Size of household (frequency of the number of occupants in each household)

From this figure it can be calculated that, of the estimated 16 000 residents of Imizamo Yethu, 6.9% of the total populations energy use patterns have been represented in this survey.

8.2.2 Fuels Used

Figure 19 below shows the various fuels used by households for cooking as primary, secondary, or tertiary fuels on a logarithmic vertical axis. A total of 199 participants completed this part of the survey, thus the results represented in Figure 15 are indicative of the entire sample group. The predominant primary fuel is electricity used by 92.5% of the sample population with no more than 7.5% of the sample population collectively using LPG, Paraffin, biogas and wood. Most of the sample population (73.9%) use a secondary fuel for cooking, while 26.1% do not use a secondary fuel. The types of secondary fuels used are more variable than the primary fuels, with paraffin being predominantly used as a secondary fuel over biogas, wood, LPG and electricity in decreasing frequencies respectively. In total, there were 125 participants (62.8% of the sample population) who used three different fuels for cooking.

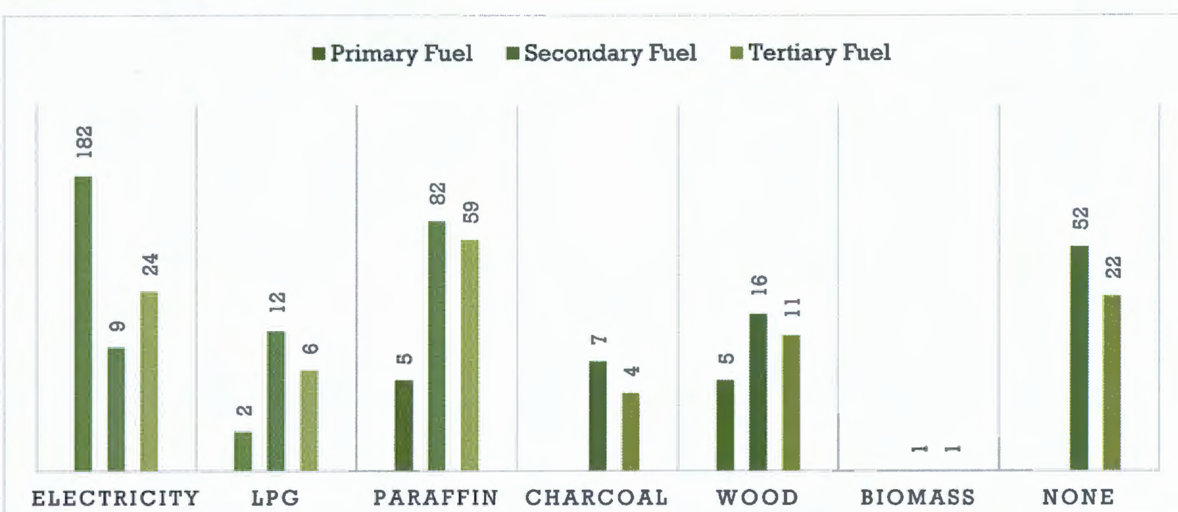


Figure 19 Summary of fuels used in sample group

While the results indicate this is so, the high number of participants that selected electricity as a tertiary fuel exceed the number of participants that did not list electricity as a primary fuel. This result also indicates a need for change in the way this question is asked in the future, with the primary fuel being removed from the list of options available for secondary fuels used. The total number of participants that use electricity as a primary, secondary or tertiary fuel, exceed the total number of participants that completed this question, indicating that participants selected electricity as a secondary or tertiary fuel as well as a primary fuel. The reasons behind this are not clear, although it may seem that the phrasing of the question for tertiary fuels "Have you used any other fuels in the house this week?" could have confused participants. Perhaps a clearer phrasing of the question would include the fuels listed by the participant previously, such as:" Have you used any other fuels besides F01 and F02 this week?" F01 and F02 being substituted with the relevant fuels, primary and secondary respectively, as supplied by the participant. It is unknown how this has affected the results of the other fuels.

As there were only 16 participants that did not use electricity as their primary cooking fuel, the types of stoves used by this population are summarised in Figure 20 below. While most of the stoves listed in this figure are legal, the Koala Paraffin stove is an illegal stove, which 8%, only one participant, of the sample group utilise.

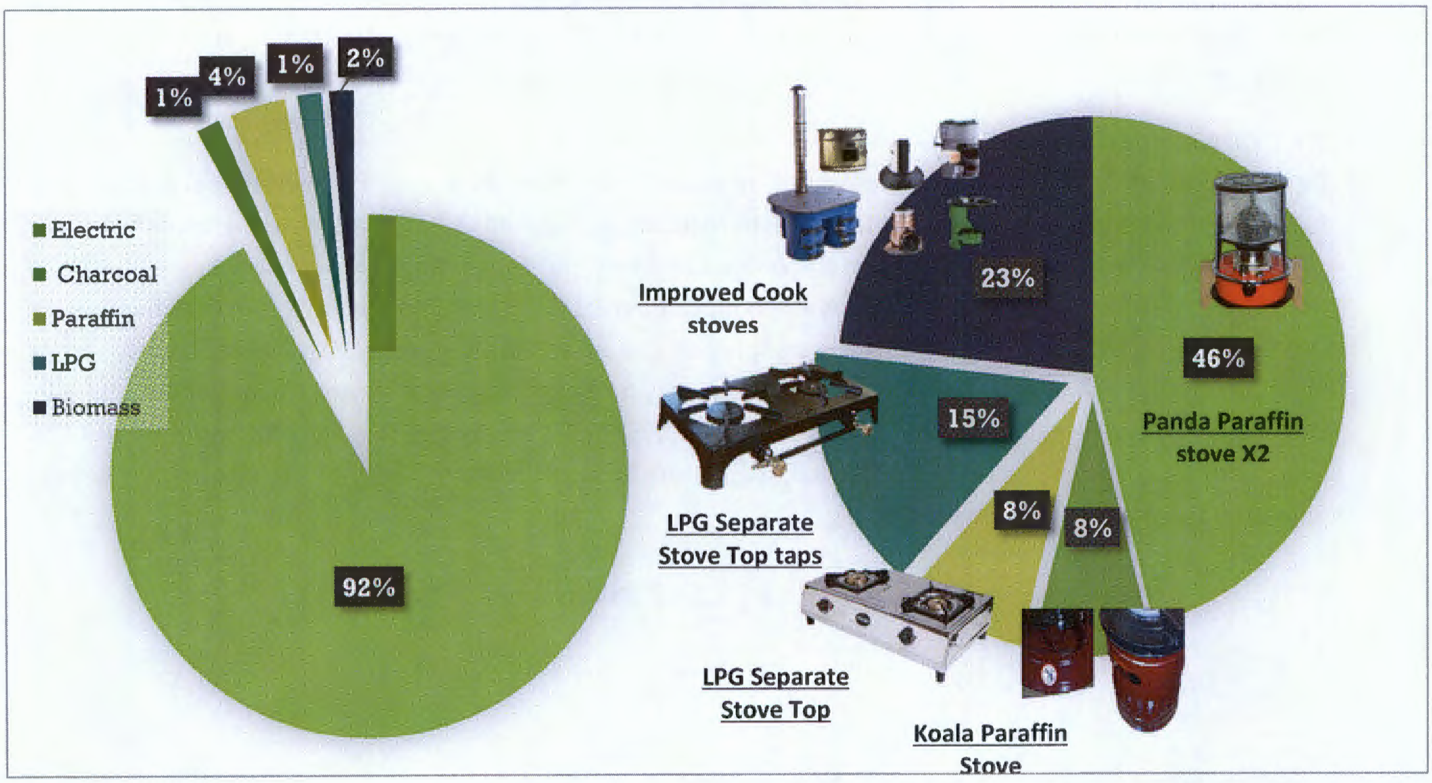


Figure 20 Summary of all stove types owned within the sample group (left) and of non-electric stoves in the sample group (right)

8.2.3 Stove Type and Condition

The condition of these stoves is equally important to avoid fires and explosions in informal settlements. The condition of all the stoves in the sample group are represented in Figure 21. This data gives an indication of stove safety standards in Imizamo Yethu.

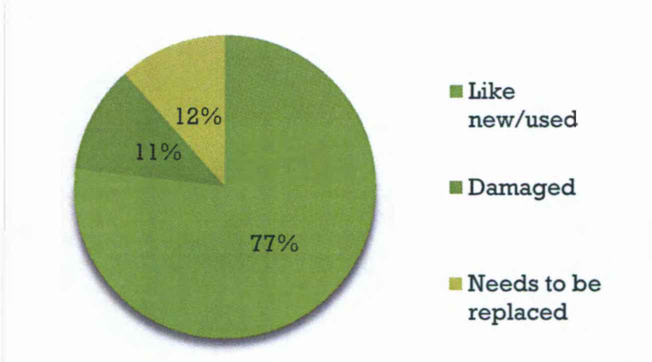


Figure 21 Condition of stoves owned by the sample group

8.2.4 Expenditure on Fuel

The expenditure on fuels can be observed for the entire sample group in Figure 22below. While this form of analysis is useful for a general overview of the fuel expenditure of the community of Imizamo Yethu, this data is better analysed per household over long periods of time, as depicted in Figure 15, in order to identify patterns in consumption behaviour over the seasons and tariff changes. From Figure 22below the decrease in the number of responses can be observed from its highest point in week 1 to its lowest point in week 6, indicating that the results are less significant as time proceeded. The most common expenditure bracket was between R50 and R100 for the first three weeks of the study period, while the last three weeks the pattern changes with the lower expenditure ranges, between R30 and R50, increasing in frequency compared to the higher expenditure frequencies. This increase could be attributed to the change in season. Because the responses were submitted at different times, it is difficult to develop any theories as to why these changes in expenditure patterns occur, unless this data is analysed at a household level.

The expenditure on secondary fuels, depicted in Figure 23 below, follows a different pattern compared to primary fuel expenditure. The predominant expenditure ranges are either nothing or less than R20, with low frequencies of secondary fuels expenditure over R30 a week. This indicates that multiple fuel use, while it is predominant in this community, is not shared equally between the available fuels and electricity is predominantly used for the bulk of the community's energy needs. There does not appear to be any correlation between primary and secondary fuel expenditure, indicating that primary fuels are used more than secondary fuels with little chance of one replacing the other. The sharp decrease in total responses in week three is due to issues experienced with the survey, where the survey would not load and would prevent users from starting that week's survey.

