Energy infrastructure transition in urban informal households in South Africa

by

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Declaration

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Abstract

South Africa possesses an abundance of solar energy resources that can be used to provide various energy services. The multiple fuel use model is evident in urban informal households and the fuel types and energy carriers that are most commonly used by these households are electricity, paraffin, gas, and firewood, which causes environmental destruction, morbidity, and adverse socio-economic conditions, and stifle economic development. The financial expenditure on fuel and energy carriers is exorbitant, because the majority of people that live in informal households have low paying jobs or are unemployed. The study aims to enhance our understanding of the transformation of the energy infrastructure that urban informal households use for various energy services. The objectives of this study were to identify the fuel types and energy carriers that urban informal households commonly used for lighting, cooking, space heating, water heating and operating household appliances as well as to identify the roles of stakeholders that might increase the uptake of distributed renewable energy technology on a local level by urban informal households. This research provides consumption patterns that inform potential energy infrastructure transitions. The findings suggest that electricity, paraffin, wood fuel and gas are most commonly used for energy services in urban informal households. There is an awareness amongst most stakeholders about the benefits of distributed renewable energy technologies but the deployment and education campaigns around these technologies are disjointed. The regional innovative system approach to socio-technical transition could be used to deploy distributed renewable energy technologies to urban informal households in South Africa.

Opsomming

Suid-Afrika beskik oor ŉ groot hoeveelheid sonenergie-hulpbronne wat gebruik kan word om verskeie energiedienste te verskaf. Die veelvuldigebrandstofgebruik-model is sigbaar in stedelike informele huishoudings en die soorte brandstof en energiedraers wat die algemeenste deur hierdie huishoudings gebruik word, is elektrisiteit, paraffien, gas en brandhout, wat vernietiging van die omgewing, morbiditeit en negatiewe sosio-ekonomiese toestande tot gevolg het en ekonomiese ontwikkeling onderdruk. Die finansiële uitgawes aan brandstof en energiedraers is buitensporig, aangesien die meerderheid mense wat in informele huishoudings woon ŉ lae inkomste verdien of werkloos is. Die doel van die studie was om begrip te bevorder van die transformasie van die energie-infrastruktuur wat deur stedelike informele huishoudings vir verskillende energiedienste gebruik word. Die doelstellings van die studie was om die soorte brandstof en energiedraers te identifiseer wat in die algemeen deur stedelike informele huishoudings vir verligting, kook, ruimteverhitting, waterverhitting en gebruik van huishoudelike toestelle gebruik word, asook om die rolle van belanghebbendes wat die gebruik van verspreide hernubare energietegnologie op ŉ plaaslike vlak deur stedelike informele huishoudings kan verhoog, te identifiseer. Die bevindinge toon dat elektrisiteit, paraffien, houtbrandstof en gas die algemeenste vir energiedienste in stedelike informele huishoudings gebruik word. Daar is bewustheid onder die meeste belanghebbendes van die voordele van verspreide hernubare energietegnologieë, maar die benutting en opvoedingsveldtogte met betrekking tot hierdie tegnologieë is onsamehangend. Die streeksinnoveringstelselbenadering tot sosio-tegniese oorgang kan gebruik word om verspreide hernubare energietegnologieë in stedelike informele huishoudings in Suid-Afrika aan te wend.

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List of acronyms and abbreviations

DoE	Department of Energy
DRE	Distributed Renewable Energy
Eskom	Electricity Supply Commission of South Africa
MLP	Multiple Level Perspective approach on sociotechnical transition
NGOs	nongovernmental organisations
PV	photovoltaic
REN21	Renewable Energy Policy Network for the 21st Century
RIS	regional innovative systems
SHS	solar home system
SNM	strategic niche management
TIS	technological innovation systems
TM	transition management

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CHAPTER 1: INTRODUCTION

1.1 Background

My personal interest in energy infrastructure transition in urban informal households was sparked during my nine years of employment in local government. I worked in Khayelitsha, a suburb on the periphery of the Cape Town Metropolitan Municipality, where a large section of residents live in informal households. I gained first-hand experience of the health and safety dangers that commonly used fuel types (e.g. paraffin, firewood, gas, and coal), and the lack of access to the main electricity grid, pose to urban informal households. A case in point is the common phenomenon of the electrocutions of persons who try to illegally connect informal households to the main electricity grid.

As a result of these personal and work experiences, I started volunteering at Greenpeace Africa on campaigns that created awareness of the potential that renewable energy technology, specifically solar energy, has to increase energy access for South African households. These awareness campaigns also highlighted the need for the national utility of South Africa (Eskom) and the South African government to increase investment in solar energy infrastructure and to decrease subsidies for and investments in the dominant fossil fuel electricity-generating sector, which has detrimental impacts on health and the natural environment as suggested by Gets (2013).

My work experiences with informal settlements and Greenpeace Africa made me realise that municipalities, due to their mandate to provide basic services such as electricity provision to citizens, are perfectly positioned to facilitate access to modern renewable energy infrastructure, and solar energy technology in particular, to urban informal households, which can potentially circumvent the adverse health and safety impacts of the fuel types that are commonly being used by urban informal households.

Having identified solar energy technology as a potential solution to the lack of energy access that some urban informal households experienced, I completed the Renewable and Sustainable Energy stream of the Postgraduate Diploma in Sustainable

Development at Stellenbosch University, which exposed me to the renewable energy industry when I did subjects including Renewable Energy Systems, Renewable Energy Finance, Solar Energy and Renewable Energy Policy. These modules exposed me to infrastructure transitions, and the potential of solar energy technologies to increase access to clean energy sources to urban informal households. In these modules various class discussions, lecturers and group work activities centred on the accessibility of distributed renewable energy (DRE) technologies to South African households. Vermaak, Kohler and Rhodes (2014) assert that the transition of energy infrastructure in South Africa may afford more people access to modern energy sources and a higher quality of life. During on-going discussions with my study supervisor, I identified the opportunity to research the ability that the uptake of renewable energy technologies in urban informal households may have to transform the energy infrastructure in these households, which could increase access to modern energy sources for them.

From here, I found further encouragement from the fact that the majority of the existing research on energy infrastructure transitions focused on developed countries. Many researchers on transition theory recommend that similar studies be undertaken in developing countries. There has been increased research on the energy transition infrastructure of Asian and sub-Saharan African countries. However, there is limited research that focuses on energy patterns in urban areas in the global south, although the developing countries will be disproportionately responsible for the increasing demand of energy (Musango, 2014; Shrestha *et al.*, 2008).

Finally, it is acknowledged that South Africa's solar energy resources can be used to increase access to energy, specifically for urban informal households, as well as to meet the wide-ranging challenges that the energy sector is currently experiencing (Fluri, 2009). In this thesis, I argue that the regional innovative systems approach to socio-technical transitions may enable the transition to the use of modern and clean energy.

1.2 Energy challenges in urban informal households

The most significant energy challenges facing the African continent are energy supply and energy access (Fakier *et al*., 2014). The Renewable Energy Policy Network for the 21st Century (REN21, 2015) suggests that only 43 % of the African population had access to electricity in 2012, which left 622 million without electricity access. Along the same lines, Hancock (2015) indicates that 25 sub-Saharan African countries face an energy crisis, evidenced by persistent power cuts. Some researchers argue that many parts of Africa have some of the best solar energy resources in the world that can be used to facilitate economic growth, increase the accessibility of energy and alleviate poverty on the continent (Fakier *et al.*, 2014; Tait & Winkler, 2012). Similarly, Sebitosi and Okou (2010) believe that the lack of existing energy infrastructure in most African countries presents an opportunity to exploit the abundant solar energy resource in Africa, in order to increase energy access and energy supply. This abundance of solar energy resources that can be used to increase energy supply and access to specifically African cities is clearly illustrated in Figure 1.1. This figure illustrates the global horizontal irradiation, which is the irradiation component that reaches a horizontal earth surface without any atmospheric losses due to scattering or absorption.

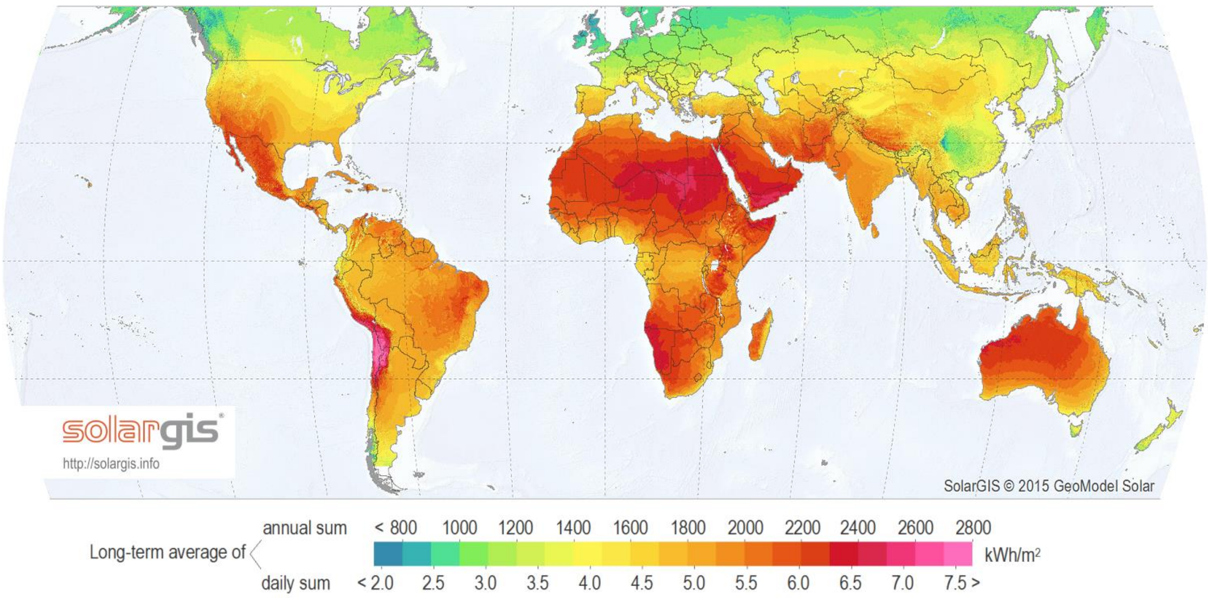

Figure 1.1: Map of global horizontal irradiation that illustrates the vast potential of many African regions for photovoltaic power
Source: SolarGIS, 2015

Dixon (2011) indicates that cities in developing countries, particularly in Asia and Africa, will experience major population growth in the next 35 years. It is estimated that three billion people will be added to the world's urban population between 2005 and 2050 (Hodson *et al*., 2012). According to Araujo (2014) an increase in the population is directly proportional to energy use and this increase in energy demand will escalate pressure on existing energy infrastructure in cities. Many of these new arrivals in cities cannot afford formal housing and will thus settle in informal dwellings on the periphery of the cities. These informal homes are characterised by a lack of adequate energy infrastructure to be connected to the main electricity grid.

The South African local government sphere that is mandated with the provision of basic services, which includes electricity provision, to a growing number of households is under pressure to provide reliable electricity supply to informal households that lack electricity infrastructure that connects them to the main electricity grid. An alternative solution to provide urban informal households with electricity is for municipalities to facilitate the uptake of DRE technologies, which can increase access to and supply of energy.

Urban informal households form a significant part of the African urban population particularly in South Africa. Currently it is estimated that informal urban households constitute 13.9% of all dwellings in South Africa (Statistics South Africa, 2011). The fuel types that are commonly used by urban informal households have many adverse socio-economic and health effects. Candles and paraffin are normally used for lighting and have been responsible for major fires in informal settlements. The in-house combustion of wood and coal to provide cooking services causes indoor air pollution and leads to respiratory tract diseases. While this is true, a recent study that was conducted by the Department of Energy (DoE, 2013) in South Africa suggested that 83% of urban informal households had access to electricity. However, this fossil fuel generated electricity has a number of detrimental social, economic and environmental impacts (Sebitosi & Okou, 2010).

The environmental destruction caused by the large fossil fuel and electricity generation sector, the above-inflation electricity hikes that are forecasted for end consumers, as well as regular power cuts, are some of the challenges that are faced by this industry.

The South African electricity utility Eskom generates over 90% of its electricity from coal, which have adverse socio-economic and environmental impacts compared to renewable energy technologies. In addition, the irregular load-shedding episodes and the constant tariff increases under Eskom's Multi-Year Price Determination make it challenging for end-consumers to access electricity (Franks, 2014).

As a result, there has been a global trend of disinvesting in fossil fuel energy and investing in renewable energy technology such as photovoltaic (PV) technology. The cost of PV technology in particular are dropping and becoming competitive (GreenCape, 2015). South Africa, which has some of the best solar energy resources in the world, as illustrated in Figure 1.1, could deploy small scale PV generators so that informal households can use these for various energy services. These abundant solar energy resources may make accessing and supplying energy services more feasible, specifically for urban informal households. However, it is mainly urban formal households that fall in the upper Living Standards Measurement group that are able to afford distributed solar energy technologies.

Various researchers insist that access to energy is vital for the socio-economic development of specifically developing countries (Thorne & Felten, 2014; Musango, 2014; Mainali *et al*., 2014). Many developing countries want to emulate the economic development paths of developed countries, which were largely dependent on fossil fuel combustion. For South Africa, in particular, economic growth is dependent on a reliable supply of electricity. South Africa has a high unemployment rate that can be decreased with the growth of commercial activities. South Africa is one of the most unequal countries in the world, and many urban informal households suffer from poverty and unemployment. With its great solar energy potential South Africa can grow its economy by generating energy from renewable energy technology and also developing a new industrial sector.

The transformation of energy infrastructure in urban informal households is related to the evolution of the current energy infrastructures. In other words, improvement in access to energy and in the quantity and quality of energy use is largely based on infrastructure improvements. In addition, there is a wide gap in terms of understanding the existing situation of clean energy access to the urban poor, the barriers to energy access and possible solutions to address this challenge (Sing *et al.*, 2014). Thus, it is essential to better understand the demand for energy services of urban informal households to better plan for future energy related programmes, such as the rollout of small-scale PV electricity generators, which are aimed at improving energy access and overall energy resource flows.

The introduction and uptake of DRE technologies such as the ECOlite solar home system, solar turtle, solar water heater, and solar bottle bulb may increase energy supply and access to urban informal households. However, in order for this transition process to be successful the involvement of a wide-range of stakeholders is necessary.

1.3 Research problem

It appears that limited consideration has been given to the energy infrastructure transition process in urban informal households from commonly used fuel types, such as firewood, paraffin, gas, and coal and gas to modern, cleaner fuel types, specifically DRE technologies. By ignoring the potential of renewable energy technologies to serve as supplementary and/or alternative energy carriers, opportunities to potentially alleviate the detrimental socio-economic impacts that commonly used fuel types have on urban informal households are missed. This also prevents the increase of energy access and more reliable energy supply, in particular for urban informal households in South Africa.