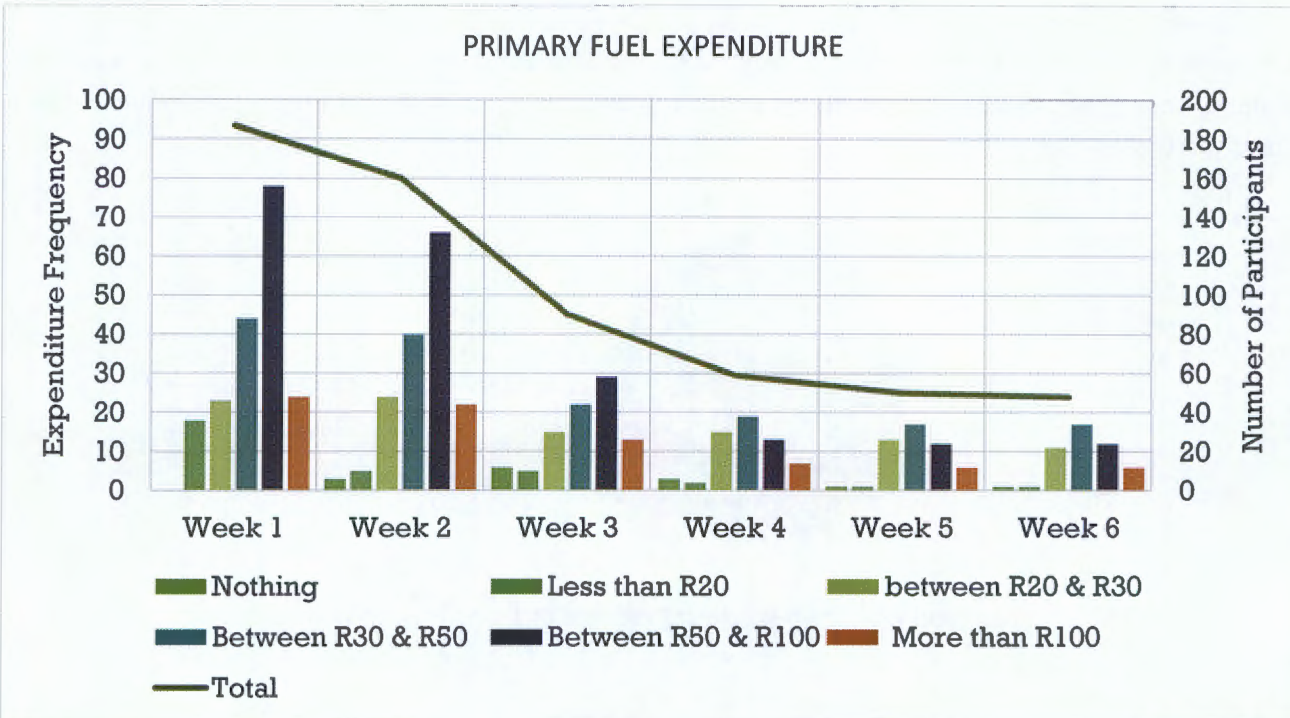


Figure 22 Primary fuel expenditure

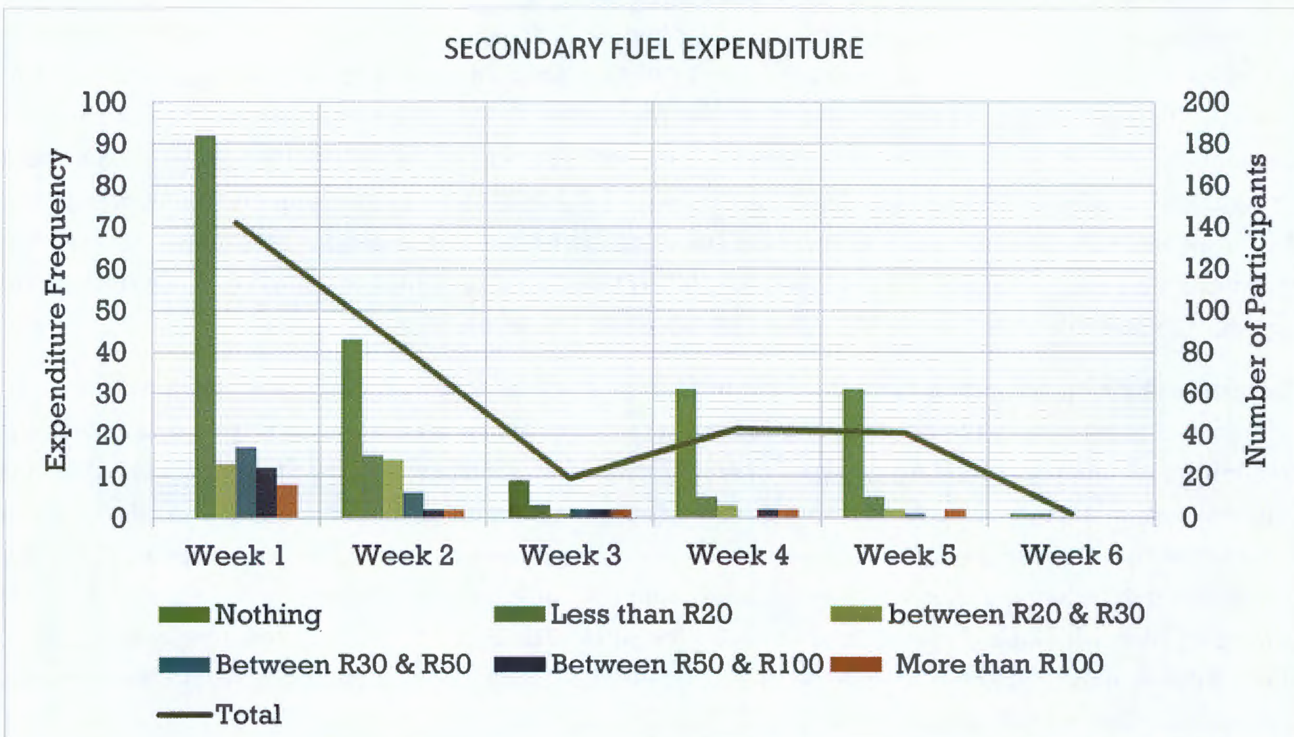


Figure 23 Secondary Fuel Expenditure

The frequency of electricity purchases are summarised per week and per month in Figure 24 below. The high numbers of participants that purchase electricity once a week indicate that the weekly electricity purchases are likely lasting the week while two or more purchases are likely indicate that the amount of electricity purchased each time is either in small amounts and does not adequately supply the household for the week. Another hypothesises reason for this may be to prevent other family members from using the electricity. The high numbers of participants that purchase electricity only once a month indicate that they can afford to buy electricity to last the whole month. The high number of participants that purchase electricity 4 times a month correlate to the high number of participants who purchase electricity once a week, indicating that at least 30% of the sample group purchase electricity on a weekly basis. There is a high number of participants that purchase electricity more than 10 times a month, indicating that the availability of electricity is relative to the availability of income in the household for at least 12% of the sample population.

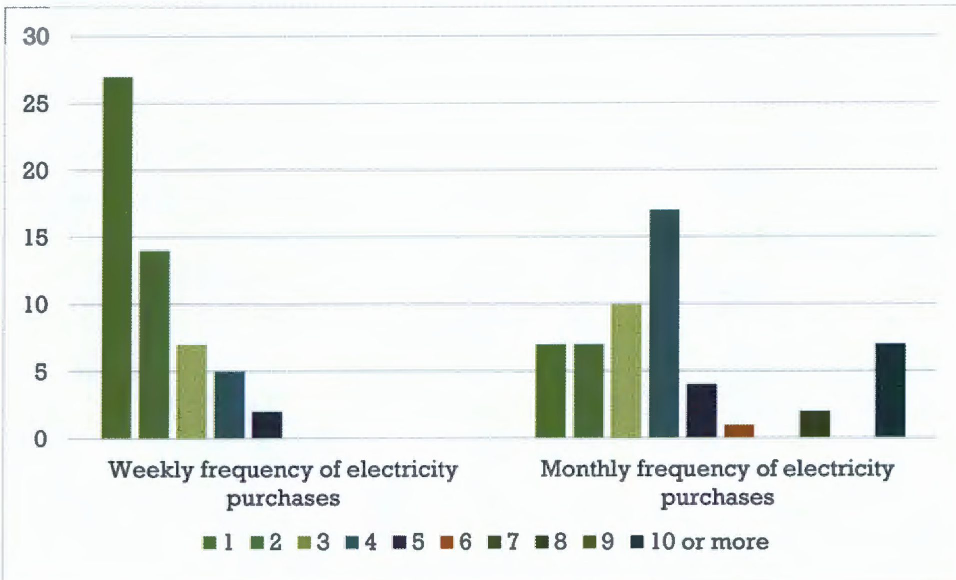


Figure 24 Frequency of Electricity Purchases

8.2.5 Electricity Connections

Since the predominant fuel used in Imizamo Yethu is electricity, further characteristics of the type of grid connection people are accessing and the prices for private leases are observable in Figure 25 below.

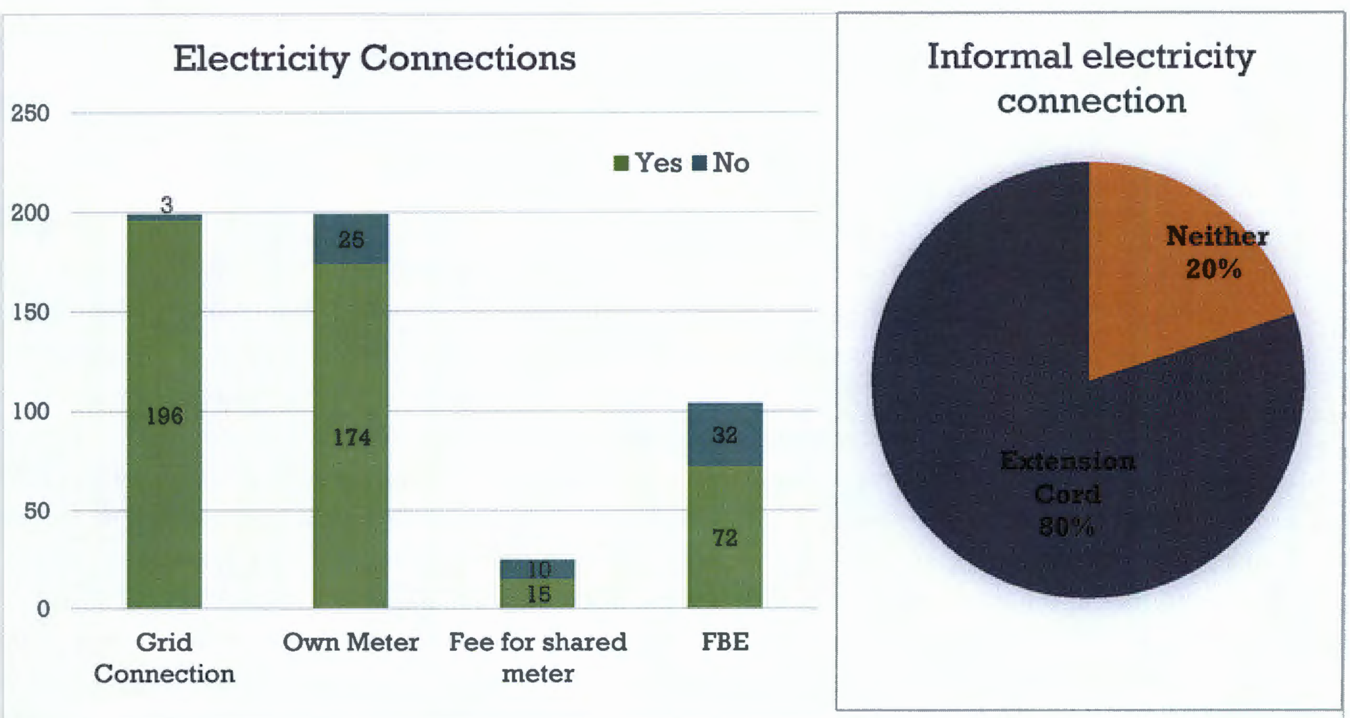


Figure 25 Type of Formal (left) and Informal (right) Electricity Connections in the sample group

A total of 98% of the sample population was connected to the grid, with 87% of the total sample population having their own meter. There were two types of informal electricity connections surveyed in this project, shared meter agreements, where more than one household uses a single meter, and an extension cord lease, where a household is connected to another household's connection via an extension cord, for which a lease fee is charged. The 13% without their own meter had a combination of shared meters and extension cord agreements with neighbours. Of these extension cord leases, 60% pay a fee for an extension cord lease. The fees paid for these leases range from R150 to R500 per month.

8.2.6 Appliance Ownership

The rate of ownership for common household appliances are listed in Figure 26 below as the percentage of the sample group that owns each appliance. These appliances were selected as indicators of energy services that promote communication, technology and ease of living. The 93% ownership of cell phones is surprising considering that a cell phone is required to participate in the survey. This result indicates that some users may be sharing cell phones with other people, or that they do not own the phone themselves. This requires further investigation.

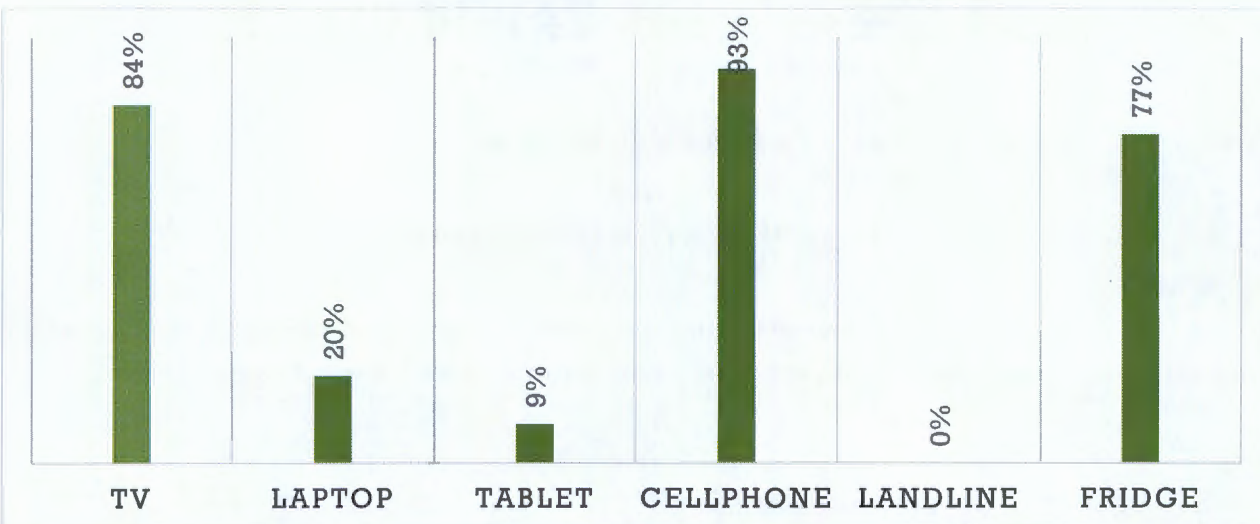


Figure 26 Appliance Ownership in the sample group

8.2.7 Satisfaction of Energy Supply

The perceptions of having adequate energy services in the household are represented in Figure 27 below, where household perceptions on lighting, cooking, heating and cooling are listed as basic energy services. From Figure 27 it can be observed that most people feel that their energy supply for lighting is adequate or more than adequate, with 19% feeling that it is inadequate. Reasons for this perception include that electricity is too expensive, it is often stolen, there are other appliances that use the electricity and the electricity runs out before the end of the week. Most people feel that their energy supply for cooking is adequate or more than adequate, with 10% of the sample group perceiving their supply for cooking as inadequate. The reasons given for these perceptions are that the electricity is stolen, there are no adequate appliances to use for cooking, electricity is too expensive or the electricity used to cook runs out before the end of the week. Participants' perception of energy services for heating and cooling are similar, with 38% and 40% of the sample population perceiving their energy for heating and cooling respectively, as inadequate. Reasons for this include that there are too many appliances that require electricity, electricity is expensive and the large number of household occupants use up the electricity and the electricity purchased gets finished quickly.

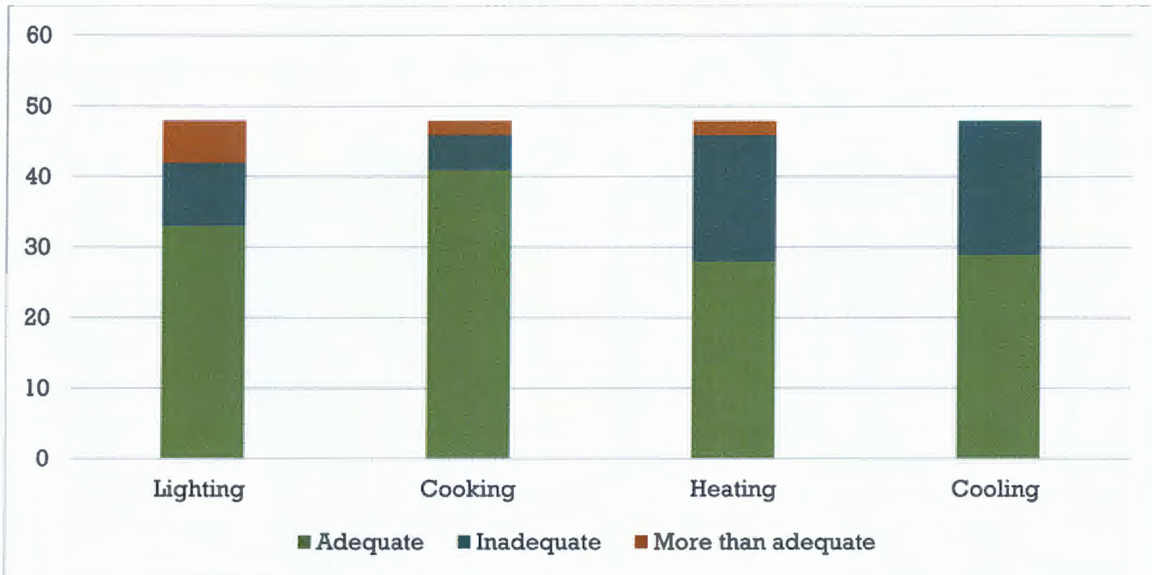


Figure 27 Satisfaction of energy supply for basic household energy services

The range of data acquired using this method has been quite diverse. This is largely due to the questionnaire serving four objectives to determine:

- Patterns of energy consumption
- Levels of economic poverty
- Types of appliances commonly used
- Impact of energy poverty on the household

The types of questions used to gather information in this survey have been discussed previously, but the appropriateness of these question types to gather information pertaining to the above topics need to be analysed to determine the feasibility and potential of this tool. The patterns of energy consumption were well identified using the multiple-choice questions and the predefined expenditure ranges. Administering these questions on a weekly basis allows the participants' energy use to be tracked from week to week. The success of defining an economic context in each household was more difficult. This was largely because not all participants had full knowledge of the household income. The text responses given for the economic questions were not all viable responses. However, with the viable responses given, a list of predefined income ranges can be defined for this community and used as multiple-choice responses for these questions. This allows responses to be more accurate and informative and decreases the number of invalid responses for these types of questions. The types of appliances used by participants was clearly defined and the multiple-choice questions functioned well for this purpose. Equally, the participant's perception on the adequacy of their energy services was a useful indicator of how energy poverty has affected the household. The frequency of electricity purchases and the period over which a household has no electricity are also good indicator of the impact of energy poverty in the household. The multiple-choice questions worked well for this function.

This chapter has analysed the data acquired from the six-week survey. Although the sample sizes for each question are not uniform for all questions, a decent volume of useful data has been collected to illustrate basic patterns of household energy use in this community. The value and applicability of the adapted MEPI could not be fully assessed in this study as there was insufficient data to determine this at the time of writing. The quality and quantity of data collected can be deemed as valuable and valid for short-term study and a continuation of the data collection process is likely to yield stronger patterns and trends in energy use that can be used to identify key issues and concerns in improving energy access moving forward.

9. Conclusion and Recommendations

Energy poverty is a complex and multidimensional issue and it needs to be understood at a household level in order to implement effective strategies and incentives to improve energy access and address energy poverty. In South Africa, informal settlements are the most vulnerable to energy poverty. The informality and high population density in these areas increases the difficulty in defining and understanding energy poverty in the areas. The use of mobile phones to gather information from this demographic group is key, because not only are the state of households in constant flux but the energy access in these households are constantly changing due to a variety of factors, including tariff increases, changes in household income, changes in the number of household occupants and weather changes. The use of a digital data-collecting platform is not unique but the manner in which it was utilised allowed households to be independent sources of data. Because the rate of data collection is largely dependent on the users and the actual process requires little supervision to be undertaken for long periods of time, this method has managed to create a state of automation in the data collection process that other long-term surveys have not been able to achieve previously. This study aimed to explore the potential of a digital data collection tool and the conditions and process required to create, implement and maintain such a system while generating valid and useful energy poverty data that can be used for research purposes.

The adapted MEPI has been successful in differentiating households at different levels of energy poverty by considering primary energy services and appliance ownership that are specific and defining factors of the way energy poverty is experienced in South African informal settlements. Further expansion on this index would include more statistical inference to apply this to large populations as was undertaken by (Nussbaumer *et al.*, 2012)

The manner in which this project was implemented was not ideal, initially with poor community engagement and later the malfunctioning of the platform software and issues with the survey and airtime pay-outs. However, despite these issues the results indicate that the potential shortcomings of this method have been minimised while the advantages have been clearly demonstrated by reaching a large number of households, extracting personal information from these households at a reasonably consistent rate considering the impediments posed by external factors.

The use of single respondents as independent data contributors to this project has its benefits and drawbacks. The information flow was only limited by the number and types of questions asked per week and not by the respondent. However, the accuracy of this information can only be verified by follow up surveys, the process of which is time consuming considering the size of the population to be verified. The sheer volume of data collected using this method over a relatively short period is impressive. Aside from administrative issues that needed to be undertaken with the developers and the WhatsApp helpline, there was little input required from the researcher given that the survey was designed and compiled prior to implementation of the project. To have procured 199 household surveys, even if most were incomplete, within a two-month period would be challenging and resource intensive using traditional means such as household interviews. The digital data collection platform also succeeded in acquiring expenditure patterns over long periods of time, this would be even more time consuming to achieve using traditional survey methods. Equally, the responses gathered had a high viability with very few responses proving to be unusable in the data collection process as listed in Table 7.

A major weakness of this method is verifying collected data. Future studies using this method should aim to test new methods of verifying data. A suggested method may involve programing automatic verification questions that would require, for example, photographs of prepaid electricity receipts or stoves. Another major disadvantage of this method is that participation and responses to questions are variable, and there is no guarantee that every user that has registered will participate in the full survey. To compensate for this the reach of the project must be far enough to attract enough interest to engage an adequate proportion of the population in order to reach valid conclusions or theories about the extent and level of energy poverty in an area. This needs to be assessed and addressed in future research to gain not just the interest of the public but also their long term and consistent participation to the project.

9.1 Key findings and Recommendations

The key to the success of this research method is proper community engagement, as it is through this that interest and participation in the project is promoted and sustained. Sustaining participation is necessary for large populations and different mechanism and means can be employed to achieve this. Currently the SMS reminders, WhatsApp helpline and airtime incentives are the main mechanisms to promote long term participation however, with better community engagement, a more direct approach can be employed by using local events or rallies to promote participation in the project. Similarly, better mechanisms need to be designed and implemented when managing the system, which include automated airtime pay-and automated reminders or a different method of reminding users to participate. The latter would involve a possible staggering of the airtime incentive, which pays out more airtime the more survey the participant has submitted. Equally, the amount of airtime rewarded to the participant can be reassessed according to the community and study period.

The functioning of the software needs to be optimal before a new survey is to be launched. The malfunctioning of the survey during the study period was a crucial turning point for the project that negatively affected the interest and participation of the sample group. As such there needs to be a better means of managing maintenance issues. This could be resolved by having a capable developer working more closely with the research.

Overall, the quality and quantity of the data has been sufficient to determine levels of household poverty according to the adapted Multidimensional Energy Poverty Index (MEPI). The MEPI adaptation was designed to work for this function and did so adequately but needs to be reassessed for better implementation in the progression of the survey as the total number of complete MEPI indexes were insufficient considering the total sample population that was surveyed. The lessons learnt from implementing this project would inform future research and implementation of this digital data-collecting tool. From the experience with this system, there are certain functions that would benefit from some improvement and evolution.