1.4 Research questions

The objectives of this study were to identify the fuel types and energy carriers that urban informal households commonly used for lighting, cooking, space heating, water heating and operating household appliances as well as to identify the roles of stakeholders that might increase the uptake of DRE technology on a local level by urban informal households. The two research questions are

i. What are the current energy flows of urban informal households?
ii. To what extent can renewable energy technologies contribute to the provision of energy services in urban informal households?

1.5 Significance of the research

This study is important because it may provide insight into how the process of energy infrastructure transition can be successfully facilitated in urban informal households, as well as the value of deploying clean, modern energy sources to urban informal households. The study may therefore benefit various stakeholders in the following ways:

i. Local government, which is mandated with the provision of basic services including electricity, may use this study to inform the roll-out planning and implementation of DRE technologies in urban informal areas.
ii. The use of the Regional Innovative Systems approach to socio-technical transitions to effectively rollout renewable energy technologies, such as distributed PV electricity generators, may improve the socio-economic conditions of specifically, urban informal households.
iii. Non-governmental organisations (NGOs) that advocate for the widespread uptake of renewable energy technologies may increase their effort to increase the uptake of these technologies, specifically in urban informal households.
iv. Policy and decision makers may be informed about and acknowledge the important roles that other stakeholders play in the energy infrastructure transition process, especially civil society and public administration.
v. Civil society may realise the important role that they play in the energy transition process and may increase pressure on the relevant government departments and political parties to prioritise the deployment DRE technologies.
vi. Financial stakeholders, such as banks and other funding organisations, may decide to introduce different financial models that could make DRE technologies more financially accessible to urban informal households.
vii. Investors may be convinced of the need to increase investment in renewable energy technologies, specifically DRE technologies.
viii. This research provides consumption patterns that inform potential energy infrastructure transitions.
ix. The objectives of this study promotes the attainment of some of the United Nations' 17 Sustainable Development Goals including ensuring healthy lives at all ages, ensuring access to affordable and modern energy for all, building resilient infrastructure and fostering innovation, making cities resilient and sustainable,

ensuring sustainable consumption and production patterns, and taking urgent action to combat climate change and its impacts.

1.6 Limitations of the study

i. The study focused only on informal households in South Africa that are situated in urban areas. Due to the vast differences in energy infrastructure and income opportunities between urban and rural areas the results may overestimate the amount of informal households with access to the main grid.

ii. The study focused on DRE technologies, in particular solar energy systems, as a potential alternative and/or supplementary energy carrier for urban informal households.

iii. The questionnaire was administered to a mix of informal households that live in backyards of formal dwellings and informal households that were situated in informal settlements.

iv. Female participation was only 40% in the questionnaire and 30% in the semi-structured interview. This is an underrepresentation of the female-headed households in the study.

v. The supply capacity of DRE systems was not taken into consideration.

vi. Some DRE technologies are limited to particular energy services, for example the ECOlite system that only provides lighting.

1.7 Assumptions of the study

i. The study assumed that urban informal households in general needed to increase energy access in order to improve their socio-economic conditions.

ii. The study assumed that the deployment of distributed solar energy technologies was the most effective way to increase energy access to urban informal households.

iii. The study assumed that the abundant solar energy resources in South Africa will remain constant and may even increase due to global warming.

iv. All informal households can afford DRE technologies to provide energy services.

v. The use of DRE technologies is cheaper that main grid electricity.

vi. Households insure DRE systems against damages and theft.

vii. Policies and regulatory frameworks are in place that promote the uptake of DRE systems.

1.8 Research design

Figure 1.**2** illustrates the research design that was used to address the research objectives (see Section 1.4) in order to inform the energy infrastructure transitions in urban informal households in South Africa. Each step is discussed in more detail in Chapter 3.

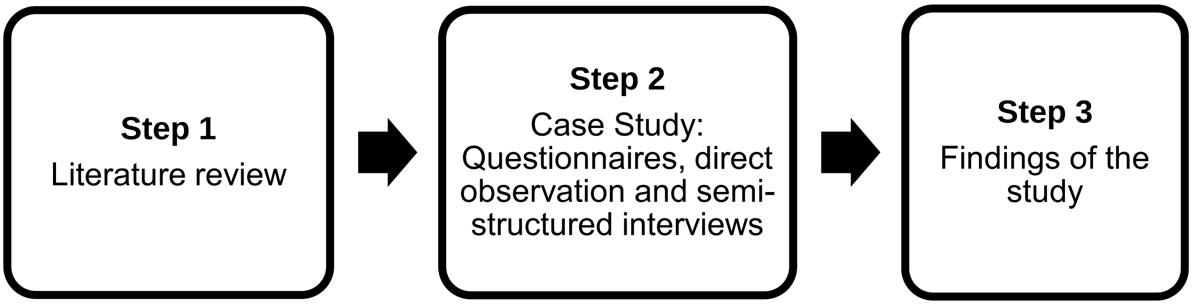

Figure 1.2: The research design used in the current study

The first step in this study was to conduct a literature review, focusing on transition theories, with a special focus on the regional innovation system (RIS) approach to socio-technical transitions. The other core themes that were covered in this literature review included energy concepts and related theories. The objectives of the literature review were to develop a framework to inform the questionnaire and a semi-structured interview that was used in the study.

1.9 Chapter Outline

Chapter 1 provides the background to the research questions and the rationale for the study. The research questions are stated as well as the research problem that motivated the research questions. Chapter 1 also describes the significance as well as the limitations, assumptions and the design of the study.

Chapter 2 presents a literature review that is divided into the following themes, namely: (i) socio-technical transitions and dominant approaches; (ii) energy related theories and concepts; and (iii) benefits of energy access.

Chapter 3 discusses the research design and methodology that were employed. A comprehensive literature review was the starting point of the research design, after which the case study was undertaken.

Chapter 4 presents and discusses the results of the study.

Chapter 5 concludes the study by offering key contributions, findings and limitations as well as making recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Incorporating DRE systems into the energy portfolio of urban informal households, may increase their energy access and consequently improve their socio-economic conditions. Cheng and Urpelainen (2014) state that the choices of fuel used for various energy services are critical for reasons of poverty alleviation, public health, and environmental protection. This chapter begins by critically reviewing the concept of and approaches to socio-technical transitions. The review suggests that the use of the RIS approach to socio-technical transitions may facilitate the successful introduction of cleaner energy technologies to urban informal households while keeping in mind their culture, preferences and lifestyles. It is very likely that the deployment of these clean energy technologies in urban informal households in South Africa will increase energy access as well as reliable energy supply.

Various energy theories are also discussed in which the potential of urban informal households to leapfrog electricity supply from the main grid, as well as the common occurrence of fuel stacking is analysed. This chapter further discusses the concept of energy access and the social, environmental and economic implications of universal access to energy. Finally, DRE technologies that may serve as alternative and/or supplementary energy carriers for energy services such as cooking, lighting, water heating, space heating, and operating household appliances in urban informal households are explored.

2.2 Socio-technical transitions

Socio-technical transitions are processes whereby multiple stakeholders influence and shape the evolution of technical systems to be more user-friendly and accessible. Van den Bergh *et al*. (2011) describe socio-technical transitions as processes that explain the co-dynamics of technologies, institutions, social and economic sub-systems and conditions in functional domains, such as energy supply, water supply, and transportation. Markard *et al*. (2012) agree with this definition and regard sectors, such as water supply, transportation and energy supply, as socio-technical systems because they consist of technological, material, organisational, institutional, economic, and socio-cultural components.

Markard *et al*. (2012), for example, regard one the changes that transpires in the socio-cultural component during the transition process, as the transformation in consumer perception of what constitutes a particular service or technology. For example, end-users may be used to warming water for bathing purposes with an electric geyser, but on realising that electric geysers are responsible for around 60% of their household electricity cost may find a solar water heater more appealing to provide the same service. Even though purchasing a solar water heater requires a high initial investment, the savings that households could affect over the long term may make this change in water-heating appliance more attractive. In addition, the environmentally friendly operation of the solar water heater, as opposed to electric geysers that operate on fossil fuel-generated electricity, would also add weight to the change.

Some researchers observe that transition processes may be disruptive to vested interests and intimidate leadership incumbents in the affected socio-technical system (Mattes *et al*., 2015; Taylor *et al*., 2014). A case in point is the relentless subsidisation of the fossil fuel-generated electricity industry in South Africa. Many senior government officials and politicians that governs the country have financial interests in coal- and uranium-producing mines (Scholvin, 2014; Baker, 2011). Low-cost and abundant coal deposits also favours the adherence to coal based electricity in South Africa (Baker, 2011). As a result, the support from government in the form of tax breaks and subsidies for the fossil fuel-generated electricity industry will make it difficult for newer electricity-generating industries, such as the renewable energy sector, to compete.

A more recent example is the veil of secrecy that surrounded the cabinet's decision to implement the nuclear procurement programme (Marrian, 2015). This programme does not mean that the South African government does not invest in alternative energy-producing technologies. On the contrary, the DoE recently issued a request for bids to manufacture, supply, deliver, and warehouse solar water heater systems as part of a national solar geyser roll-out (Creamer, 2015). However, it is argued that it is very difficult for new entrants in the energy producing market to compete against the highly subsidised coal and nuclear energy industries.

Transition processes occur over a long period of time in which new products, services, business models and organisations develop according to Hess (2014). Furthermore, technological transition processes lead to the creation of more efficient infrastructure that is more accessible and easily replicable over a number of decades. For example, it is almost certain that the supply of piped water to urban formal households has made water more accessible to most communities compared to the days when water had to be collected from rivers, streams and boreholes.

Table 2.1: Historic socio-technical transitions over the last 300 years and the new technologies, industries and infrastructures that they brought about

Technological revolution	New technologies and new or redefined industries	New or redefined infrastructures
FIRST: From 1771, the Industrial Revolution in Britain.	• Mechanised cotton industry • Wrought iron machinery	• Canals and waterways • Turnpike roads • Water power (highly improved water wheels)
SECOND: From 1829, the Age of Steam and Railways in Britain that spread to continental Europe and the United States of America.	• Steam engines and machinery that are made of iron and fuelled by coal. • Iron and coal mining that now play a central role in growth. • Railway construction, rolling stock production, and steam power for many industries such as textiles)	• Railways (use of the steam engine) • Universal postal service • Telegraph (mainly nationally along railway lines) • Large ports and transoceanic sailing ships. • Urban gas supply
THIRD: From 1875, the Age of Steel, Electricity and Heavy Engineering in the USA and Germany which overtook Britain.	• Cheap steel (especially Bessemer) • Full development of steel. • Engine for steel ships. • Heavy chemistry and civil engineering. • Electrical equipment industry. • Copper and cables	• Worldwide shipping in rapid steel steamships (use of Suez Canal). • Worldwide railways (use of cheap steel rails and bolts in standard sizes). • Large bridges and tunnels • Worldwide telegraph • Telephone (mainly nationally)

	• Canned and bottled food. • Paper and packaging	• Electrical networks (for illumination and industrial use).
FOURTH: From 1908, the Age of Oil, Automobiles and Mass Production in the USA spreading to Europe.	• Mass-produced automobiles. • Cheap oil and oil fuels • Petrochemicals (synthetics) • Internal combustion engine for automobiles, transport, tractors, airplanes, war tanks, and electricity • Household electrical appliances • Radio and television • Refrigerated and frozen foods	• Networks of roads, highways, ports and airports • Networks of oil ducts • Universal electricity (industry and homes) • Worldwide analogue communications • National broadcasting networks
FIFTH: From 1971, the Age of Information and Telecommunications. in USA, spreading to Europe and Asia	• The information revolution • Cheap microelectronics • Computers and software • Telecommunications • Control instruments • Computer-aided biotechnology and new materials	• Worldwide digital telecommunications (cable, fibre optics, radio and satellite) • Internet/electronic mail and other e-services • Multiple-source, flexible-use, electricity networks • High-speed physical transport links (by land, air and water) • Global 'narrow-casting' networks

Source: Adapted from Swilling and Annecke, 2012

Table 2.1 illustrates the five transitions that are associated with specific technological innovations that emerged at particular historic moments since the dawn of the industrial era (Perez, 2002). One of the new and improved infrastructures that evolved in the various socio-technical systems during this period are water canals, which form part of the urban water management and transition continuum. De Haan *et al*. (2015) encourage cross-sectoral comparisons in the study of transitions. For example comparing the lessons learnt from water with those learnt from energy as a means to inform general transition theory. These authors also claim that the study of urban water provision serves as a valuable lens through which to study transition in general and provides the basis for on-going conceptual and theoretical development (De Haan *et al*., 2015). An example is the different actors that enter the water governance discourse when new green infrastructure, such as sustainable urban drainage systems and low impact design, is developed. Consequently, a power shift happens in the water governance arena from the central government to municipalities, water utilities, the private sector, community cooperatives and individual households, who share responsibilities regarding ownership, maintenance and potential revenues (De Haan *et al*., 2015).

Araujo (2014:112) defines energy transition as, *"a shift in the nature and pattern of how energy is utilized within a system"* and notes that this definition recognises the change associated with fuel types, access, sourcing and delivery of the energy system. What Araujo (2014) means is that the process of changing the way in which energy is normally generated, involves more than replacing existing technology, and includes a change to potentially cleaner fuel types, thereby increasing the energy access of households, providing different ways of sourcing energy, and effectuating a more efficient energy system. What is more, this process of energy transition broadens the access to clean energy in order to alleviate energy insecurity and energy poverty. As a result, a more 'just' society will be fostered by transition processes (Newell & Mulvaney, 2013).

The possible changes that might take place in the technical, material, organisational, institutional, political, economic and socio-cultural components during the socio-technical transition of the energy system are further outlined:

2.2.1 Technical changes

There may be a change in the Material Flow Analysis of localities and an increase in use of renewable resources to generate energy (Hodson *et al*., 2011). The design, construction, and operation of energy infrastructure create a socio-technical environment that plays an important role that may reshape how resources are procured, used, and disposed of by localities. The change from using finite resources to renewable resources to generate energy opens up the possibility to meet the energy needs of more households (Hodson *et al*., 2011)

Households could generate their own electricity with small-scale PV generators as opposed to obtaining it from centrally managed coal and nuclear power stations to. For example, the Danish energy system is experiencing an increasing shift to DRE technologies according to Araujo (2014). In addition, Germany decommissioned most of its nuclear power plants and has been making large investments in renewable energy technologies, such as PV electricity generators.

2.2.2 Material changes

It is very probable that material changes will manifest during the process of energy infrastructure transition in the form of decoupling of non-renewable resources for the generation of energy. Swilling and Annecke (2012:31) allege that one of the main anthropogenic causes of climate change is the carbon emissions into the atmosphere that are generated by the combustion of fossil fuel. This suggests that in order to curb these carbon emissions, countries should invest more in renewable energy technologies, for example PV electricity generators that emit little carbon. Parallel to this decoupling process may be the increased use of renewable resources such as wind energy, solar energy, domestic waste, and sewage for the generation of energy (Hodson *et al*., 2012). As a result, the energy infrastructure transition process may lead to a decrease in the use of fossil fuels such as coal and nuclear products as well as fresh water. These finite resources may be replaced by infinite renewable resources such as wind and sunlight to generate energy. Above all, instead of dumping organic waste without using it, food, sewage and animal waste can be gathered at municipal sewage treatment systems in order to capture the methane that it release so that it can be harnessed to generate heat and electricity (Hodson *et al*., 2012).

2.2.3 Organisational changes

It appears that due to globalisation, international intergovernmental organisations such as United Nations, the International Energy Agency, the International Renewable Energy Agency, and the Organisation for Petroleum Export Countries, and international and regional financial institutions such as the World Bank and the African Development Bank, will have a great influence during energy transitions according to Araujo (2014). The United Nations Environmental Programme and the International Renewable Energy Agency in particular provide institutional, financial and human resources to new projects that focus on sustainable energy provision. Developing countries with limited resources to manage and realise these energy projects, in particular, will be affected.

The South African Civil Society Energy Caucus, which is a network of concerned citizens and organisations that focus on protecting communities that faces energy poverty, could contribute to the energy transitions on local government level (Baker, 2011). Various principles of this organisation promotes energy infrastructure transition including: (i) the promotion of local content, ownership and participation in energy developments, (ii) ensuring that communities have a voice in the provision household energy and all energy policies, (iii) requesting for decentralised energy production as close as possible to demand, (iv) and the recognition of indigenous knowledge and energy service options that may not be fashionable as well as a call for greater support of off-grid electrical options (Baker, 2011:45).

2.2.4 Institutional changes

The growing attention that climate change and energy access have received in the past few years has urged governments to introduce new policy measures that advocate and stimulate the deployment of energy technologies with a relatively lower carbon emission rate. For example, according to Bulkeley *et al*. (2013), the City of London created the 2004 Energy Strategy and a Vision for London's energy future that aimed to decrease fossil fuel dependence and increase renewable energy technologies into the city's energy portfolio in order to decrease carbon emissions. In addition, London also developed the *2007 Climate Change Action Plan,* which goal was to establish a low carbon energy regime in order to stabilise the carbon emissions of this city in 2025 at 60% below the 1990 levels (Bulkeley *et al*., 2013).

According to Taylor *et al*. (2014), the City Council of Cape Town adopted the Integrated Metropolitan Environmental Policy in 2001, which specified that an Energy and Climate Change Strategy was needed. This Energy and Climate Change Strategy was initiated in 2003 and adopted in 2007. The City of Cape Town's *Energy and Climate Change Strategy* puts energy at the front and centre of local climate change concerns, focussing on: the city's heavy reliance on fossil fuel based energy (notably coal-based electricity, petrol and diesel), the high levels of greenhouse emissions and other air pollutants associated with such energy consumption as well as the existence of unacceptable levels of energy poverty within parts of Cape Town (DoE, 2013; City of Cape Town, 2001).

2.2.5 Political changes

Taylor et al (2014) note that the largest political parties in South Africa, the African National Congress and the Democratic Alliance do not have any dedicated party structures that focus on sustainable development issues such as energy access and energy security. Furthermore, these political entities do not have policy positions on ‘environment versus development’ matters. This situation may change with the growing importance of sustainable development matters on the global agenda and political parties may appoint green champions in every branch to engage with local sustainable development matters such as energy access and energy security.

Monstadt and Wolff (2014) suggest that environmental policies that are formulated to boost the energy infrastructure transition from a carbon-intensive regime to the increasing use of renewable energy technologies should have a high transformative capacity to activate key changes in four features of urban energy regimes. Firstly, the environmental policy should extensively change the existing technological structures. Secondly, the institutional arrangements and practises in the production, distribution and use of energy will be impacted by the policy. Thirdly, the arrangement of power relations of actors will dramatically change. Finally, the labour and knowledge base and the existing boundaries of the regime will change. However, if the transformative capacity of the environmental policies is low, they may only have a supplemental and sustaining impact on the four features above (Monstadt & Wolff, 2014).

2.2.6 Economic changes

It is highly likely that the energy infrastructure transition process will cost developed and developing nations great amounts of money to accomplish. Dixon (2011) suggests that these economic challenges can be overcome by innovative financial strategies to provide \$20 trillion to \$30 trillion for additional upfront funding for infrastructure. In addition, developed countries need to help developing countries with their infrastructure initiatives (Dixon, 2011). It is, however, almost certain that this financial aid from developed countries to support the energy infrastructure transition processes in developing countries could foster a dependency syndrome and a new form of colonisation of the developing countries.

2.2.7 Socio-cultural changes

According to Dixon (2011) the behavioural change of people helps to aid the transition in the energy socio-technical system that may result in low carbon economies. It is highly likely that the growing awareness of the impact of climate change on people's everyday life and choices will spur them on to start considering cleaner technologies to provide energy services, such as cooking, lighting, water heating, space heating and operating household appliances in their homes. Geels (2013) reaffirms that the socio-technical transition in the energy sector is fuelled by the urgent need to address the challenges of climate change, pollution, and the depletion of natural resources and biodiversity. Besides, Araujo (2014) reaffirms that transition in the energy sector may be influenced by fuel price fluctuation, environmental and security concerns, technological innovation and goals to improve energy access.

In contrast, inadequate financial resources, opposition from local communities to renewable energy projects, as well as the lack of institutional frameworks, and coal subsidies, hinders the transition to cleaner energy infrastructure on a global scale (Eleftheriadis & Anagnostopoulou, 2015). Developed countries and intergovernmental organisations may form partnerships with developing countries to raise financial resources that could assist in the roll-out of renewable energy projects. These agreements may also include the use of experienced energy specialists from developed countries, such as Germany, to implement renewable energy projects and train of inexperienced staff in recipient countries. Recipient communities of renewable energy technologies need to be involved from the pre-feasibility stage of the project to guarantee the successful deployment of these technologies.

It is highly likely that demonstrating to investors in the fossil fuel energy sector the socio-economic benefits of cleaner energy technologies may convince them to switch their allegiance to the renewable energy sector. Bulkeley *et al*. (2013) believe that there is too much emphasis on innovation in the literature on socio-technical transition of energy supply and argue that the political economy in which infrastructure is provided is crucial. The political resistance from the reigning industrial regime tend to oppose transitions according to the political coalition perspective (Hess, 2014) because it threatens the vested interests of the incumbent political and financial leadership in the present socio-technical regimes (Taylor *et al*., 2014; Baker, 2011).

Socio-technical transitions are a lengthy irregular process that threatens the vested interests of the incumbent energy technology (Mattes *et al*., 2015). This point should be of interest to municipalities that are responsible for providing electricity to communities. Furthermore, investors in renewable energy technologies and entrepreneurs in this space should understand that changing the energy infrastructure is a lengthy process. It is clear that the energy infrastructure transition process, which is fuelled by climate change, resource depletion and pollution, may pressure both developed and developing countries to change to cleaner energy technologies. Consequently, the next section of this literature study analyses transition approaches that could be used as frameworks to understand the dynamics of the transition of the energy system of specifically urban informal households.

2.3 Transition theories

Transition theories have been heralded by many as providing a way of explaining historical transitions such as sailing to steam ships, horses to cars, propeller aircrafts to jets, the introduction of pipe-based water supply, and the shift from cesspools to sewer systems (Geels, 2004). According to Rauschmeyer *et al*. (2015) transition research aims to develop analytical tools that take into account the complexity of societal systems and their mechanisms of innovation. Such transitions materialise under difficult circumstances because existing regimes are characterised by lock-in and path dependence and are directed towards incremental innovation along anticipated trajectories (Rauschmeyer *et al*, 2015). Investigating and understanding the intricacies of societal systems, and breaking the hold that incumbent technologies have on the current technological regime, make transition processes very lengthy.

The current study used a framework that was based on the work of Mattes *et al*. (2015). These authors draw on the RIS approach to socio-technical transitions, energy transitions in particular, to contend that local development dynamics result from interfaces among various sub-systems, including: science and education, policy and decision makers, public administration, industry, finance, intermediaries, and civil society.

There appear to be five main approaches to the study of socio-technical transitions, namely: (i) strategic niche management (SNM); (ii) multi-level perspective (MLP); (iii) transition management (TM); and (iv) technological innovation systems (TIS) (Mattes *et al.*, 2015; Markard *et al*., 2012). Each of these theories is discussed in more detail. The literature review of the current study was limited to these five frameworks because they adopt systemic views of far-reaching systemic transformation processes of socio-technical systems, as described by Markard *et al*. (2012). Even though there are differences among these five perspectives of socio-technical transitions, there are some similarities; for example, the use of the same concepts (Markard *et al.*, 2012). For instance, Mattes *et al*. (2015) demonstrate that the MLP-, SNM-, and TIS approaches to socio-technical transitions do not adequately address the processes on a regional or city level.

Admittedly, it is also important to note that there is a broad range of general and technologically focused theories that have been used to study and explain the particularities of transitions that were not covered in this research. This section probes the characteristics of the SNM, MLP, TM and TIS approaches to socio-technical transitions as frameworks to study the energy infrastructure transition process in urban informal households. The section ends of with an analysis of the RIS approach to socio-technical transitions that was used as a framework in the current study to understand the energy infrastructure transition processes in urban informal households.

2.3.1 The strategic niche management approach to socio-technical transitions

The SNM approach to socio-technical transitions is considered to be the creation and support of unique technologies. This approach is used within the MLP approach to socio-technical transitions to study the development of niche innovations (Oyake-Ombis *et al*., 2015; Markard *et al*., 2012). Lopolita, Morone and Taylor (2013) remind us that the two-fold purpose of the SNM approach is to understand the process of technological development and to influence this in a desired manner.

The SNM approach to socio-technical transitions plays an important role in the development of innovative technologies by bringing together the knowledge and expertise of different actors in the socio-technical innovation process (Oyake-Ombis *et al*., 2015; Lopolita *et al*., 2013; Seyfang *et al*., 2014). This role is fulfilled by three procedures that form part of the SNM approach to successfully develop and start niche innovations. These procedures are the following: (i) the building of social networks; (ii) the voicing and shaping of shared expectations; and (iii) social learning (Oyake-Ombis *et al*., 2015; Lopolita *et al*., 2013; Seyfang *et al.*, 2014). Maintaining cordial professional relationships, with industry role-players and a wide range of other stakeholders in various sectors, could be a huge advantage for inventors who want to launch a unique technology in a highly competitive market. Correspondingly, it is possible that inventors of these novel technologies can discover the hopes of recipient communities regarding what these technologies can do for them. This information can then be used to correct any misconceptions about the performance and output of these technologies.

Seyfang *et al*. (2014) suggest that the three processes that form part of the SNM approach to socio-technical transitions promote niche technologies in the following ways. Firstly, detailed and robust expectations from the recipient market and the technology inventors about innovation performance could contribute to successful niche building provided that it is confirmed by on-going projects. Next, social networks contribute to technological niche building when their membership originates from wide-ranging perspectives. By extension, the learning processes not only accumulate facts and data on how to improve the innovation, but also generate second-order learning about alternative cognitive frames and different ways of valuing and supporting the niche (Seyfang *et al*., 2014). Finally, through the process of social learning, niche innovations gain momentum and can eventually compete with established technologies (Markard *et al*., 2012).

However, the SNM approach to socio-technical transitions also has various weaknesses that render this approach challenging to apply to the energy infrastructure transition process of specifically urban informal households. Seyfang *et al*. (2014) and Markard *et al*. (2012) suggest that niches have been designed in sheltered environments where new innovations can develop without being subjected to the selection pressures of the prevailing regime. Though it should be conceded that this protective environment is conducive to the longevity of locally produced niches, the niche technology will find it challenging to compete against similar cheaper imported technologies or commonly used fuel types that urban informal households presently use after the initial innovation stages.

Besides, this approach simplifies the intricate plurality of the socio-technical structure; for example, it transforms community-led initiatives into unrealistic homogenous niches working against a similarly problematic conceptualisation of a homogenous regime (Seyfang *et al*., 2014). It is highly unlikely that a technological innovation that solves the energy challenges of one community or household will be able to solve the energy challenges of other communities or households in the same Living Standards Measurement group.

Furthermore, niche analyses have focused on market context and business-led technological innovation and not on grassroots innovations that favour a bottom-up approach (Seyfang *et al*., 2014). Even though the business aspects of technological innovations are crucial, this top-down approach may cause several challenges that could restrict the diffusion of technological innovation. It is probable that neglecting to include and consult civil society bodies and NGOs in the pre-feasibility and feasibility stages of designing energy solutions could cause resistance to supporting the deployment of these energy solutions. In addition, communities that are kept out of the loop may have unrealistic expectations about the performance of potential energy solutions due to misinformation.

There are several reasons why the current study did not use the framework of the SNM approach to socio-technical transitions. While it is true that the SNM approach includes a wide range of stakeholders during the innovation process, the top-down approach during this process could be problematic if used as a framework to understand the energy infrastructure transitions in urban informal households. There appears to be minimal focus on civil society stakeholders and the policy and decision-making subsector, which should both form an important part of the energy infrastructure transition process. In addition, it may not be possible to duplicate the protective environment in which these niches are developed, particularly in the developing world.

2.3.2 The multi-level perspective approach to socio-technical transitions

The MLP approach to socio-technical transitions is the study of long-term historical transitions in a broad range of empirical areas. This approach explains technological transitions through the interplay of dynamics at three different levels, namely: niches, regimes, and landscapes (Rauschmayer *et al*., 2015). Figure 2.1 illustrates how the MLP approach is organised into niches, regimes and landscapes (Smith *et al*., 2010; Dixon, 2011).

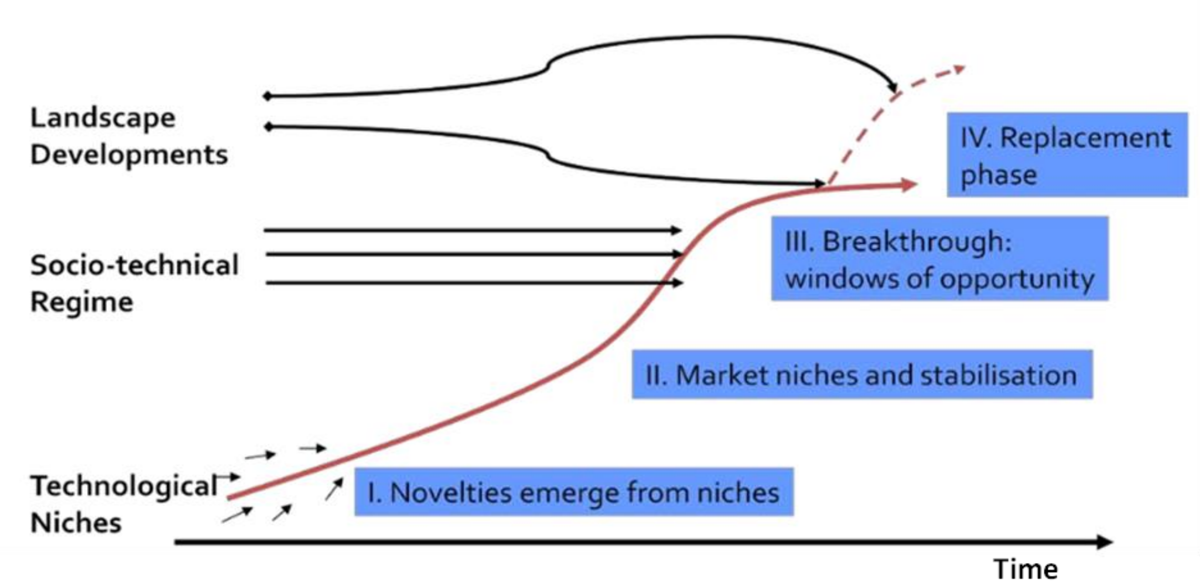

Figure 2.1: A graphic illustration of the MLP approach to socio-technical transition
Source: Geels, 2004

As shown in Figure 2.1 the three levels of the MLP approach to socio-technical transitions are socio-technical niches, regimes and landscapes (Lopolito *et al*., 2013). The transition process occurs in the MLP approach to when dynamics at the niche, regime and landscape levels come together and reinforce each other (Geels & Kemp, 2007).