9.1.1 Evolution of management functions

The functioning of the question form should be improved by allowing multiple questions to be created on the same page at the same time. This would function as a series of characteristics, as listed in the individual question edit page (listed in the appendix), are selectable from a series of dropdown menus. This architecture is easier to use and allows multiple questions to be added simultaneously. It also allows the administrator to see the question flow and logic for all questions, which means that questions are planned better and any errors can be clearly identified and fixed.

The data export function, while sufficient for the exploration of this method, can be extended in order to acquire all the information gathered. The data export function should be a separate function on the management system rather than an option on each page containing data. This function must allow the administrator to specify the type of data and the time range to be exported.

Now that the airtime pay out function has been tested and no instances of exploitation or malfunctioning of this function has occurred, it can be automated to pay out to participants when they have completed the survey. As specified in the original design of this platform the SMS reminders should be automated. The SMSs should be customised to be sent out according to the date of the first survey submission, twice a week.

8.1.2 Changes in the management of software development

It is clear from the difficulties experienced with the current developers of the system that a new third party vendor needs to be assigned. The next developer to work on this system needs to have an understanding of the aims and objectives of this study as well as a general background information on household energy poverty and living conditions in informal settlements in South Africa. The developer should work closely with the researcher so that small but pivotal improvements and fixes can be made timeously with no complications.

9.1.3 Community engagement/participation

The community engagement for this project was not implemented as well as it could have been. The use of the taxis to advertise the project would have been useful if the taxi drivers were consulted in addition to the taxi owners association. Equally, promotion of this project in formal community meetings and societies would be productive in raising participation and understanding of the project.

9.1.4 Energy Education and data collection

The use of energy education tools to promote the use of the application and participation in the survey was initially requested by the community of Enkanini. However, the purpose of these tools to modify energy consumption behavior by informing participants of their electricity use and the efficiencies of their household appliances which undermines the purpose of the survey to identify energy consumption patterns without this external factor. Future research should analyses how energy education can be integrated with the survey function and how this affects the data collected. A suitable experiment design would include a group that have access to only the survey functioning and a group that has both energy education tools and survey access, to observe if this factor has an effect on the data collected.

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10. Appendix

10.1. Follow Up Survey

For participants who have finished the 6 week survey:

- What kept you participating in the survey?
- Did the SMS's help to keep you in the survey?
- How much would you say your household spent on electricity this week?
- Can you send a photo of your electricity receipt for the most recent week available?
- How much did you spend on F02?
- What are you currently heating your home with?
- Do you live in a brick house or a self-made structure?

Do you think you have learnt more about energy/saving energy through this project?

For participants who did not complete the 6 week survey:

- Why did you participate in the survey?
- Why did you stop participating in the survey?
- Did you receive the SMS reminders sent to you?
- How much would you say your household spent on electricity this week?
- Can you send a photo of your electricity receipt for the most recent week available?
- How much did you spend on F02?
- What are you currently heating your home with?
- Do you live in a brick house or a self-made structure?
- Do you think you have learnt more about energy/saving energy through this project?'

10.2 Survey

		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10
F01	What is your main cooking fuel?	Electricity	LPG	Paraffin	Biogas	Charcoal	Wood	Biomass	Dung or other		
M01	Please select the stove most like yours										
M02	In what condition is our stove?	Like new/used	Damaged	Needs to be replaced							
M03	Are you connecte d to electricity ?	Yes	No								
M04	Do you have your own electricity meter?	Yes	No								
M05	Do you get free basic	Yes	No								

	electricity ?										
M06	How much electricity do you use in a month?	less than 50kWh	Between 50 and 100kWh	more than 100kWh							
M07	Do you own a fridge?	Yes	No								
M08	Do you own a television ?	Yes	No								
M09	Do you own a laptop or tablet?	Yes	No								
M10	Do you have access to a cell phone or landline?	Yes	No								
F02	Do you use other fuels for cooking?	Yes	No								

M12	How often do you use F02?	Every week	Every Month	Not often							
M13	How much did you pay for F01 this week?	<R20	R20-R30	R30-R50	R50-R100	>R100		if <R20 or >R100 get approximate amount (input field)			
M14	How much did you pay for F02 this week?	<R20	R20-R30	R30-R50	R50-R100	>R100		if <R20 or >R100 get approximate amount			
M15	How much did you pay for electricity this week?	<R20	R20-R30	R30-R50	R50-R100	>R100		if <R20 or >R100 get approximate amount			
F03	Do you use any other fuels in the house?	No	Yes	Electricity	LPG	Paraffin	Biogas	Charcoal	Wood	Biomass	Dung

M16	Do you share a electricity meter or lease an extension cord?	Shared meter	Extension cord								
M17	Do you pay any additional fees for your shared meter?	No	Yes	Specify amount (input field)							
M18	How much do you pay per month for your extension cord lease?	Input field	It changes every month, this month I paid (input field)								
M19	Is the amount of energy your househol d has less than enough, just	It is just enough for your househol d's needs	It is more than enough for your househol d's needs	it is not enough for my needs							

	enough or more than enough for your household's needs?										
M20	What is the main reason why you feel that the amount of energy is inadequate to meet your household's needs?	There are many electricity power cuts in my area	The supply of electricity to my household is limited	Firewood is very scarce	Gas or paraffin not available in the shops	Other (specify)					
M21	Do you charge your cell phone at home?	Yes	No								
M22	What size gas canister	1.25kg	2kg	3kg	4.5kg	5kg	6kg	9kg	12kg	>12kg (specify with	

	do you use?									input field)	
M23	How much do you pay for a single cell phone charge?	Input field									
M24	How do you pay for your cellphone charging?	By hour	by minute	by full charge							
M25	What type of cell phone do you have?	drop down menu									
M26	What do you mostly use for your lighting?	Electricity	Paraffin lamps	Battery operated lamps	Solar powered lamps	candles					
M27	Do you think your amount of energy	enough for the househol d needs	not enough for househol d needs	more that enough for household needs							

	for lighting is										
M28	Do you think your amount of energy for cooking is	enough for the househol d needs	not enough for househol d needs	more that enough for household needs							
M29	Do you think your amount of energy for heating rooms and keeping warms is	enough for the househol d needs	not enough for househol d needs	more than enough for household needs							
M30	Do you think your amount of energy for cooling rooms and keeping cool is	enough for the househol d needs	not enough for househol d needs	more than enough for household needs							
M31	Do you have a geyser or	Geyser	Solar water heater	none							

	solar water heater?										
Sectio n	Variable	Question	Type	Option 1	Option 2	Option 3	Option 4	Option 5			
A	HH01	Please enter your full name	Written field								
	HH02	Male or female?	Radio Button	Male	Female						
	HH03	Birthdate ?	Written field								
	HH04	What is you address?	Written field								
	HH05	How many people live with you?	Written field								
B	HH06	What is your highest level of Education	Radio Button	none	primary	secondar y	matric	University/Diplo ma			

	HH07	Are you employed ?	Radio Button	yes	no						
	HH08	What work do you do?	Radio Button	Officials/Administrators	Professionals	Technicians	Sales workers	Office & clerical	Craft (trade) workers	Operatives	Labourers
	HH09	Is this work full time or part-time?	Radio Button	Full time	part time						
	HH10	If you have your own business, what type of business is it?	Radio Button	store/shop	Neighbourhood store selling from home	Hawker in nearby town	Sewing	Baking	Brewing beer/alcohol	Carpentry	Cell phone service (pay phones)
C	HH11	How much do you earn per month on average?	Input field								
	HH12	What are your main expenses for the week?	Input field (table)	Groceries	Fuel	Education fees	Transportation	Other(specify)			

10.3 System Functioning and Screen Shots

10.3.1 Survey Submission

The user starts by visiting the project website. This is possible on any mobile phone with an internet connection including WAP/GPRS or higher, or on a tablet or computer with an internet connection. On the home page the user can select the language in which they wish to answer the survey. They can also access the load shedding schedule, which is changed manually by the administrator, as well as the Appliance Consumption Calculator without registering. They can then register for the survey by entering their name, phone number, mobile network (for airtime), town and address. The user is then sent an SMS containing a short URL link to the login page and their personalised login code. The system automatically sends out R2 airtime for registration to ensure that users have enough airtime to submit the first survey. Once the user has logged in with this information they can check for available surveys. If a survey is available they can select "Complete Now" where the questions will appear one by one as each question is submitted. Once all the survey questions for that week are completed the feedback report will come up stating the users expenditure on the various fuels used in their household to date. This report also includes safety information and efficiency hints specific to the fuels used by the household. This process is repeated from login to feedback report once a week for 6 weeks. The frequency of these surveys can be increased or decreased according to the project specifications.

10.3.2 Navigating the Management System

There are six basic functions of the management system:

- User management
- Survey Management
- Airtime Management
- Content Management
- Communication Management
- Data Management

User Management

User management consists of a web page in which the system assigned user number, name, cell phone number, address and survey week of all users are listed. The administrator is able to edit the user information which lists the basic information provided by the user as well as their login code and the date of registration. The administrator can also delete users from this page and from the database. The statistics of each user can be viewed individually, which lists basic information, the number of questions answered by the user and the MEPI value calculated for the users as well as a graph of the average fuel spend and a list of all the questions answered and the submitted responses. The user audit function allows the administrator to view what questions were answered by the user and when.

Survey Management

The survey management component consists of a web page in which all questions are listed along with the variable code, frequency (how often each question is asked), as well as the week to which the question has been assigned. The option to add a question is situated at the top of the page, which redirects to a form to create a new question. This form is fairly simple, it includes a space to fill in the variable code of the question, the questions wording in English, Afrikaans and isiXhosa. This form also allows the administrator to make the question dependant on the response of a previous question with the "Replies on" option. This drop down menu allows you to select the independent question from the existing database while the "relies being" menu allows the administrator to determine whether the question must be equal to, more than, less than or unequal to the relevant responses listed in the "Relies option". Thereafter the administrator can select the type of response required, either a multiple choice answer (Select) or open answer (text). The options for a select question can be entered in all three languages on the same form with commas separating the options. The administrator must fill in the week to which the question is assigned, the frequency as well as the status of the question. The status of the question is a feature that allows you to disable a question if the administrator does not want the question to be asked. This is a better alternative to deleting questions as any responses that result from these questions will have the same variable number, thus deleting a question would compromise the integrity of this linked data. The administrator also has control over the order in which the questions are asked within the survey using the Priority option. This option allows the administrator to input the priority of the question in relation to the other questions for that week, if a question has "1" as a priority it will be asked first. Finally, the administrator need to fill in a create date for the question, thereafter the question can be saved and stored in the database.

Airtime Management

The airtime facility in the management system controls the pay out of airtime vouchers to users. Hopefully, the more experience gained from implementing the application the better the functioning of the application. With this, the airtime facility will become less vulnerable to exploitation and this function can be automated. For the pilot, airtime is paid out according to the current survey week of each user. The amount paid to each user can be entered on the Bulk Weekly Voucher web page while the week this amount is to be paid can be selected from the drop down menu. The system sends network relevant airtime vouchers to users who have not yet received a voucher for that week of the survey, preventing users from receiving more than one airtime voucher per week of the survey. The number of users currently in each week of the survey, total number of users who have completed that week of the survey and the total number of vouchers purchased for that week are listed on this web page. Airtime vouchers can also be purchased for users individually, on the Purchase Airtime web page. The number and network of the user is required to purchase individual. The Purchased List webpage lists all the airtime vouchers that have been purchased. Each transaction is recorded here and it is possible to search the page for the vouchers sent to individual users. Each transaction, has a status that allows the administrator to see whether the transaction was successful, still pending or an error has occurred.