Socio-technical niches are emerging new technologies that serve as a source of transformative ideas and capabilities. These also provide an environment conducive to revolutionary alternatives, which may not be competitive against the selection environment prevailing in the regime. The success of the socio-technical niche depends on powerful role players that mobilise widespread social legitimacy by persuading a variety of constituencies on different terms. In this manner, niches compete with and beat incumbent regimes (Lopolito *et al*., 2013; Smith *et al*., 2010).

Socio-technical regimes include specific policies, technologies, institutions, practices and behaviours. The socio-technical configurations in regimes are established as the stable and dominant way of realising a particular societal function. A regime is a dynamic structure that sustainable niches need to overcome if they are to unsettle the regime and seed a transition. Dynamics within the regime derive from partially autonomous developments within regime components, as well as responses to landscape developments (Smith *et al*., 2010).

Socio-technical landscapes include the cultural and political values, and deeply embedded socioeconomic trends within society. Acceptance of niche-innovations may require changes in consumer practices; changes in public policy to favour green options, for example carbon taxes, stricter environmental regulations, and green infrastructure investments; and reorientations of incumbent firms and investors who could use their resources to develop, market and implement green options. Without such changes green niche-innovations may continue to face uphill struggles and an uneven playing field. Landscape factors might put pressure on exiting regimes and open windows of opportunity for niches to break through and contribute to radical changes or shifts in socio-technical regimes (Markard *et al*., 2012).

The MLP approach to socio-technical transitions scrutinises the larger problem framing of innovating entire systems of production and consumption (Smith *et al*., 2010). Similarly, Smith *et al*. (2010) claim that this approach emerged out of explanations for historic transitions to new socio-technical systems; for instance, new systems of transport, food processing, and sewage disposal (see Table 2.1). Furthermore, Geels (2013) maintains that the MLP approach emerged to address environmental problems such as pollution and climate change and argues that a large-scale sustainability transition that relates to energy is essential.

This approach views sociotechnical transitions as occurring in situations in which external pressures destabilise a prevailing regime to allow for breakthroughs in the form of green niches (Araujo, 2014). The argument of Geels (2013) that a large-scale sustainable energy transition process is necessary is confirmed by the experiences of South Africa, which faces multiple challenges with its carbon-intensive energy regime.

A great deal of electricity is lost due to the long distance that it is carried to the outlying areas of South Africa (Sebitosi & Okou, 2010). Some of the residents of Mpumalanga Province where most of the coal-fired power stations are situated are experiencing health problems due to the coal mining activities (Gets, 2014). Due to the increase in electricity demand power cuts are a constant threat. South African cities, like their sub-Saharan Africa counterparts, are experiencing increased migration that puts increasing pressure on the already limited capacity of the respective local governments to provide electricity. What is more, the above-inflation hikes in electricity prices that have become a regular occurrence are making electricity more inaccessible.

These niche innovations battle against unsustainable systems that they can potentially replace or reconfigure (Geels, 2013). For instance, the use of fossil fuels to generate electricity in South Africa causes destruction of the natural environment, pollution of fresh water sources as well as air pollution. The deployment of cleaner energy technologies such as renewable energy technologies can broaden energy access and energy supply with less environmental destruction.

Several researchers have pointed out various weaknesses of the MLP approach to socio-technical transitions (Hodson & Marvin, 2010; Mattes *et al*., 2015; Oyake-Ombis *et al*., 2015). For example, the MLP approach focuses spatially mainly on national level and not on the city level. Another oversight of this approach is that there is little focus on how systemic transitions can contribute to the understanding of socio-technical transitions in an urban setting. This is a significant oversight, seeing that cities harbour an increasing number of citizens and are viewed as sites of intense economic activity and pollution (Hodson & Marvin, 2010). Above all, the MLP approach has been applied predominantly in developed countries to analyse long-term developments and major changes in socio-technical systems (Oyake-Ombis *et al*., 2015). Consequently, this study did not apply the MLP approach to socio-technical transitions to investigate the energy infrastructure change in urban informal households in South Africa.

2.3.3 The transition management approach to socio-technical transitions

According to Markard *et al*. (2012) the TM approach to socio-technical transitions combines the work of technological transitions with insights from complex systems theory and governance approaches. The guiding principles for this approach are derived from conceptualising existing sectors as complex, adaptive societal systems and understanding management as a form of reflexive and evolutionary governance. In addition, the TM approach is used as a combination of problem structuring and envisioning in multi-stakeholder arenas and also develops new coalitions by implementing agendas in experiments, evaluation and monitoring (Markard *et al*., 2012).

Rauschmayer *et al*. (2015) point out that the TM approach to socio-technical transitions is widely used to ground the governance of sustainability transitions in Europe scientifically. The TM approach acknowledges the importance of spatiality. Furthermore, Nevens *et al*. (2013) highlight several characteristics of this process-oriented framework, namely: long-term thinking, the consideration of numerous spheres and diverse stakeholders, and a focus on learning and system innovation while maintaining a wide playing field. On the one hand, the inclusive nature of this approach could be beneficial to the current study; on the other hand, the limited use of it in sub-Saharan Africa could pose a challenge as the energy infrastructure situation is different to that found in Europe, where this approach has been used extensively.

Critics have pointed out a few shortcomings of the TM approach to socio-technical transitions. The TM approach is criticised for its gullibility regarding power, politics and democratic legitimacy (Raushmayer *et al*., 2015). It is very probable that being naïve about the impact that decision- and policymakers may have on the energy transition process could render this approach useless to understand the energy transition process of particularly urban informal households. In addition, the TM approach does not monitor or assess the impact that transition processes have on the individual. It is for these reasons that this study did not apply the TM approach to socio-technical transitions to investigate the energy infrastructure transition in urban informal households in South Africa.

2.3.4 The technological innovation systems approach to socio-technical transitions

The TIS approach to socio-technical transitions involves the emergence of new technologies and the institutional and organisational changes that accompany technological development. Recent TIS approach studies have changed the focus from technological innovation contributing to the economic growth of countries to new technologies as nuclei for fundamental socio-technical transitions.

The TIS approach to socio-technical transition analyses is usually used to identify drivers of and barriers to innovation and also focuses on interactive interplays among actors in different locations, and strives to include all technological actors (Markard *et al*., 2012). Mattes *et al*. (2015) argue that the dominant theories on socio-technical transitions, such as the TIS approach, have not sufficiently addressed spatial issues, which is surprising considering the vast differences in local energy transitions among different countries, cities and socio-demographic areas. Seeing that the current study focused on urban areas in particular, the TIS approach was thus not applied.

2.3.5 The regional innovation systems approach to socio-technical transitions

The RIS approach to socio-technical transitions involves the interaction of various subsystems that results in an energy reorganisation process on a regional or city level. This approach captures the intricacy and the collaborative nature of these changes. The level of analysis includes institutions as rules of the game, organisations as collective actors and individual actors. This approach also includes factors that influence innovation directly as well as indirectly such as economic structures, education systems and political initiatives.

The RIS approach to socio-technical transitions depicts both technological learning and the economic, political and social changes that are involved in this process of change. This approach extends over the following spheres, namely: education and science, policy and decision makers, industry, intermediaries and finance. Above all, when this approach is used to analyse energy transition processes, it also includes public administration and civil society, for example NGOs and concerned citizens, as sub-sectors (Mattes *et al*., 2015).

It is important to focus on the small-scale regional level because there are clear indications of the growing importance of the involvement of stakeholders at the local levels in energy transformation (Mattes *et al*., 2015). A case in point is the deployment of DRE technologies such as solar water heaters and small-scale PV electricity generators to energy-intensive corporations and households in South Africa. Initiatives such as these could increase the energy access and energy security of energy-intensive organisations and individual households as well as save them money on potentially high electricity bills.

The stakeholders in these various subsystems and their roles in the energy infrastructure transition, of specifically urban informal households, vary considerably but should be of equal importance. The strategy to successfully transform energy infrastructure of urban informal households were informed by eight case studies that showcased how unique public-private partnerships that operate renewable energy projects can increase energy access in developing countries (Sovacool, 2013). Some of these roles may be as follows:

2.3.5.1 Education and science

Education concerning energy issues should be included in the syllabus from pre-primary school level till high school level. Furthermore, funding should be allocated to research on how DRE technologies can increase energy access in specifically urban informal households. Consequently, learners and tertiary students would be aware of DRE technologies that could potentially increase energy access in their communities. For example, universities play an important role in promoting learning and training through constant interactions with households and energy supply companies in the Zambian PV project (Sovacool, 2013).

2.3.5.2 Industry

REN21 (2015) suggests that the private sector could increase its financial support for DRE technology that services off-grid, low-income customers, who are becoming a fast-growing market for goods and services. A case in point is HIBS, a private company, that provided one-third of the initial capital outlay for the Cinta Mekar micro-hydro project in Indonesia. HIBS also agreed to underwrite any cost overruns in exchange for 50% of the projects revenues and profits (Sovacool, 2013).

2.3.5.3 Policy and decision makers

Political parties could encourage energy champions and establish energy committees that would actively engage in electricity policy issues as well as increase knowledge of climate change issues. Furthermore, political parties could support, draft and implement policies that would make the deployment of DRE technologies easier. Policy and decision makers could also gain grass-roots support for newer distributed technologies that could generate cleaner energy and benefit their constituency.

2.3.5.4 Public administration

Baker (2011) suggests that the national DoE provide meaningful stakeholder engagements with all relevant parties. A recent example of a flawed DoE engagement process is the lack of proper consultation with the solar water heating manufacturing clusters of South Africa prior to the request for bids for the manufacture, supply, delivery, and warehousing of solar water heaters (Creamer, 2015). As most of the power generation in South Africa is coal based (Sebitosi & Okou, 2010) the national Department of Health could commission studies that might ascertain the extent of the harm to public health that coal mining pollution causes and to institute an urgent programme of action to minimise and manage the impact of this. An example of a productive public-private partnership is China's Renewable Energy Development Programme that partnered renewable energy manufacturers, national and provincial governments with the World Bank to create a self-sustaining market for SHSs (Sovacool, 2013).

Municipalities are in a unique position to facilitate and increase the energy transition process in small communities; for instance, thousands of municipalities in the United States of America and Europe that are using cleaner energy technologies (REN21, 2015). Municipalities can also support unconventional, innovative schemes that could raise funds for renewable energy projects. For example, the City of Johannesburg Municipality has started to sell green bonds to raise funds for the municipality's clean energy projects. The Project Management Office that was established to coordinate China's Renewable Energy Development Programme is responsible for selecting participating companies, authorising grant payments, and developing awareness programmes to promote renewable energy. This would be an ideal role for municipalities.

2.3.5.5 Intermediaries

Intergovernmental organisations could increase their financial and logistical support that focus on increasing energy access, specifically for developing countries. For example, the Africa-European Union Renewable Energy Corporation Programme contributes to the African-European Union energy partnership's political targets of increasing renewable energy use and bringing access to modern energy an additional

100 million people by 2020. Intergovernmental organisations could also provide policy advice, private sector cooperation, project preparation support activities and capacity development. (REN21, 2015). Another example is the *Sustainable Energy for All* initiative of the United Nation's Secretary General, which mobilises global action to achieve universal access to modern energy services, double the global rate of improvement in energy efficiency and double the share of renewable energy in the global energy mix by 2030 (REN21, 2015).

2.3.5.6 Finance

An increasing number of financial and ownership options may increase the deployment of renewable energy technologies. For example, public-private partnerships are increasingly being used to advance renewable energy deployment in municipalities where renewable energy resources are bountiful, but budgets are limited. Furthermore, in some countries, several large employers have launched a bulk corporate purchasing programme to reduce the installation costs for their employees significantly (REN21, 2015).

Sovacool (2013) details several case studies how pro-poor public-private renewable energy partnerships expand energy access in developing countries. Three solar PV energy supply companies in Zambia partnered with an international donor and the national government to make SHS affordable and profitable by using a 'fee-for-service' finance model. The solar lantern project in India partnered banks, an infrastructure fund, a local lighting company, entrepreneurs that utilised a hybrid finance model which included microfinance to provide cheaper and cleaner lighting alternatives (Sovacool, 2013).

2.3.5.7 Civil society

Civil society could play a greater role in the energy sector and also propose future energy scenarios. For example, the South African Civil Society Energy Caucus is an informal network of individuals and organisations that work on energy issues in South Africa. This entity focuses on how energy issues intersect with the degrading environment, as well as social and health impacts. It also lobbies government to reach certain targets, for example 50% of energy supply from renewable energy and a solar water heater of one square metre per person within 20 years (Baker, 2011).

Furthermore, public organisations can also promote and invest in community-owned public renewable energy projects that could benefit the community. The community receives 50% of the profit that is generated from the Cinta Mekar microhydro project in Indonesia which they build in partnership with public and private organisations. All households in this community gained access to affordable electricity and earned revenue from selling excess electricity to the main grid (Sovacool, 2013).

The argument that the RIS approach to socio-technical transitions is the most fitting socio-technical transition approach to facilitate the energy infrastructure transition in urban informal households builds on the above ideas proposed by Mattes *et al*. (2015). Based on the insights of this approach, the current study interprets energy infrastructure transition processes in urban informal households as a conjunction of changes, decisions and bargaining processes occurring within and among the subsystems involved. Along the same lines, Mattes *et al*. (2015) suggest that a change in the energy infrastructure may be triggered, pushed or hindered by subsystem, and that the interaction between them increases the necessity to coordinate this process of transition (Mattes *et al*., 2015).The engagement of a wide range of stakeholders, together with the focus on the spatial dimension of the RIS approach to socio-technical transitions, makes this approach ideal for the transition of energy infrastructure in urban informal households.

Several researchers have noted the leading role that the private sector, NGOs, and civil society have played in the transition of energy infrastructure by advocating for the wide spread roll out of renewable energy sources (Practical Action, 2014; Taylor *et al*., 2014). In the last few years, large investments have been made by the private sector in the renewable energy sector in South Africa. For example, the South African Energy Minister announced that private sector investment in renewable energy projects had reached R193 billion in 2015 (Brown, 2015).

NGOs such as Greenpeace Africa have been in the forefront of making the public aware of the harmful impacts of the energy carriers and fuel types that are commonly used by urban informal households and the advantages of the use of renewable energy (Gets, 2013). However, the South African national government's response to the deployment of renewable energy technologies in order to increase energy access has not been adequate for a number of reasons. Baker (2011) points out that the consultation process that the DoE uses when making decisions on energy policy issues is not open and transparent. Furthermore, the renewable energy sector does not enjoy the full political backing that it deserves as compared to the highly subsidised fossil fuel electricity-generating sector (Baker, 2011).

The participation of a wide-range of stakeholders in the transition process is vital for a sustainable transition process that will function over many years. Markard *et al*. (2012) argue that energy infrastructure transitions should be conceptualised as socio-technical transitions because of the numerous stakeholders that are involved in the process. Hodson and Marvin (2010) observe that these stakeholders, such as utilities, municipalities, consumers, and businesses, view the operations of energy infrastructure from various angles in respect of different issues, including economic growth, climate change and resource consumption. For example, Eskom may view the availability and consumption of the coal resource to be as very important because the majority of electricity is being generated with coal (Sebitosi & Okou, 2010). Many cities and municipalities, for example Cape Town, have begun preparing programmes of climate change adaptation in an attempt to manage existing and expected local climate risks (Taylor *et al*, 2014).

2.4 Energy-related theories and concepts

In this section, the energy ladder theory, the leap-frogging phenomenon and the multiple fuel-use model are discussed to gain a better understanding of what factors influence households to use specific fuel types for energy services such as cooking, lighting, water heating, space heating, and operating household appliances. This section also investigates the factors that may influence the deployment of cleaner technologies for these energy services.

2.4.1 The energy ladder theory

The energy ladder hypothesis is one of the foremost energy transition theories. It suggests that households gradually ascend an ‘energy ladder’ as their socio-economic conditions improve (Lay *et al*., 2013). To put it another way, low-income households that use firewood and paraffin to provide various energy services will start using electricity and gas when the household income increases.

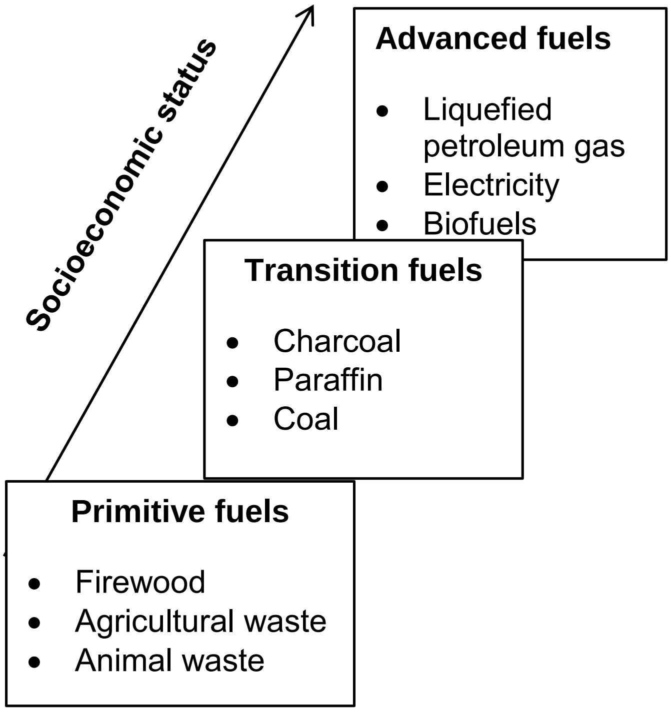

Figure 2.2: An illustration of the energy transition process according to the energy ladder theory
Source: Adapted from Van der Kroon et al., 2013

The three levels of the energy ladder theory are illustrated in Figure 2.2. The energy ladder begins with primitive fuels such as firewood, agricultural waste and animal waste, moves through to transition fuels such as paraffin, coal and charcoal, and then moves on to modern commercial fuels such as liquefied petroleum gas, biofuels and electricity; as incomes rise and urbanisation grows (Burke & Dundas, 2015; Vermaak *et al*., 2014; Lay *et al*., 2013).

According to this theory, households fall into one of these three levels, depending on the household's energy needs, as well as the benefits that these energy services can provide (Vermaak *et al*., 2014). Lay *et al*. (2013) argue that the energy ladder theory was motivated by the huge differences in energy use between wealthy and poor countries, as well as among households with differing incomes within industrialising countries. Van der Kroon *et al*. (2013) suggest that these differences in energy use patterns among countries can be ascribed to disparities in their economic status.

Hiemstra-van der Horst and Hovorka (2008), however, argue that the link between the specific fuel type that households decide to use for an energy service and their income level may not be as strong in the urban areas of developing countries as presumed by the energy ladder. Furthermore, the suggestion by the energy ladder theory that wood is used by only low-income households, is an oversimplification. An example is that in Maun, Botswana, households from all income groups make use of firewood to provide energy services despite the commercial use of alternative fuel types and energy carriers (Van der Kroon *et al*., 2013).

A more recent example that reaffirms that an increase in household income does not necessarily lead to a reduction in residential biomass energy use is a national-level longitudinal study that included 175 countries during 1990-2010 (Burke & Dundas, 2015). This study found that an increase in female participation in the labour force caused a reduction in the use of biomass energy use. This indicates that if women do not have time to collect firewood, these households will use less firewood for various energy services for example cooking. Even though an increase in household income leads to an increase in the adoption of modern fuel types such as liquefied petroleum gas and electricity, this does not mean that these households will use less biomass energy. This is in line with the multiple fuel use model of household energy use according to which higher incomes see households adopt modern fuel types while not commensurately phasing out traditional energy fuel types such as biomass (Burke & Dundas, 2015).

Hiemstra-van der Horst and Hovorka (2008) recommend that broader aspects that may influence the choice of fuel type, other than just household income, should be considered. One of those influences could be the development and implementation of renewable energy policies and ambitious targets of a locality. For example, if a municipality sets a target to generate 100% of its electricity from renewable energy, like an increasing number of municipalities and cities worldwide are doing, the uptake and use of renewable energy technologies by all citizens may not depend on household income (REN21, 2015). The introduction and steady uptake of distributed solar energy technologies may make it possible for every person to access the technology required to satisfy modern energy needs. For this to happen decision and policy makers need to support the deployment of distributed clean energy technologies to all households.

An example is Stellenbosch Municipality that includes informal settlements where people live without municipal services, such as water and electricity (Treurnich, 2016). The most urgent need amongst residents of one such informal settlement, Enkanini, was electricity. The municipality could not provide residents with on-grid electricity immediately, and decided that the provision of solar energy could be a viable alternative to conventional electricity. For the vision to work, four steps were taken to remain compliant with legislation while simultaneously meeting the needs of Enkanini residents (Treurnich, 2016).

Firstly, the municipality's Indigent Policy was amended to appoint service providers to provide off-the-grid electricity and to pay them the free basic electricity subsidy (Department of Minerals and Energy, 2003). Secondly, procurement processes were followed to appoint these service providers (Treurnich, 2016). Next, community buy-in was obtained. Finally, a service level agreement was signed in April 2015 where-after the free basic electricity subsidy was paid directly to the service provider (Treurnich, 2016).

2.4.2 The leap-frogging phenomenon

In defining leapfrogging, a number of researchers have emphasised the advantages that this phenomenon may have for industrialising countries that have limited energy supply infrastructure to increase energy access to all their citizens while not increasing their carbon footprint. Gallagher (2006:383) states that, *"industrializing countries can avoid the resource-intensive pattern of economic and energy development by leapfrogging to the most advanced technologies available, rather than following the same path of conventional energy development that was forged by highly industrialized countries".* What Gallagher (2006) means is that developing countries can use low carbon energy technologies to grow their economies, unlike developed countries whose economic development depended on fossil fuel generated energy that was characterised by a high carbon emission rate.

Davison *et al*. (2000:2) define leapfrogging as, *"the implementation of a new and up-to-date technology in an application area in which at least the previous version of that technology has not been deployed"*. They assert that leapfrogging happens when an innovative energy technology instead of conventional energy technologies is used to generate energy. According to Perkins (2003:178), there is general agreement that *"leapfrogging implies a development strategy for industrializing countries to bypass the 'dirty' stages of economic growth through the use of modern technologies that use fewer resources and/or generate less pollution".* Davison *et al*. (2000) and Perkins (2003) thus suggest that developing countries have the opportunity to leapfrog into the 21st century without retracing the now discredited resource-intensive economic development pathway that was used by industrialised countries.

However, in order for industrialising countries to follow a growth path that is mainly independent of fossil fuels, the following five conditions should be met: (i) a shift towards clean production approaches; (ii) action from the outset; (iii) technology transfer from developed economies; (iv) strengthening of the incentive regime; and (v) international assistance (Perkins, 2003).

Along the same lines Gallagher (2006) states that developing countries can avoid the resource-intensive pattern of economic and energy development by leapfrogging to the most advanced energy technologies available, rather than following the same path of conventional energy development that was forged by the highly developed nations. However, this author suggests that in order to increase the technological capabilities of developing countries, foreign firms need to be incentivised to transfer the cleaner technologies. What is more, Perkins (2003) insists that by leapfrogging to a cleaner production paradigm, developing countries may also avoid becoming locked into hydrocarbon intensive technologies as has happened in developed countries.

Gallagher (2006) identifies two different types of leapfrogging that are relevant to this research: (i) leapfrogging by skipping over generations of technology; and (ii) skipping over generations and leaping further ahead to become the technological leader. For instance, the first kind of leapfrogging has been observed in the telecommunications industry where many African communities adopted cellular phones without ever using landlines (Szabo et al., 2013; Swilling and Annecke, 2012; Sebitosi and Okou, 2010).

Similarly, China skipped over wire-based communication technology to adopt cellular phones on a massive scale (Gallagher, 2006). An example of the second kind of leapfrogging is illustrated by the performance of the Korean steel industry, which not only leapfrogged up to, but also eventually surpassed, the former top producers of steel to become one of the technological leaders of this industry (Gallagher, 2006).

According to some researchers the first kind of leapfrogging is possible in the energy infrastructure arena as well. Fischer-Kowalski and Swilling, (2011:67) assert that *"…there is a space for innovation that does not exist in countries where existing infrastructure are a sunk cost and difficult to change…"* In other words, the lack of access to the main electricity grid by some urban informal households is an opportunity for the education and science sphere, the industrial sphere, the policy and decision making sphere, the public administration sphere, the industrial sphere, intermediaries, the financial sphere as well as civil society, to facilitate the deployment of DRE technologies.

Sub-Saharan African countries can build energy sectors based on distributed power generation and distribution (often referred to as distributed power), exploiting their own indigenous renewable energy sources and thereby reducing transmission losses and creating jobs (Thorne & Felten, 2014). Furthermore, the 'leap-frogging' of the main electricity grid to distributed cleaner energy sources for energy supply may speed up the access to energy for urban informal households in particular.

However, there are several requirements for a new technological application, such as distributed solar energy technology, to be successfully implemented in developing countries. Davison *et al*. (2000) argue that it requires the application of implied knowledge regarding the organisation and management of the technology and its application to the contextual environment in which it is to be used. In addition, the development of appropriate human resources skills is required. Furthermore, demonstration pilot sites to test new technologies and applications, innovative policies and tariff structures and new approaches to demonstrating the impact of such methods on the economic, social and cultural development of affected areas might increase the successful uptake of these technologies. Besides, when leapfrogging one must identify both technical and social concerns and ensure that the new technology is not embedded to the detriment of social considerations. Above all, municipalities should adopt and implement policies that incentivise energy production in order to make the ownership of small scale embedded generators more attractive (Breytenbach, 2015).

It is very possible for urban informal households to leapfrog the dominant energy carrier, namely: electricity from the main grid generated mostly from burning fossil fuels, and introduce renewable energy technologies such as solar home systems (SHSs). With increasing growth putting pressure on electricity provision in South Africa, the country can avoid the carbon-intensive economic development growth path followed by developed countries, which grew their economies and increased their living standards on fossil fuel energy, by rolling out renewable energy technologies such as SHSs to its citizens. The distributed nature of photovoltaic Solar Home Systems may make access to energy more viable, especially for the many urban informal households that lack access to the main electricity grid.

In contrast, several researchers pointed out the weaknesses of leapfrogging. Davison *et al*. (2000) argue that the fact that technology leapfrogging exist alone does not guarantee or even encourage prosperity. This depends on the policy environment, how leapfrogging is operationalized who is involved and who undertakes to support initiatives. Perkins (2003) corroborates this and says that political will and long-term financial and technological support are vital to assist the leapfrogging process. If countries do not attempt to update technologies, they face exclusion from mainstream global economic trends, continuing deprivation and poverty (Davison *et al*., 2000). Ultimately there are no alternatives to leapfrogging.

2.4.3 Multiple fuel use model

Several researchers argue that household energy transition, particularly in developing countries, happens according to the multiple fuel use method (Yonemitsi *et al*., 2014; van der Kroon *et al*., 2013; Hiemstra-van der Horst & Hovorka, 2008). The multiple fuel use method suggests that when the income of households increases, they may adopt new advanced fuels and technologies that partially substitutes traditional fuels. Furthermore, households may switch back to traditional fuels even after adopting modern energy carriers. Figure 2.3 illustrates the process whereby households use multiple fuels at the same time. This phenomenon is also known as fuel stacking.

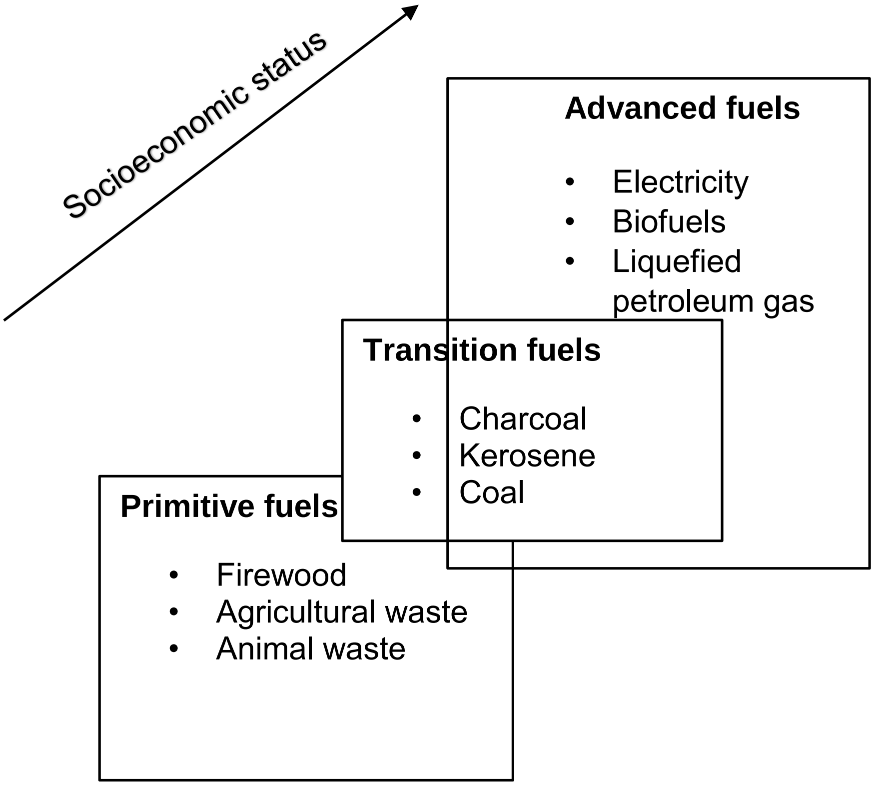

Figure 2.3: The energy transition according to the multiple fuel use model
Source: Adapted from Van der Kroon *et al*., 2013

According to some researchers, the multiple fuel use patterns in households are the result of complex interactions among economic, social and cultural factors in developing countries (Ahmad & De Oliviera, 2015; Cheng & Urpelainen, 2014; Yonemitsu *et al*., 2014). These researchers suggest several reasons why fuel stacking occurs in households, specifically in developing countries. Firstly, the irregular and variable income flows of poor households may prohibit the regular consumption of advanced energy types such as electricity and gas. These households therefore apply specific budget strategies in order to maximise their fuel security. Secondly, fuel-stacking behaviour is caused by the unreliable supply and availability of fuel types and energy carriers. An example is the frequent electricity outages that occur across South Africa, which force households to have back-up fuel for example gas and wood, available for cooking, lighting, water heating, space heating and operating household appliances.