Content management

There are five different web pages to add, edit or delete content displayed on the application. The first contains general content, such as the welcome page, the wording for buttons, feedback reports and the load shedding schedule. These are all easily accessible in the Content webpage under the Management Tab in the main administrator system. All content can be edited in all three languages. Stove types are also editable and new stove can be added at any time, these are in the form of low quality pictures of various paraffin stoves. The safety tips can also be edited in text form or by adding pictures depicting health and safety measures. Each tip or warning can be linked with an associated fuel, such as paraffin. The content for the Appliance Consumption Calculator can be edited by adding the name of the appliance as well as the cost to run the appliance per minute and the number of kWh used per minute. The News Content is content that has not yet been utilised during the project but allows the administrator to post messages to users when they login to the page. It can also be used as a consent form as the user will not be allowed to continue unless they have stated they have read the news content.

Communication Management

The communication between the administrator and the users can be conducted through the application content or by SMS. The SMS function, used on a regular basis, was mostly used to remind users to fill in the surveys and to notify users of issues with the survey. SMSs can be sent out to individuals or to all users, or to users in specific weeks. The SMS content can be filled in and a create date must be selected to send the SMS/s.

Data Management

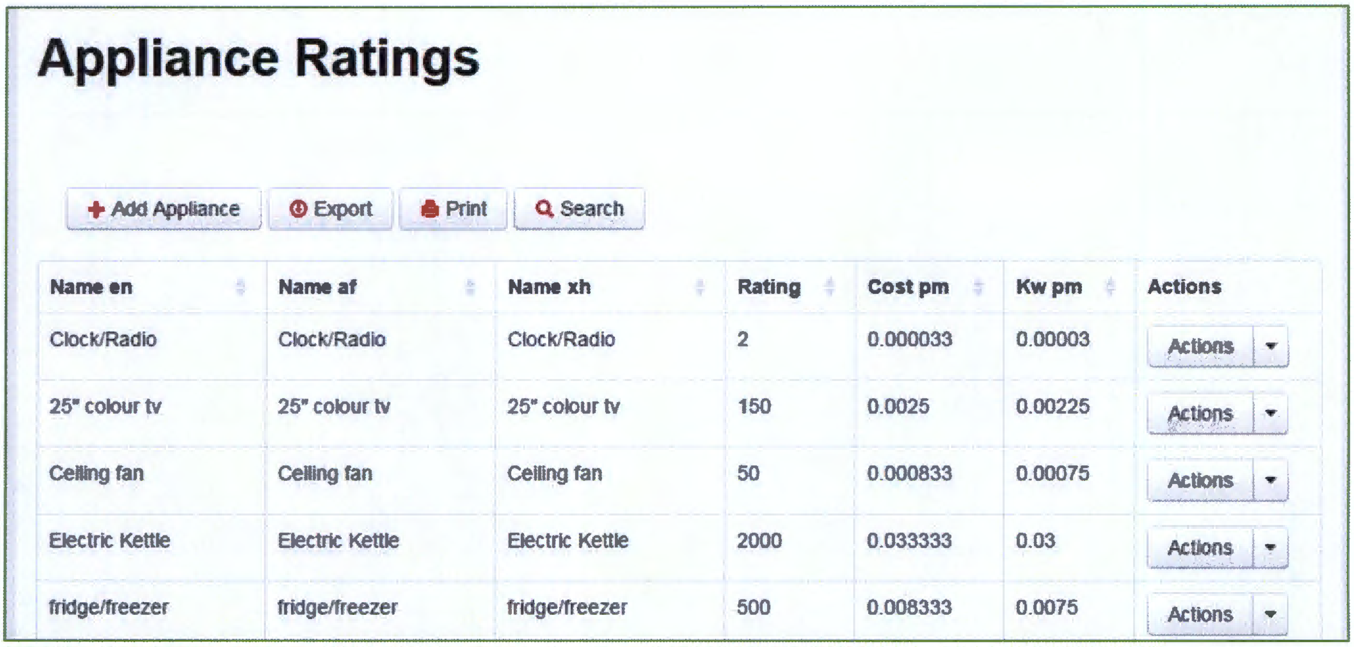
The responses from all users can be viewed on the All Answers web page, where all survey responses are listed and can be filtered by date. This information can also be exported in excel format to be analysed in Excel. For a briefer overview of existing responses the data is visualised in graph form on the Question Stats webpage where the variable can be selected and the existing responses for that variable are represented in bar graph format.

10.4 Screen Shots of System

All Answers

From: 2015-05-21 12:05 To: 2015-05-28 12:19 Filter Download CSV File

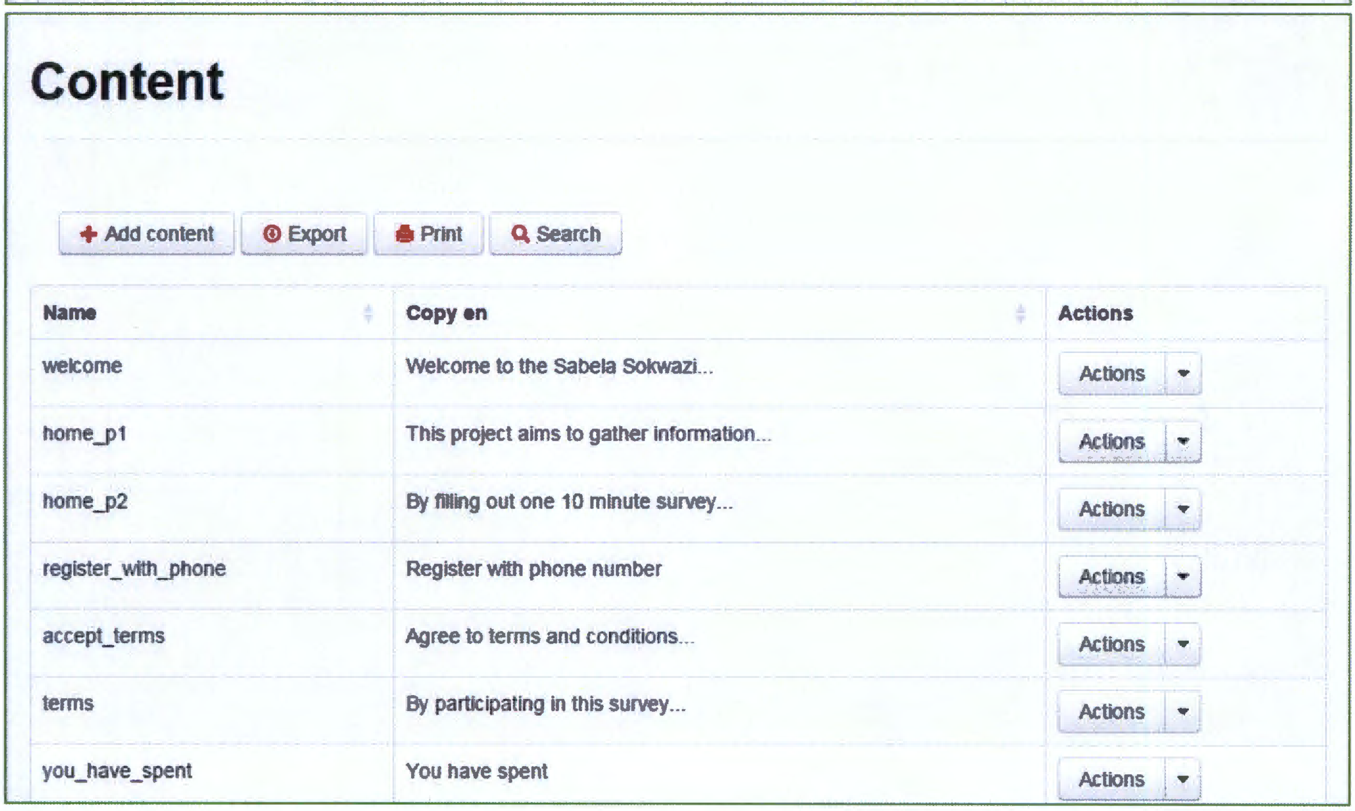
Question Id	Kim Code	Question En	Answer	Options	User Id	Name	Createdate
23	M14	How much did you pay for F02 this week	Between R50 & R100	Less than R20,between R20 & R30,Between R30 & R50,Between R50 & R100, More than R100	299	Sharon	2015-05-27 18:14:50
22	M13	How much did you pay for F01 this week	Between R50 & R100	Less than R20,between R20 & R30,Between R30 & R50,Between R50 & R100, More than R100	299	Sharon	2015-05-27 18:14:02
21	M12	How often do you use F02?	Every week	Every week,Every Month,Not often	299	Sharon	2015-05-27 18:13:24
38	M11a	How much did you pay for F03 this week?	Between R30 & R50	Nothing, Less than R20,between R20 & R30,Between R30 & R50, Between R50 & R100,More than R100	299	Sharon	2015-05-27 18:12:45
19	F03	Have you used any other fuels in the house	LPG	No, Electricity, LPG, Paraffin, Biogas, Charcoal, Wood, Biomass	299	Sharon	2015-05-27 18:12:12
18	F02	What other fuel do you use for cooking	Biogas	Electricity,LPG,Paraffin,Biogas,Charcoal,Wood,Biomass, None	299	Sharon	2015-05-27 18:11:51
17	M22	What size gas canister	9kg	1.25kg,2kg,3kg,4.5kg,5kg,6kg,9kg	299	Sharon	2015-05-27



Appliance Ratings

Add Appliance | Export | Print | Search

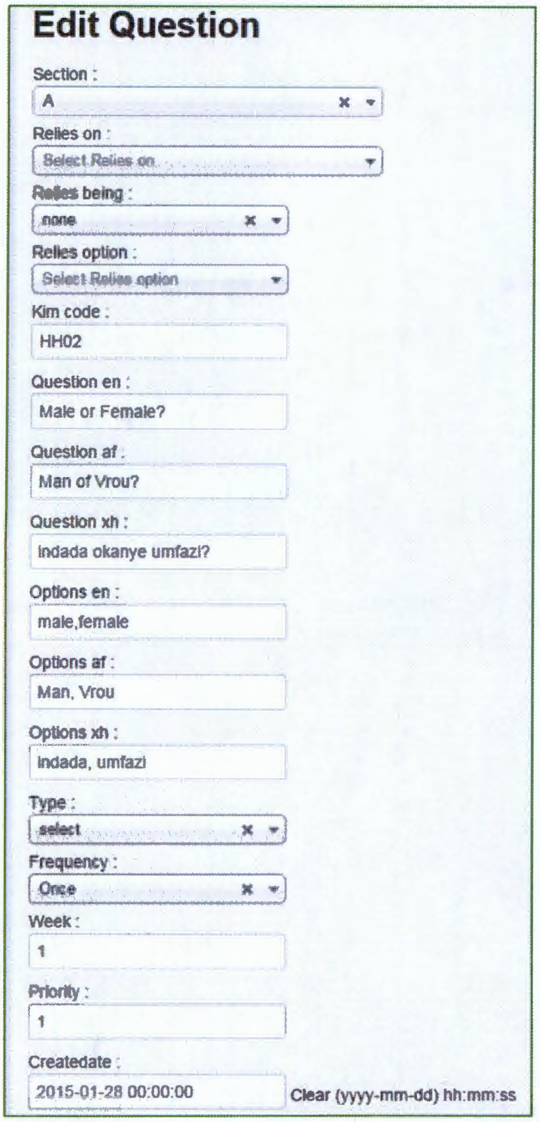
Name en	Name af	Name xh	Rating	Cost pm	Kw pm	Actions
Clock/Radio	Clock/Radio	Clock/Radio	2	0.000033	0.00003	Actions
25" colour tv	25" colour tv	25" colour tv	150	0.0025	0.00225	Actions
Ceiling fan	Ceiling fan	Ceiling fan	50	0.000833	0.00075	Actions
Electric Kettle	Electric Kettle	Electric Kettle	2000	0.033333	0.03	Actions
fridge/freezer	fridge/freezer	fridge/freezer	500	0.008333	0.0075	Actions

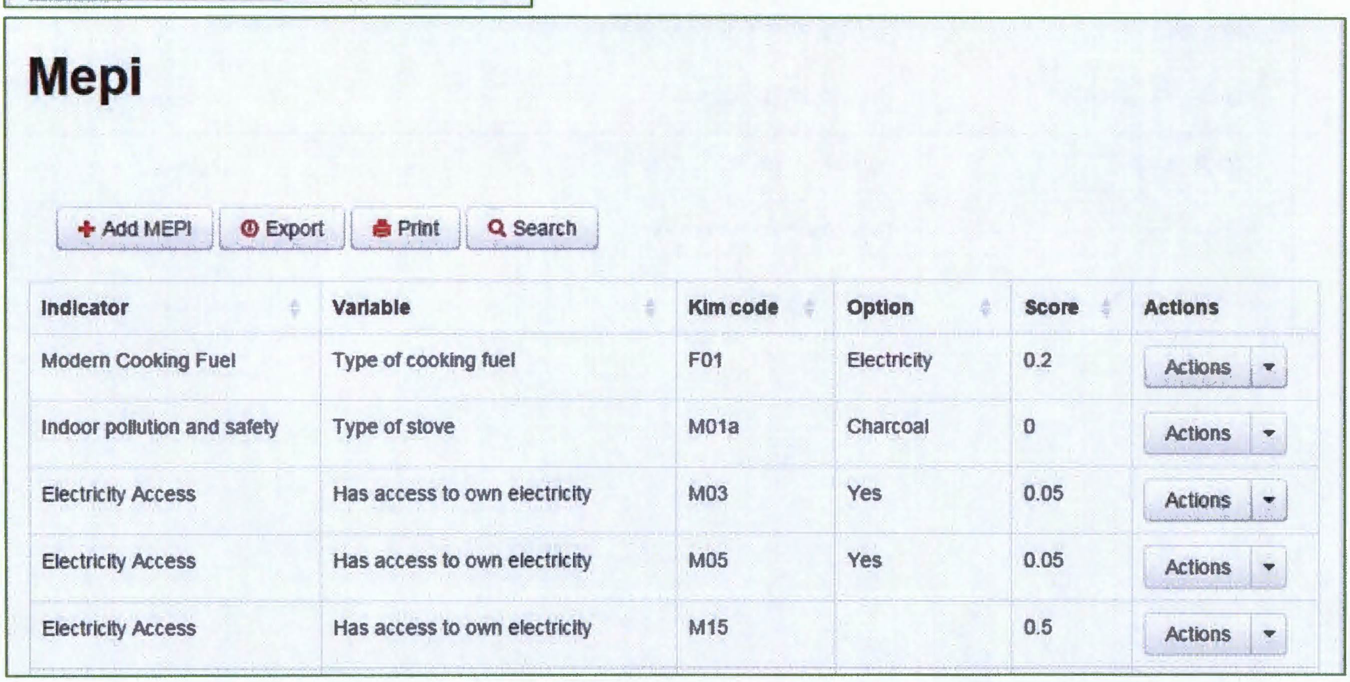


Content

Add content | Export | Print | Search

Name	Copy en	Actions
welcome	Welcome to the Sabela Sokwazi...	Actions
home_p1	This project aims to gather information...	Actions
home_p2	By filling out one 10 minute survey...	Actions
register_with_phone	Register with phone number	Actions
accept_terms	Agree to terms and conditions...	Actions
terms	By participating in this survey...	Actions
you_have_spent	You have spent	Actions





Mepi

Add MEPI | Export | Print | Search

Indicator	Variable	Kim code	Option	Score	Actions
Modern Cooking Fuel	Type of cooking fuel	F01	Electricity	0.2	Actions
Indoor pollution and safety	Type of stove	M01a	Charcoal	0	Actions
Electricity Access	Has access to own electricity	M03	Yes	0.05	Actions
Electricity Access	Has access to own electricity	M05	Yes	0.05	Actions
Electricity Access	Has access to own electricity	M15		0.5	Actions

Select User: M16

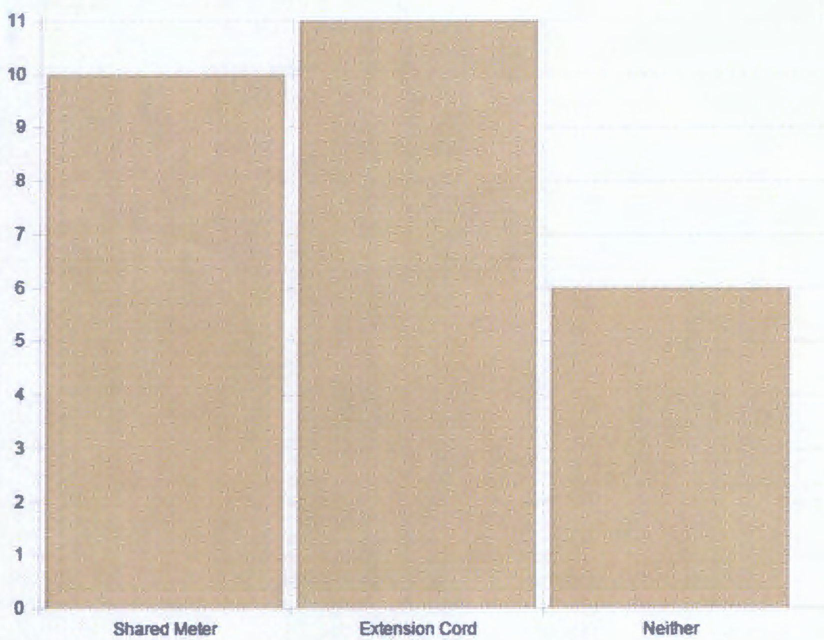
M16 Stats

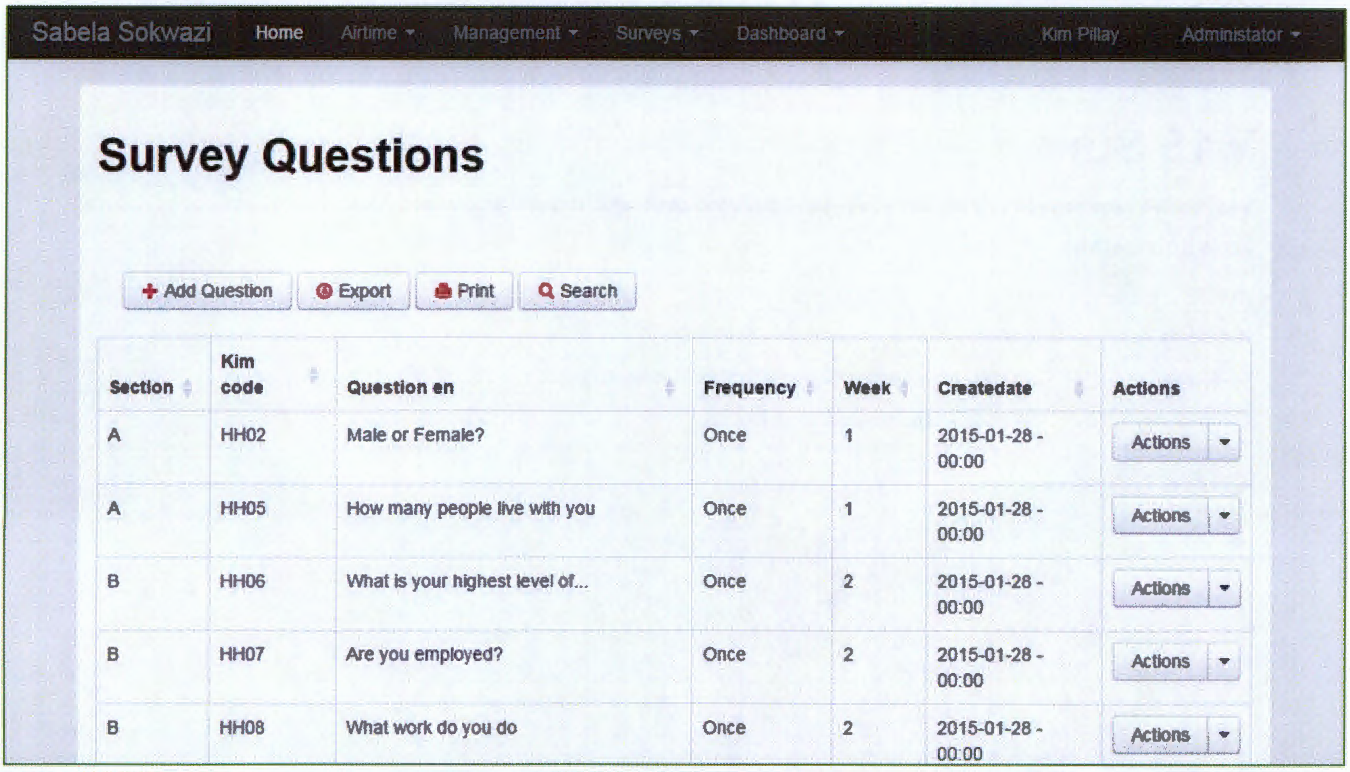
Welcome the question profile. From here you will ba able to see question details and answer averages.

Question Details

ID	14
Kim Code	M16
Question	Do you share a electricity meter or lease an extesion cord
Options	Shared meter,Extension cord, Neither

Slot Stats

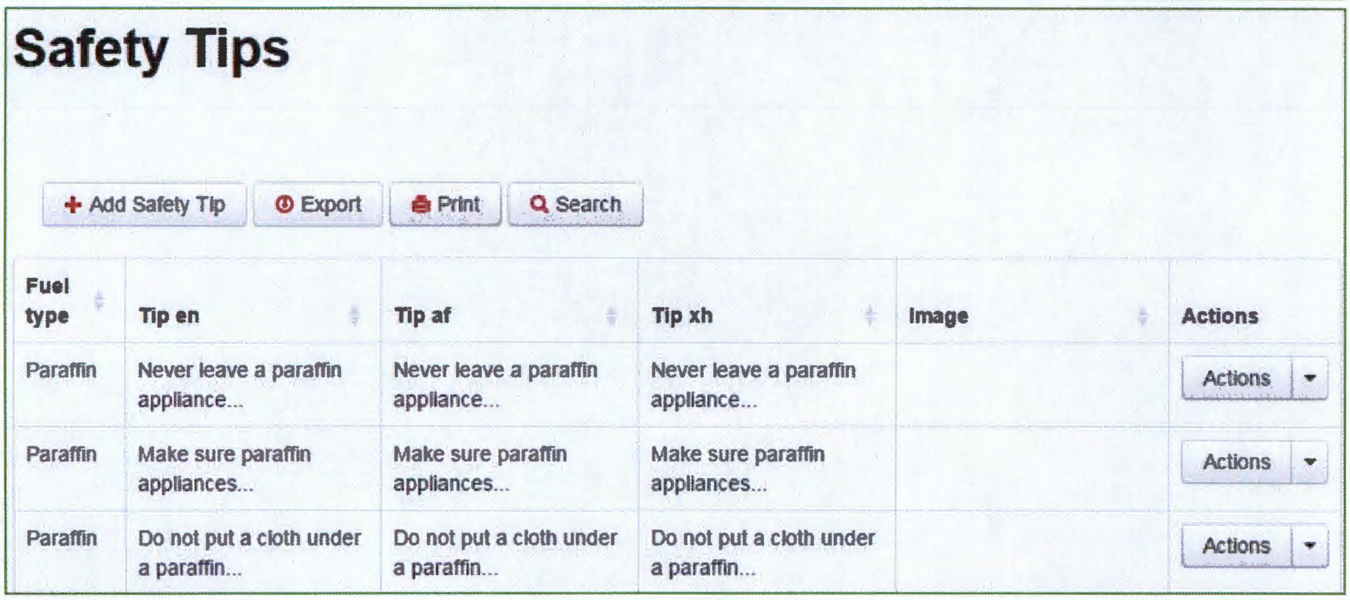




Survey Questions

+ Add Question | Export | Print | Search

Section	Kim code	Question en	Frequency	Week	Createdate	Actions
A	HH02	Male or Female?	Once	1	2015-01-28 - 00:00	Actions
A	HH05	How many people live with you	Once	1	2015-01-28 - 00:00	Actions
B	HH06	What is your highest level of...	Once	2	2015-01-28 - 00:00	Actions
B	HH07	Are you employed?	Once	2	2015-01-28 - 00:00	Actions
B	HH08	What work do you do	Once	2	2015-01-28 - 00:00	Actions