Thirdly, commercial energy prices might make the preferred fuel temporarily unaffordable (Cheng & Urpelainen, 2014; Yonemitsu *et al*., 2014); for example the above-inflation electricity price hikes in South Africa over the past couple of years.

Finally, some traditional methods of cooking are often rooted in local cultures, which may prevent the use of modern fuels (Yonemitsu *et al*., 2014). For example, a barbecue in South Africa is a very popular method of preparing meat on a wood or charcoal fire. The use of wood and coal is not limited to low-income households for this popular preparation method but is practised by people from all income levels.

In brief, these widely varying reasons for multiple fuel use relate to how urban informal households make choices about the fuel type or energy carrier that they use for a specific energy service.

2.5 Definitions of energy access

This section explores the concept of energy access. Defining energy access appears to be contentious and a universal definition for this concept does not exist (Mensah *et al*., 2014). Araujo (2014) agrees that even though there is increasing attention on energy transition, there is no universally accepted definition for the concept of energy access. Likewise, Mensah *et al*. (2014) remind us that definitions of energy access may be subjective and that they do not consider cultural practices.

According to the energy ladder theory (see Section 2.4.1) the level of energy access, required by households to satisfy modern society needs, is 2000 kilowatt hours per person per year (Vermaak *et al*., 2014). Energy access has been defined as the availability of electricity in areas reached by grid or off-grid electricity solutions. In the case of off-grid solutions, electricity is provided by a distributed power source or a renewable energy device (Brew-Hammond, 2010). Practical Action (2014:42) defines energy access as, *"… the full range of energy supplies and services required to support human, social and economic development are available to households, enterprises and community service providers"*. In other words, Practical Action (2014) believes that energy access transpires when households and organisations that serve society have sufficient sources of energy to fulfil their socio-economic needs.

According to the DoE (2013:viii), the concept of universal household access to energy requires *"…all households to have access to modern energy sources which includes electricity and a range of renewable energy sources while it excludes health and environmental hazardous energy sources such as paraffin, candles and firewood"*. The DoE (2013) insists that energy access come about when all households have access to clean energy sources that do not pose an environmental or a health hazard to people. Furthermore, the International Energy Agency (2013) defines energy access as *"a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing consumption over time to reach the regional average."* What the International Energy Agency (2013) means is that energy access occurs when a household has the right to use clean energy fuel types to cook and an electricity connection as well as the ability to increase its energy consumption use to the average of the area where it resides.

In the current study, the energy access definition of Practical Access (2014) was combined with that of the DoE (2013), because the reliability and affordability of electricity are vital to accruing the benefits of accessing energy sources. This definition excludes fuel types such as coal, wood, and paraffin that may cause harm to the health and safety of households that commonly use them. For the purpose of this study, energy access was defined as follows: *"Households and the organisations serving them are able to source clean affordable energy at all times in order to provide energy services such as cooking, lighting, water heating, space heating, and the operation of household appliances."* Accordingly, this study attempts to investigate whether the energy infrastructure transition processes of urban informal households might increase their energy access by specifically introducing DRE technologies that could be used for cooking, lighting, water heating, space heating, and operating household appliances.

2.6 Benefits of energy access

Various researchers argue that energy access is crucial for the growth of a developing country's economy and the well-being of its citizens (Thorne & Felten, 2014; Sagebiel & Rommel, 2014; Castro-Sitiriche & Ndoye, 2013; Musango, 2014). A recent report on developing countries, for example, states that a 1% increase in per capita electricity consumption increases the Human Development Index by 0.22% (Ouedraogo, 2013). Similarly, access to electricity can create more jobs, allow longer study periods, improves medical care through refrigeration and free women from manual laundry duties (Hancock, 2015; Pode, 2013). In other words, access to clean energy sources is vital for the social and economic development of countries. Therefore, the United

Nation's *Sustainable Energy for All* initiative aims to attain universal access to energy for all (Mensah *et al*., 2014).

When households have access to safe, clean energy, it has numerous positive effects on their social and economic spheres such as health and education benefits, gender equality and increased economic activities (Tait & Winkler, 2012). Practical Action (2014) notes that energy access, specifically when facilitated by renewable energy technologies, can benefit sub-Saharan African communities in the attainment of the Millennium Development Goals. For example, energy access that is facilitated by renewable energy technologies could reduce poverty by decreasing the time spent to collect wood. Energy access could also decrease hunger by providing energy services; for example, refrigeration that reduces food and crop waste. In addition, energy access may facilitate universal primary education through improved cooking facilities, which may open up time for education. Energy access provided by these modern fuels and energy carriers could also encourage gender equality and empowerment of women by allowing women and girl children more time for education or to earn a living (Practical Action, 2014).

Besides, energy access that is facilitated by relatively cleaner energy fuel types and energy carriers decrease smoke inhalation when used to cook, heat water or heat space indoors. The use of these fuel types and energy carriers also facilitates environmental sustainability by reducing deforestation and greenhouse gas emissions.

What is more, energy access increases the use of communication devices, such as radios and cellular phones specifically in developing countries. This communication facilitates the formation of partnerships by improving the frequency of dialogue information exchanges between individuals and communities (Practical Action, 2014). PV systems can provide Information and communication technology that people can use to operate internet cafes and radio stations. In addition, this energy service reduces the reduced travel time and expenses associated with communication banking and bill paying (REN21, 2015).

DRE technologies such as SHSs, cleaner biomass stoves, and solar water heaters, are increasing energy access to households that lack existing energy infrastructure across the developing world. These DRE systems allow access to essential energy services, provide new income-generating opportunities and facilitate the improvement of existing opportunities in the following ways (REN21, 2015): For example, SHSs provide lighting to individual households and enable them to operate household appliances such as television sets and radios. Furthermore, small-scale PV systems provide lighting that enables night-time and operation of stalls (REN21, 2015). In addition, these systems allow restaurants and shops to extend their operating hours after sunset and for manufacturing activities to take place at night. For example, an evaluation of China's Renewable Energy Development Programme concluded that the deployment of SHS had a positive effect on household income, improved family communication levels, increased workable hours, and improved access to information via radio and television (Sovacool, 2013).

Additional benefits of having access to reliable lighting service are the increased safety of residents and enhanced socialisation. Safety is a large concern to informal households that may be prone to break-ins and theft at night because of the unsteady architecture of their dwellings. Therefore, an accessible energy technology that could provide affordable and reliable lighting services to urban informal households could help alleviate safety concerns.

PV technology can also provide a refrigeration service that enables less wastage of perishable items such as meat, fish and agricultural products, and a safe storage for medication. As a result, less time and energy is spent on keeping goods fresh and lives can be saved with the medication that is stored (REN21, 2015).

Solar water heaters improve the comfort in homes and commercial buildings. Solar cookers or cleaner biomass stoves provide a cleaner and more cost-effective cooking service. Saving time in wood collection for heating water and cooking and improving the health of users are some of the additional benefits of using these DRE technologies (REN21, 2015). I am of the opinion that many women would view solar cookers as a more dignified manner to cook meals for their family than having to collect wood to prepare the meal.

Conversely, renewable energy technologies lack several desirable qualities of fossil fuels. The value of energy return on investment are substantially lower for renewable energy than that of fossil fuels (Hall *et al*., 2014). Energy return on investment is a means of measuring the quality of various fuels by calculating the ratio between the energy delivered by a particular fuel to society and the energy invested in the capture and delivery of this energy. Furthermore, the quality of electricity that renewable energy produce is less reliable and consistent. In addition, electricity that is generated from renewable energy technologies lacks transportability and is not sufficiently “energy dense”. Above all, there is a lack of renewable energy infrastructure that is required to meet current societal needs (Hall *et al*., 2014).

Despite these adverse attributes of renewable energy, it is highly likely that accessing clean energy may improve the socio-economic conditions of urban informal households and enable them gain access to economic opportunities. Besides increasing the standard of living and stimulating economic activities, energy access may also lead to important innovations in developing countries (Friebe *et al*., 2013). Appendix H analyses renewable energy technologies, in particular distributed PV electricity generators, which could serve as alternative and/or supplementary sources that provide energy services for urban informal households. This section discusses the regulatory framework as well as the drivers of renewable energy solutions in South Africa. The four DRE technologies are the ECOlite solar system, Solar home system, solar water heater, and the solar bottle bulb.

2.7 Summary

In Section 1.1, it was argued that the solar energy potential that exists in Africa can increase energy access. Along the same lines, Chineke and Ezike (2010) claim that between 3000 and 7000 watt/m^2/day can be used for PV applications on the African continent. However, Hermann et al. (2014) demonstrate that even though the five African regions (Northern, Western Southern, Eastern and Central Africa) have similar areas, the overall potential of renewable energy sources in each of these five regions is relatively different. Consequently, the regions need different strategies to develop their renewable energy resources.

It is argued that the RIS approach to socio-technical transitions (see Section 2.3.5) can be used to make the deployment of small-scale PV electricity generators feasible in areas that display the most potential. This strategy can lead to home-grown energy solutions. As described in Section 2.3.5, the RIS states that the interplay among the different subsystems (education and science, industry, policy and decisions makers, public administration, finance, intermediaries and civil society) can provide a useful starting point in understanding the introduction and uptake of renewable energy technology, such as small-scale PV electricity generators, in different areas (Mattes *et al*., 2015).

The RIS approach to socio-technical transitions is the preferred application to the energy infrastructure transition of urban informal households, because of the multiple stakeholder involvement in the process. The large-scale deployment of DRE technologies offers an unprecedented opportunity to accelerate the transition to cleaner energy technologies. By increasing access to cleaner technologies that provide various energy services society will benefit from better socio-economic conditions and improved public health. The decentralised nature of many of these renewable energy technologies could result in numerous employment opportunities in communities where these technologies are deployed. The sustainable uptake of renewable energy technologies can be achieved by establishing and strengthening institutional, financial, legal, and regulatory support mechanisms for renewable energy deployment.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

"I want to understand the world from your point of view. I want to know what you know in the way you know it. I want to understand the meaning of your experience, to walk in your shoes, to feel things as you feel them, to explain things as you explain them. Will you become my teacher and help me understand?" (Spradley, 1979:34)

3.1 Introduction

This chapter outlines the research design, methodology and processes that were undertaken in order to answer the two research questions namely: *"What are the current energy flows of urban informal households in Kayamandi?"* and *"To what extent* *can renewable energy technologies contribute to the provision of energy services in urban informal households?”*. The chapter first introduces the overall research design and research methodology that informed the study and then considers each research question in terms of the research instruments, data-gathering methods, research process and data analysis relevant to the question.

3.2 Research Design

In the view of Bryman *et al*. (2014:382) a research design is *“a framework for the collection of and analysis of data and the choice of the research design reflects decisions about priority being given to a range of dimensions of the research process.”* In other words, Bryman *et al*. (2014) believe that a research design provides the structure that guides the use of research methods and the subsequent data that is collected (Bryman *et al*., 2014). Research designs are broadly classified into experimental, quasi experimental and non-experimental designs (Jalil, 2013). In the current study, a non-experimental design that described the relationship between an intervention and its effects on the population of interest, as described by Jalil (2013) was used. A case study, which is an example of a non-experimental design, was used in the study.

A methodological triangulation approach that made use of both qualitative and quantitative research methods to determine whether converging, inconsistent or contradictory evidence might be obtained was employed in this study (Jalil, 2013; Yin, 2009). One of the advantages of methodological triangulation is that it improves the reliability of the study results because the bias or unreliability in one research method can be balanced out by the use of another (Yin, 2013).

Bryman *et al*. (2014) commented that a methodological triangulation approach integrates quantitative and qualitative research methods within a single project. Qualitative research usually emphasise words in the collection and analysis of data while quantitative research emphasises quantification during these processes (Bryman et al., 2014; Jalil, 2013). The quantitative research method that was used in the study was a questionnaire (see Appendix A). The questionnaire was used to investigate what fuel types were commonly used by urban informal households for different energy services such as lighting, cooking, water heating, space heating and operating household appliances. In addition, the questionnaire attempted to gauge the household expenditure on the different fuel types per month. Some of the benefits of using the questionnaire were that it was relatively easy to administer and that a large number of questions could be included (Jalil, 2013). However, this quantitative research method was more difficult to develop as compared to the qualitative research method, namely direct observation that was also used to answer the first research question. Consequently, the researcher consulted numerous books, journal articles, and reports (Bryman, 2014; DoE, 2013; Jalil, 2013; Daniel, 2012; Andres, 2012) to become acquainted with the steps to develop and administer a questionnaire on people's energy-use habits.

Two qualitative research methods were used in this study, namely the semi-structured interview (see Appendix B) and direct observation. Some of the advantages of qualitative research methods are that they capture more depth, provide insight into how and why questions, emphasise validity and are relatively easier to develop than quantitative research methods. Furthermore, qualitative research methods allow for the study of the meaning of people's lives under real-life conditions. However, some of the disadvantages of qualitative research methods are time-consuming with regard to capture and analysis of data, they are more subjective compared to quantitative research methods, and they are very demanding to apply (Jalil, 2013; Yin, 2011).

The methodological triangulation approach thus allowed the researcher to capitalise on the strengths and offset the weaknesses of both the quantitative and qualitative research methods (Bryman *et al*., 2014). Above all, this approach enhanced the reliability of the data that was obtained as consistencies were confirmed and inconsistencies highlighted (Bryman *et al*., 2014). A summary of the research design of the current study is presented in Figure 3.1.