Safety Tips

+ Add Safety Tip | Export | Print | Search

Fuel type	Tip en	Tip af	Tip xh	Image	Actions
Paraffin	Never leave a paraffin appliance...	Never leave a paraffin appliance...	Never leave a paraffin appliance...		Actions
Paraffin	Make sure paraffin appliances...	Make sure paraffin appliances...	Make sure paraffin appliances...		Actions
Paraffin	Do not put a cloth under a paraffin...	Do not put a cloth under a paraffin...	Do not put a cloth under a paraffin...		Actions

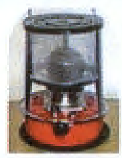
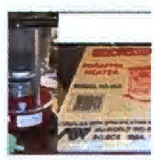
Spaza Suppliers

+ Add SMS Broadcast | Export | Print | Search

To	Week	Message	Createdate
	1	Complete the first survey to claim...	2015-04-21 - 00:00
Kimenthrie Pillay	1	Sabela Sokwazi! Remember to complete...	2015-04-23 - 00:00
Kimenthrie Pillay	1	Sabela Sokwazi. Your chance to...	2015-04-23 - 00:00

Spaza Stoves

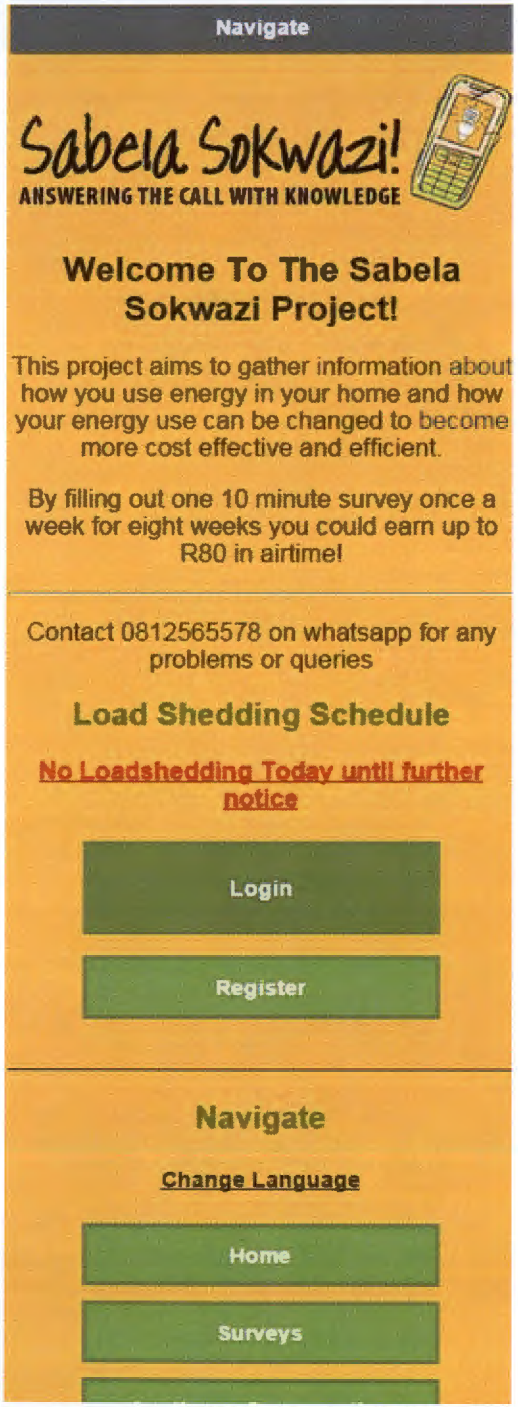
+ Add Stove | Export | Print | Search

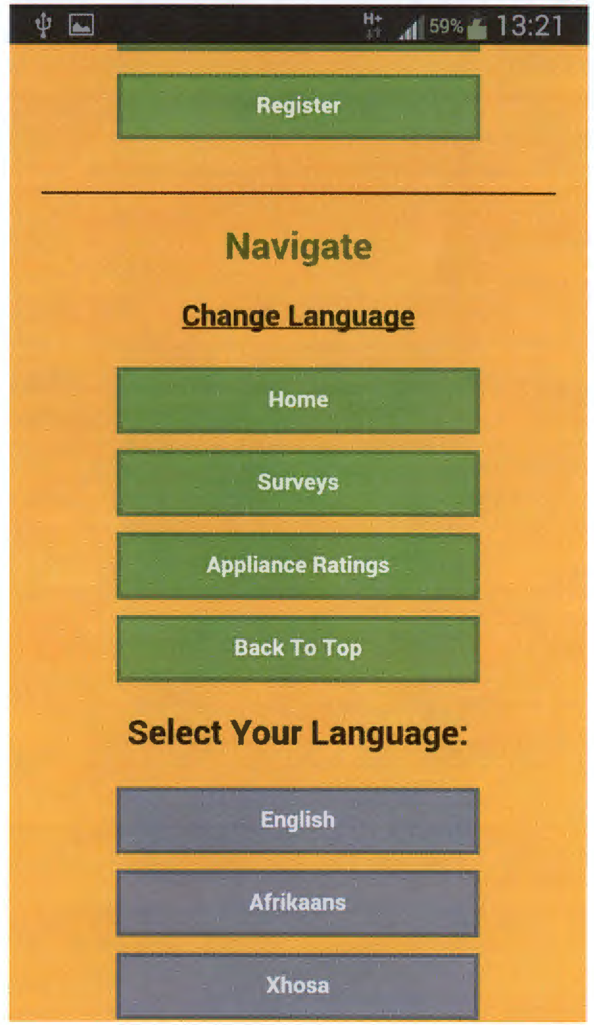
Type	Name	Image	Actions
Paraffin	Panda X2		Actions
Paraffin	GoldAir		Actions
Paraffin	Primus		Actions
Paraffin	Glory		Actions
Paraffin	SoNAM		Actions

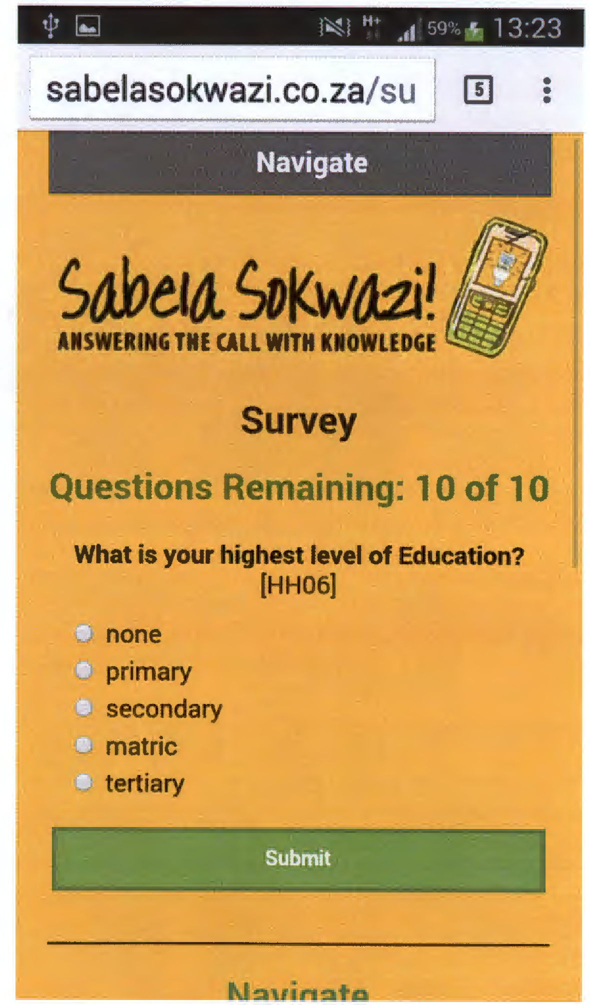
Survey Users

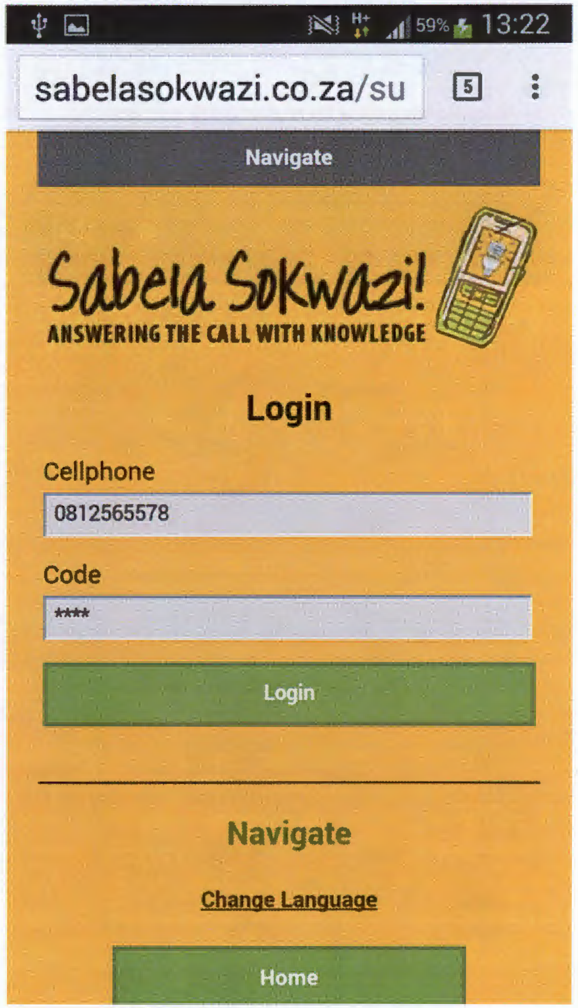
+ Add Survey User | Export | Print | Search