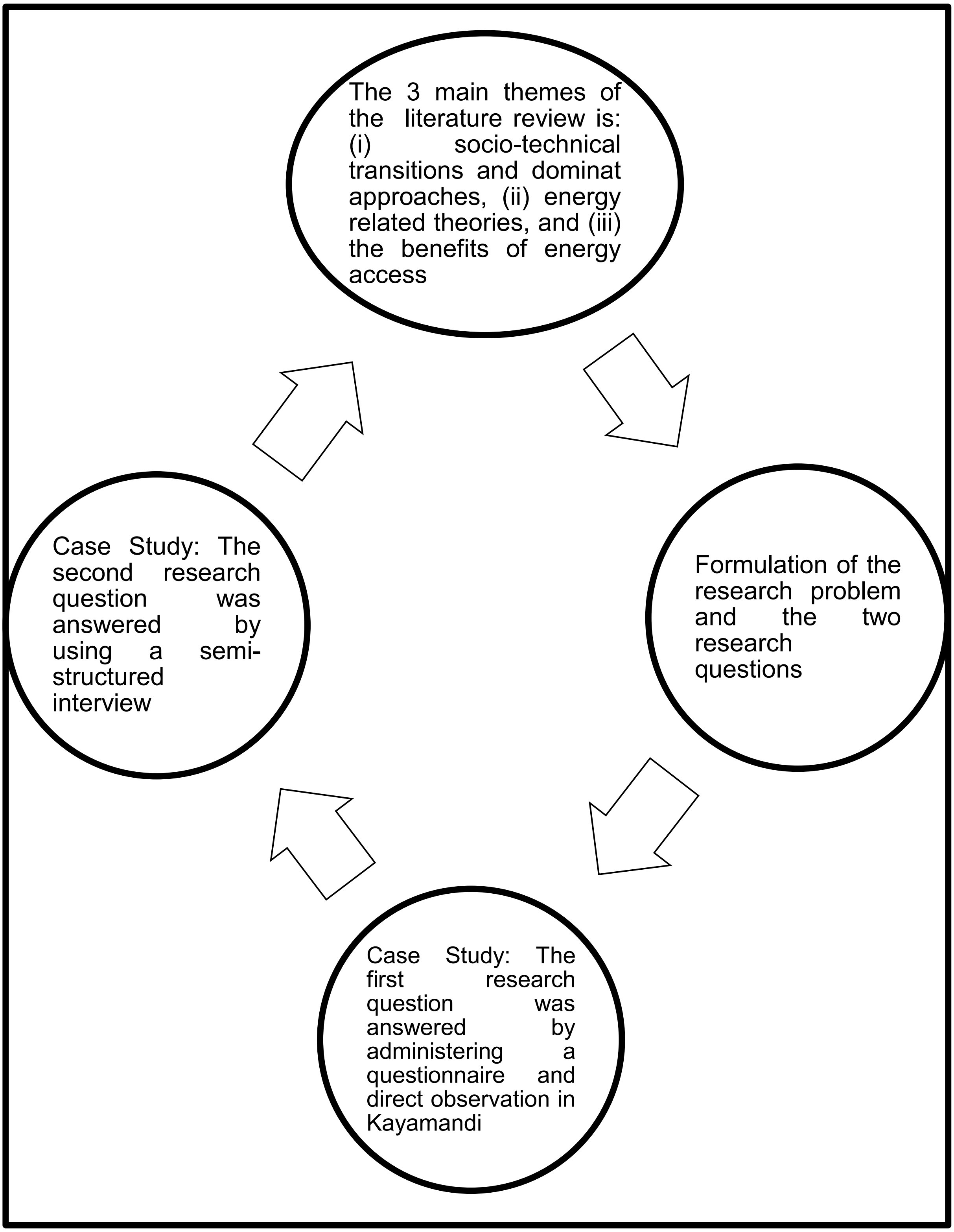

Figure 3.1: The research design that was used in the current study

3.3 Research methodology and process

This section outlines the data collection tools, the research processes, and the data analysis for the two research questions of the current study. The study was conducted in accordance with Stellenbosch University's Framework Policy for the Assurance and Promotion of Ethically Accountable Research (Stellenbosch University, 2013). The privacy of the case study participants was protected by keeping their responses anonymous and confidential, and the researcher offered an electronic or hardcopy of the Framework Policy for the Assurance and Promotion of Ethically Accountable Research at Stellenbosch University to all research participants on request.

3.3.1 Research question 1

What are the current energy flows of urban informal households in Kayamandi?

3.3.1.1 Case study

Jalil (2013:12) defines a case study as *"an intensive analysis of a single unit"*. What Jalil (2013) means is that a case study is a rigorous examination of a single element. The element under investigation in this case study was the informal households that exist in Kayamandi. In this study an informal household referred to a group of people or a person that resided in a structure that was constructed with wood panels, corrugated iron, cardboard, paper, and nails, sometimes with glass windows, on the premises of formal households, private land or government land without receiving the necessary authorisation.

This study used the case study method to shed light on the energy flows of urban informal households in Kayamandi for various reasons. The case study was one of the preferred approaches because this study focused on a contemporary phenomenon within a real-life situation rather than historical events. Yin (2009) also advises the use of case studies when *'what'* research questions are addressed as in the first research question of this study. Stake (2013) observes that a case study often includes multiple methods of data gathering which was an appropriate approach because the research took place in complex conditions and the triangulation of evidence was necessary to gain insight into the research topic (Eleftheriadis & Anagnostopoulou, 2015). Consequently, these multiple data sources enhanced the data credibility (Yin, 2013).

Moreover, one of the case study's strong points is that it evaluates power relations. In this case study, the relationship between the urban informal households and the different stakeholder groupings that was identified in the RIS approach to socio-technical transitions (see Section 2.3.5) that could influence energy infrastructure transitions in urban informal households was evaluated. Above all, a case study can help to create a planning process that is democratic transparent and inclusive (Association of African Planning Schools, 2012).

Nevertheless, critics of case study research regularly highlight some of the method's weaknesses such as its time-consuming nature and the production of large volumes of documentation (Yin, 2009). In addition, case study findings are not scientifically generalisable and many researchers employing this method lack thoroughness (Yin, 2013). The researcher took the following measures to safeguard the integrity of the case study from these weaknesses:

Firstly, the case study was carried out over a period of six months on a fulltime basis, allowing the researcher to spend numerous hours with the study participants. Secondly, the researcher resided less than 15-minute drive from Kayamandi and was able to meet study participants after work or over weekends. Thirdly, the study used analytic generalisation and not statistical generalisation. In other words, the study generalised the findings to theories and not to populations. Fourthly, the researcher took extra care to report all evidence fairly. Finally, a computerised database to organise and manage the large volumes of data was compiled which allowed the researcher to maintain thoroughness during the case study by being systematic in the data collection process. In addition, the use of a computerised database aided the researcher in tracking, organising and retrieving data sources such as notes, strategic documents, photographs, and audio files. Thus, the use of a database increased the reliability of the data.

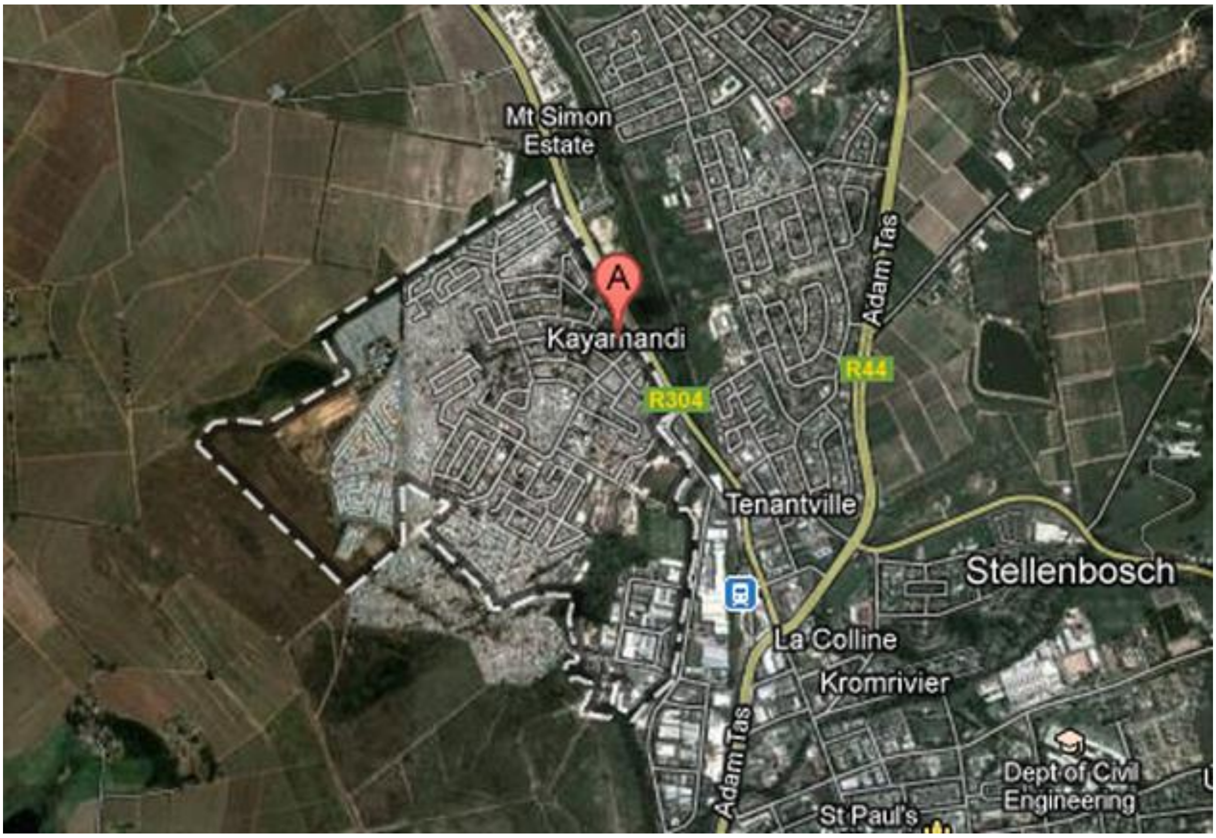

Figure 3.2: The area called Kayamandi in Stellenbosch that falls within the parameters of the area indicated by the perforated line
Source: Google Maps, n.d

Kayamandi was chosen for the case study for several reasons. According to a recent study the majority of the households in Kayamandi are classified as informal (Stellenbosch Local Municipality, 2013a; 2013b). The area was geographically convenient for the researcher and the informants were accessible. In addition, the geographic proximity and ease of access allowed for a less structured and more prolonged relationship between the researcher and the case study participants. Furthermore, the research participants lived in close proximity to each other, which reduced data collection costs. Next, the research methods, data-gathering tools, data analysis and processes that were followed during the case study are outlined.

Kayamandi is a low-income residential community on the north-western periphery of Stellenbosch town in the Western Cape Province of South Africa. It was founded as a result of apartheid segregation in the early 1950s. In 1966 a group of prominent employers in the Stellenbosch district such as Stellenbosch University, the municipality, numerous vineyards and a fruit-packing company established 38 readymade homes as hostels for black migrant male labourers employed mainly on the farms in the Stellenbosch area. Kayamandi was largely unplanned and developed rapidly in the following years (Du Toit, 2009).

Kayamandi, a Xhosa word that means 'nice home', stretches over four municipal wards namely: Ward 12, Ward 13, Ward 14 and Ward 15 (Stellenbosch Local Municipality, 2013a; Appendix E-H). According to the most recent census this area contains around 8 568 households of which the majority are classified as informal. The population totals just under 25 000 people of which 94.6% are black African. IsiXhosa is the home language of 84.9% of the residents (Statistics South Africa, 2011). Around 30% of Kayamandi residents are unemployed and of the employed, the majority earns less than R 3 200 per month (Statistics South Africa, 2011; Stellenbosch Local Municipality, 2013b). This community faces various socio-economic challenges, the biggest of which is the lack of service provision such as electricity, housing, sanitation and water. The other major problems faced by this community are the high crime rate, substance abuse and the high unemployment rate (Stellenbosch Local Municipality, 2013a).

3.3.1.2 Questionnaire

A questionnaire was used to investigate what fuel types urban informal households use for energy services, namely lighting, cooking, water heating, space heating, and operating household appliances. Questionnaires have several advantages, including that they can be applied to a large sample of households (Jalil, 2013; Yin, 2009). Furthermore, questionnaires can be completed anonymously by households and are relatively cheap. However, questionnaires have several weaknesses including that they do not fully capture the reasoning behind certain findings, for example why urban informal households do not make more use of solar energy technologies to provide energy services. Other disadvantages of the questionnaires are the impersonal nature of this research method, the danger that bias can occur if questions are not worded carefully and that not all information can be reduced to numerical data (Bryman *et al*., 2014; Jalil, 2013).

This face-to-face questionnaire format allowed the researcher to build a bond with the participants, answer questions that participants had and clarify uncertainties. Furthermore, this format allowed the researcher to ensure that all questions were answered by the participants. The final question on the questionnaire, which was, "*is* *there anything else you would like to mention?*" allowed the study participants to explain their energy use habits or fuel type choices for a particular energy service.

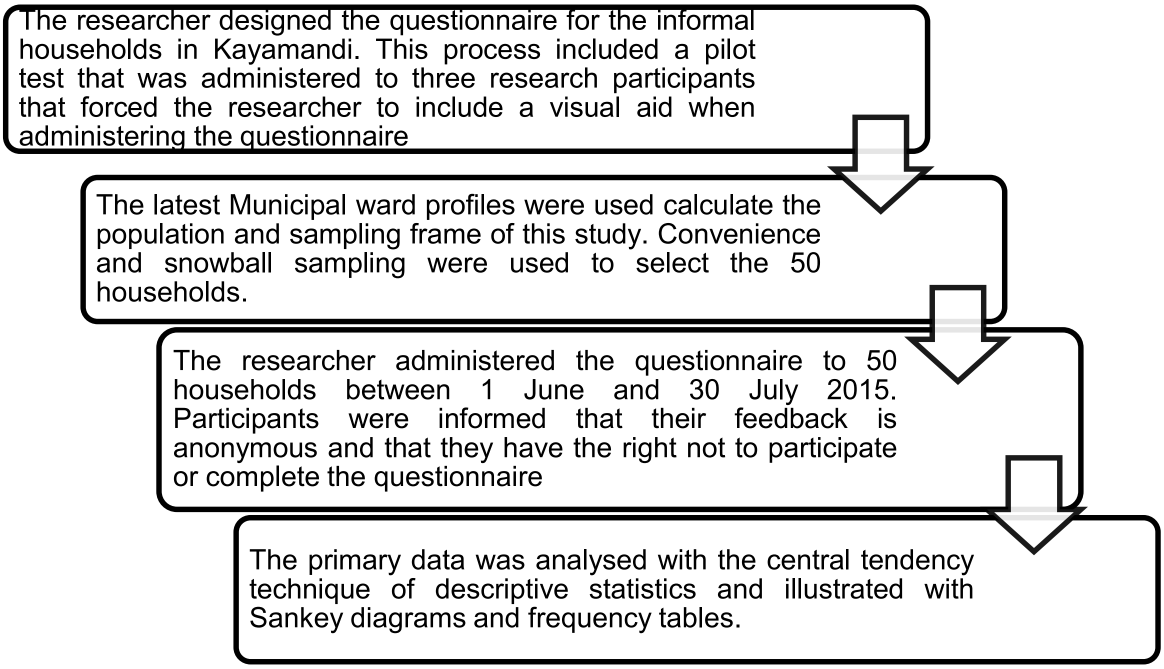

Figure 3.3: A summary of the research methodology used in administering the questionnaire to informal households in Kayamandi

In compliance with the Framework Policy for the Assurance and Promotion of Ethically Accountable Research, written informed consent was obtained from all the participants, before they completed the questionnaire (Stellenbosch University, 2013). Appendix C contains the statement of informed consent that each participant who was willing to participate in this study signed. This statement of informed consent was not attached to the questionnaire in order to prevent the participants' questionnaire responses from being identified. Participants were informed about the nature and purpose of the research and also provided with written information providing further details of this research project, as stipulated by Stellenbosch University (2013).