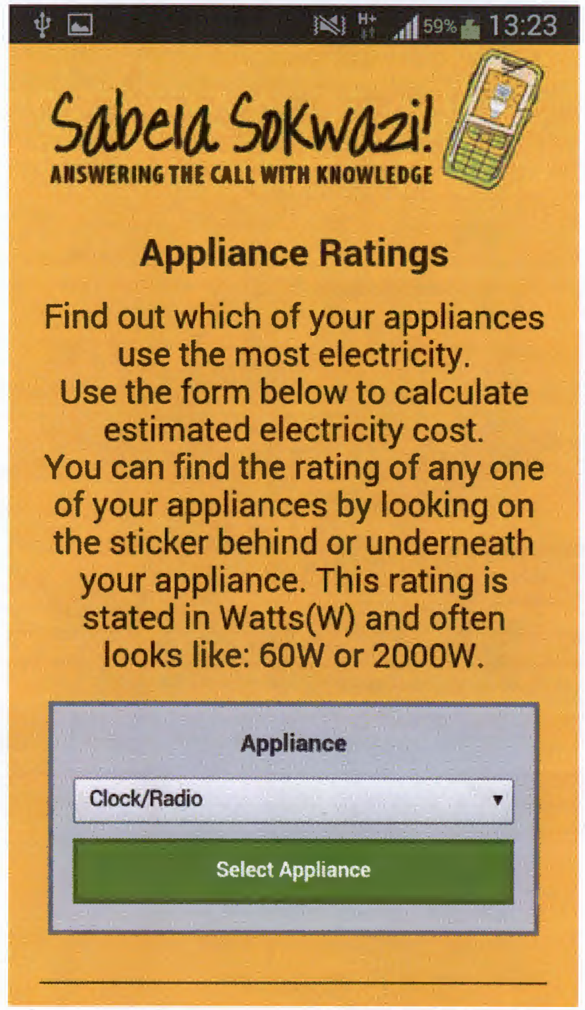
Id	Name	Cellphone	Current week	Createdate	Actions
299	Sharon	0786731021	1	2015-05-24 - 23:06	Actions
298	Lindokuhle Voyi	0610996847	1	2015-05-24 - 14:54	Actions
297	asandiswa	0782158819	1	2015-05-24 - 10:17	Actions
296	Nattie	0740595730	1	2015-05-21 - 21:08	Actions
295	Yonela	0784368423	1	2015-05-20 - 20:49	Actions
294	Afrie	0729064185	1	2015-05-17 - 16:32	Actions
293	sunshine	0732627194	1	2015-05-16 - 13:53	


Navigate
Sabela Sokwazi!
ANSWERING THE CALL WITH KNOWLEDGE
Welcome To The Sabela Sokwazi Project!
This project aims to gather information about how you use energy in your home and how your energy use can be changed to become more cost effective and efficient.
By filling out one 10 minute survey once a week for eight weeks you could earn up to R80 in airtime!
Contact 0812565578 on whatsapp for any problems or queries
Load Shedding Schedule
No Loadshedding Today until further notice
Login
Register
Navigate
Change Language
Home
Surveys

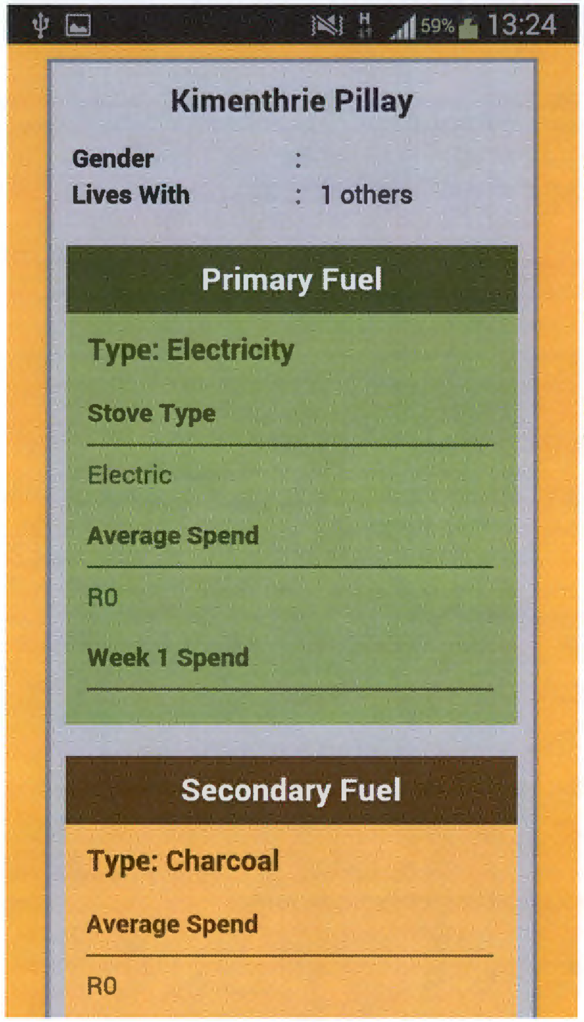

59% 13:21
Register
Navigate
Change Language
Home
Surveys
Appliance Ratings
Back To Top
Select Your Language:
English
Afrikaans
Xhosa

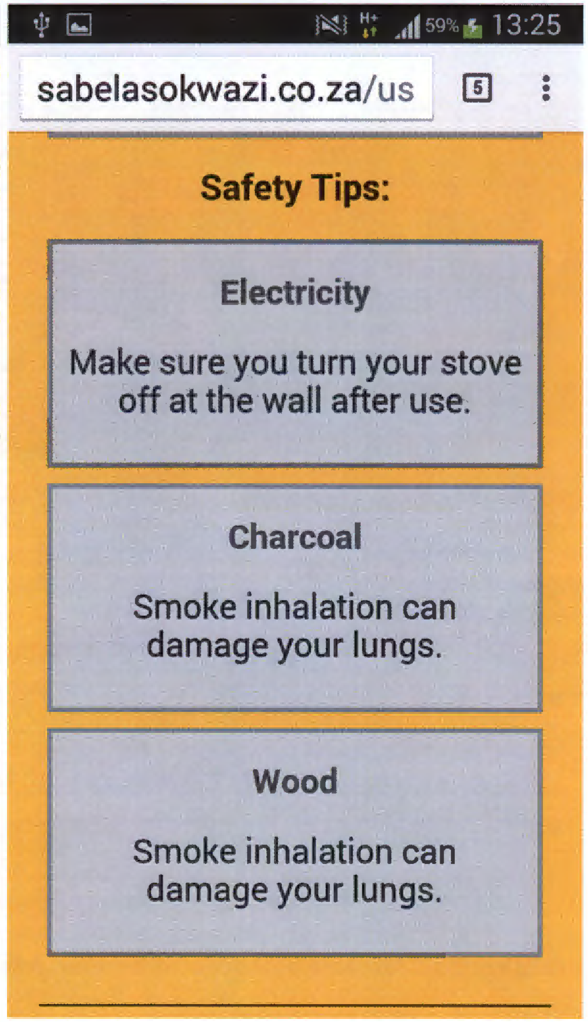

59% 13:23
sabelasokwazi.co.za/su
Navigate
Sabela Sokwazi!
ANSWERING THE CALL WITH KNOWLEDGE
Survey
Questions Remaining: 10 of 10
What is your highest level of Education?
[HH06]
none
primary
secondary
matric
tertiary
Submit


13:22
sabelasokwazi.co.za/su
Navigate
Sabela Sokwazi!
ANSWERING THE CALL WITH KNOWLEDGE
Login
Cellphone
0812565578
Code
****
Login
Navigate
Change Language
Home

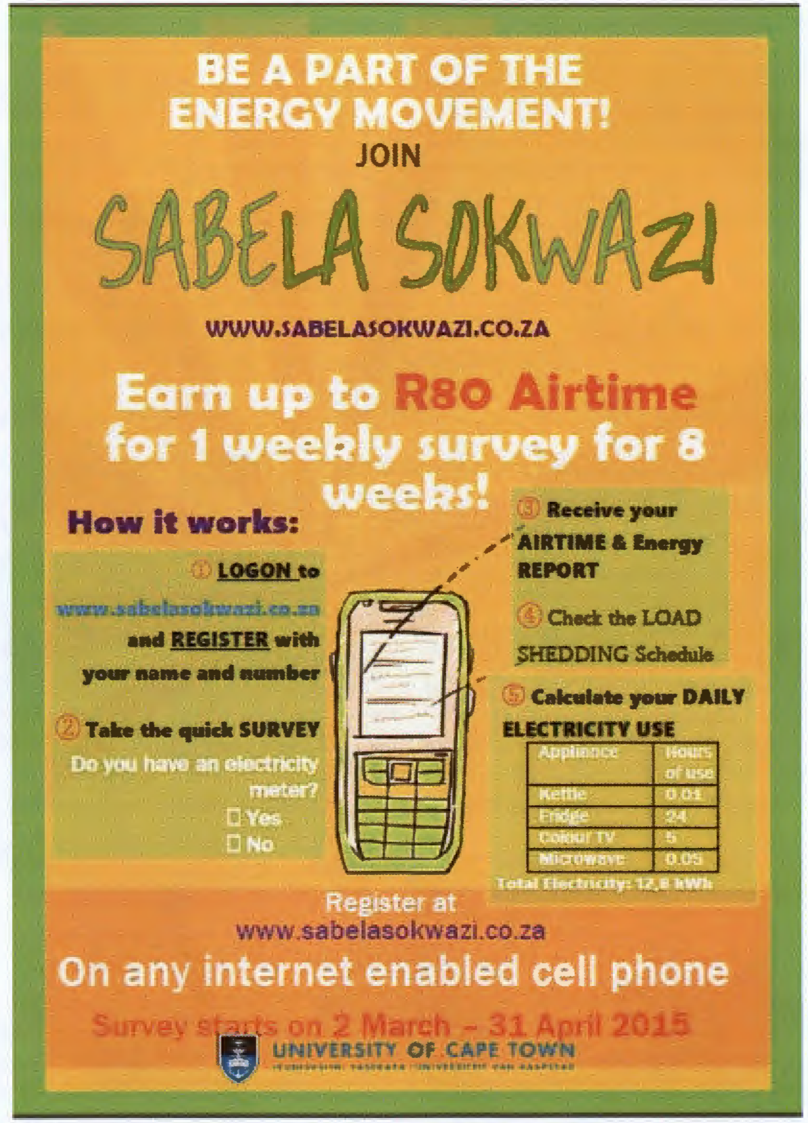

13:23
Sabela Sokwazi!
ANSWERING THE CALL WITH KNOWLEDGE
Appliance Ratings
Find out which of your appliances use the most electricity.
Use the form below to calculate estimated electricity cost.
You can find the rating of any one of your appliances by looking on the sticker behind or underneath your appliance. This rating is stated in Watts(W) and often looks like: 60W or 2000W.
Appliance
Clock/Radio
Select Appliance


13:24
Appliance
19" Colour Tv
Select Appliance
19" Colour Tv
5 Minutes
0.0075 kWh
R 0.008335
30 Minutes
0.045 kWh
R 0.05001
60 Minutes
0.09 kWh
R 0.10002
3 Hours
0.27 kWh
R 0.30006
6 Hours
0.54 kWh
R 0.60012
1 Day
2.16 kWh
R 2.40048


13:24
Kimenthrie Pillay
Gender :
Lives With : 1 others
Primary Fuel
Type: Electricity
Stove Type
Electric
Average Spend
R0
Week 1 Spend
Secondary Fuel
Type: Charcoal
Average Spend
R0


13:25
sabelasokwazi.co.za/us
Safety Tips:
Electricity
Make sure you turn your stove off at the wall after use.
Charcoal
Smoke inhalation can damage your lungs.
Wood
Smoke inhalation can damage your lungs.

10.5 Posters and Pamphlets



10.6 Costs used for Cost Effective Analysis

	Urban Traditional Survey	Rural Traditional Survey	Digital Survey
Surveys a Day	10	10	1E+12
Transport expenses	4,67	4,67	4,67
Start- Up Costs	200	200	66051,60
Enumerator/day	110	110	0
Distance to travel	20	75	0
Materials per survey	5	5	10.5
Data Cleaning Costs + Analysis + Data capture	300	300	0
Community engagement (R110 per hour)			660