(i) Questionnaire design

Themes covered in the questions

The first theme dealt with the different fuel types and the proportion in which urban informal households used them for lighting, cooking, water heating, space heating and operating household appliances. These questions appeared together with enquiries into the size of the dwelling and the number of inhabitants living in the dwelling. The second theme of the questionnaire dealt with the households' monthly expenditure on each fuel type.

Structure of the questionnaire

An introduction to each section was provided to help guide the participants. For example, the second section was introduced as follows: *"Thank you for you so much for your participation thus far. We are moving on to the second section of the questionnaire that deals with your household's financial expenditure on energy. I assure you once again that your responses are completely anonymous and confidential."* The overall length of the questionnaire was kept to less than 30 minutes to allow the study participants to attend to their responsibilities at home. The face-to-face administration of the questionnaire made it possible for the researcher to use visual aids that helped the participants to understand the questions. For example, pictures of the various DRE technologies were used if the participants were uncertain about the terms that the researcher used in the questions.

Wording of the questions

Following the recommendation of Andres (2012), four guiding principles were applied when the questions were developed. Firstly, no ambiguous questions were included. For example, Question 2 reads, *"What is the size of this dwelling?"* Secondly, each question contained only one thought or idea, thus preventing double-barrelled questions. For example, Question 6 reads, *"What fuel types do you use for cooking in this household?"* Thirdly, simple and clear language was used and technical terms were avoided because most of the participants were not technically proficient. Moreover, instructions on how to answer some questions were included. Fourthly, the questionnaire questions were formulated in relation to the first research question of this study, which reads, *"What are the current energy flows of urban informal households in Kayamandi?"* Lastly, the questionnaire consisted of mostly closed-ended questions that were grouped according to two themes.

Pilot testing

A pilot test of the questionnaire was done for various reasons enumerated by Andres (2012). Firstly, the pilot test made sure that the language that was used in the questionnaire was proper and comprehensible to the participants because they were not native English language speakers. Secondly, it was used to examine whether the questions were understood as intended and to test different versions of a question. Thirdly, the pilot test was used to determine whether the order of the questions was logical (Andres, 2012). Lastly, it aided the refining of the data collection plans with respect to both the content of the data as well as the procedures to be followed.

Before the commencement of the pilot test, the four households that participated in the pilot study were furnished with consent to participate in research forms (Appendix C) to read and sign. Two of the households resided in municipal Ward 14 and the other two households resided in Ward 15. The researcher observed that two households displayed a lack of understanding of what DRE technologies as well as their applications were. In addition, some research participants did not use the English names commonly ascribed to commonly used fuel types, for example gas, coal and firewood. As a result, the researcher decided to include a visual aid (see Appendix D) when administering the questionnaires to prevent any misunderstandings.

(ii) Sampling selection process

The current study had an exploratory purpose and a great deal of in-depth information was required, which favoured sampling. Furthermore, the large population size that was homogenous in nature necessitated sampling. A census will not have a probability sampling error because a sample of the population is not taken. While this is true, the strength of sampling is that it is able to minimise probability sampling error and systemic error when resources such as financial, logistical, material and human to conduct the study are limited, as was the case in the current study. Therefore, this study employed used sampling instead of a census. Figure 3.3 illustrates the seven different steps in the sample selection process that the researcher used (Jalil, 2013).

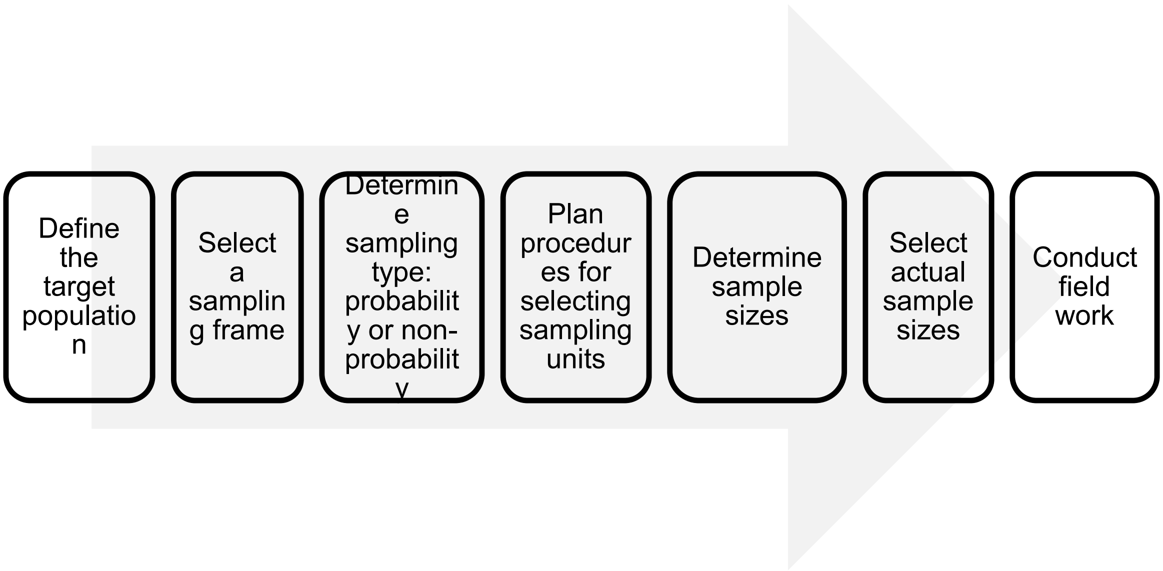

Figure 3.4: The seven steps of the sample selection process for the questionnaire
Source: Adapted from Jalil, 2013

Define the target population

In the view of Bryman *et al*. (2014:383) a population is, *"the universe of units from which a sample is to be selected*". The population for this study in Kayamandi, is all the informal households within the boundaries of municipal wards 12, 13, 14, and 15 (Appendix E–H).

Sampling frame

The sampling frame is *"the listing of all units in the population from which the sample is selected*" (Bryman *et al*., 2014:383). The questionnaire was administered to informal households, which included shacks in backyards, within the boundaries of municipal wards 12,13, 14, and 15 that fell within the settlement of Kayamandi. The total number of households in the sampling frame amounted to 4 787. Ward 12 (see Appendix E) had 1877 households that formed part of the sampling frame. Ward 13 (see Appendix F) had 56, Ward 14 (see Appendix G) had 819 and Ward 15 (see Appendix H) (Stellenbosch Local Municipality, 2013b).

Determine the sampling type

As sampling was chosen over a census, the next step was to decide between a probability sample design, a nonprobability sample design or a combination of the two. The current study made use of nonprobability sampling for various reasons. The planning and implementation of nonprobability sample designs require little or no training and skills. Above all, the small sample size of this study made a nonprobability sample design a favourable choice. Even though mixed-method sampling could have improved the generalisability of the results and added rigour, complexity and depth to the study this sampling design was not used because it is resource intensive and administratively complicated. Consequently, the current study employed a nonprobability sample design. The next step was to choose the type of nonprobability sample design for this study.

Four types of nonprobability sample design occur, namely availability sampling, purposive sampling, quota sampling, and respondent-assisted sampling. Availability sampling is unstructured, while purposive, quota, and respondent-assisted sampling are structured. Availability sampling was decided on for several reasons. The elements of the target population were selected on the basis of their availability as well as the convenience of the researcher. Furthermore, availability sampling was the least time-consuming, least expensive, and least complicated procedure compared to the structured sampling procedures. However, availability sampling has a low external validity and might have underestimated the variability of the population of this study.

Plan procedures for selecting sample units

The researcher met with the Stellenbosch Municipality official who was to accompany him after he had finished work and went to knock on the doors of residents of informal households in municipal wards 12, 13, 14 and 15. The researcher aimed to administer 25 questionnaires in each ward but only managed to get 50 households to participate within the timeframe. Some households referred the researchers to neighbours who might be home to participate in the study. After the questionnaire had been administered to 30 households the researcher realised that only eight female participants were part of the study, which amounted to 26.6% of the sample. The researcher consciously increased the representation of women to 40% of the total sample by including 12 female respondents in the remainder of the sample.

Determine sample size

Initially the researcher wanted to administer the questionnaire to 100 informal households in Kayamandi. However, due to the lack of availability of many households to participate in this study, only 50 households formed part of the sample size. The smaller sample size was acceptable due to the homogeneity of the population (Bryman *et al*., 2014). For example, 93.7% of the population was classified as black African, 63.9% of households were classified as informal and 67.2% of the population over the age of 20 years had not finished high school. In addition, 78.2% of Kayamandi residents earned less than R32 800 per annum (Statistics South Africa, 2011).

Select actual sample units

Convenience and snowball sampling were used to select the units in the sample. The researcher relied heavily on the municipal official who accompanied him when he administered the questionnaire to identify research participants. All of the respondents were at home and had about 20 minutes to spare to complete the questionnaire. Twelve of the initial research respondents referred the researcher to households that they believed might be interested in participating in this study. Ten of these referrals obliged and took part in the research.

Conduct field work

The questionnaire was administered to the 50 informal households between 1 June and 30 July 2015. The researcher realised that many potential participants were unavailable from Monday to Friday due to work responsibilities. Wards 12, 13, 14 and 15, have an employment rate of more than 50% (Stellenbosch Municipality, 2013b). As a result, the researcher administered the majority of the questionnaires on weekends and a public holiday, 16 June 2015, when many of the employed residents were available to participate in this research. In total, 28 questionnaires were administered on these days using convenience and snowball sampling.

The researcher was accompanied by a municipal official who had been a life-long resident of Kayamandi. The official explained several local words and phrases that is unique to Kayamandi and his presence was increased the willingness of people to complete the questionnaire. The colour printed visual aid (see Appendix D) was also shown to the interviewees in case the wording of the questionnaire was foreign to them. For instance, the research participants commonly referred to the use of firewood to heat their dwellings as *imbawula*. The researcher was not familiar with the term at first but the participants pointed to the fire wood on the visual aid to make the point clear.

(iii) Addressing issues of sampling error and sampling bias

Bryman *et al*. (2014:170) defines sampling bias as “a distortion in the representativeness of the sample that arises when some members of the population stand little or no chance of being selected for inclusion in the sample”. What Bryman *et al*. (2014) means is that the researcher in this study could, for instance, have favoured the inclusion of men between 20 and 29 years old. This would have been a sampling error that would have caused sampling bias. The researcher prevented this potential sampling bias by choosing a diverse set of respondents who differed in gender, and employment status. For instance, 60% of the respondents were male and 40% were female. The sample also included participants with various levels of education. Furthermore, the researcher administered the questionnaire over three weekends and a public holiday when more employed people were available to take part in the study. Besides, the questionnaire was administered over two months, which increased the chances of the informal households in the sample frame to be included in the sample.

(iv) Addressing issues of non-sampling error

The risk for non-sampling bias was addressed by explaining to research participants in detail what the study was all about in order to minimise biased communication. Likewise, the use of the visual aid (Appendix D) prevented the research participants from confusing the fuel types that they knew by another name. It was also explained to the research participants that there feedback was anonymous and confidential.

(v) Enhancing the reliability of data

A pilot test was carried out. Firstly, the pilot test made sure that the language that was used in the questionnaire was proper and comprehensible to the participants because they were not native English language speakers. Secondly, it was used to examine whether the questions were understood as intended and to test different versions of a question. Thirdly, the pilot test was used to determine whether the order of the questions was logical (Andres, 2012). In addition, it aided in refining the data collection plans with respect to both the content of the data as well as the procedures to be followed. During the pilot tests, the researcher observed that some research participants used different terms to describe commonly used fuel types such as firewood, which they referred to as *imbawula*. As a result, the researcher decided to include a visual aid (see Appendix D) when administering the questionnaires to prevent any misunderstandings.

(vi) Enhancing the validity of data

The validity of the study was enhanced by explaining to the prospective research participant the nature and purpose of the study in order to encourage them to answer all the questions as truthfully as possible. In addition, the researcher consciously tried to prevent selection bias by including participants from various socio-demographic groupings and by carrying out sampling over eight weeks.

(vii) Data analysis

The primary data that was collected from the questionnaires were described and summarised by means of descriptive statistics with the help of a calculator and Microsoft Excel 2014. The researcher used the central tendency technique that described where the majority of the data lay. Two measures of central tendency, namely the arithmetic mean, and the median were used to summarise the primary data.

Frequency tables and Sankey diagrams were used to depict the data collected from the questionnaire (see Chapter 4). The frequency tables consist of three columns, namely the fuel type or carrier, the number of households that use a specific fuel type and the percentage of households that use a specific fuel type. Sankey diagrams are tools for visualising processes and can be used to map energy consumption from source to end use, energy management and energy flows (Subramanyam *et al*., 2015; Soundararajan *et al*., 2014).

The energy flow representation in this study use colour coding and individual labelling of the flows in order to improve clarity and ease of use. The width of the arrows and lines in these energy flow diagrams represents the energy intensity of the various fuel types and energy carriers that informal households use for cooking, lighting, water heating, space heating and operating household appliances.

Soundararajan et al., 2014 also points out several objectives that energy analysis at national level using the Sankey framework has. These objectives include creating public awareness, ensuring security of supply, increasing the use of alternative energy and identifying areas of energy saving. Since the study intended to investigate the extent to which renewable energy technologies could contribute to the provision of energy services in urban informal households, using Sankey diagrams in this study was justified.

3.3.1.3 Direct observation

The direct observation research method allowed the researcher to observe the residents of urban informal households when using various fuel types and energy carriers for energy services without influencing them in any way. Consequently, the researcher could see what fuel type or energy carrier people used for a specific energy service without their having to provide information. Likewise, the researcher could also collect data where and when the activity occurred in other words where and when the residents of informal households used various fuel types and energy carriers for cooking, lighting, water heating, space heating and operating household appliances. These benefits of direct observation helped to mitigate the limitations of the questionnaire that was also used to answer the first research question, thus increasing the data credibility.

Conversely, direct observation has several weaknesses. This data collection method is time-consuming and expensive. In addition, the feelings, beliefs and attitudes that motivate fuel type preference or the amount of money spend on it cannot be observed (Bryman *et al*., 2014; Yin, 2009). The researcher took several precautionary steps to safeguard the data credibility from these weaknesses. The researcher carried out the case study over six months on a full-time basis with financial assistance from the Centre for Renewable and Sustainable Studies that is based at Stellenbosch University. Consequently, a lack of time or financial resources did not influence the quality of the data that was collected when observing informal households in Kayamandi. Even though direct observation is normally unstructured, this study adapted the phases as outlined by Cassim (2011) to facilitate this data-gathering process.

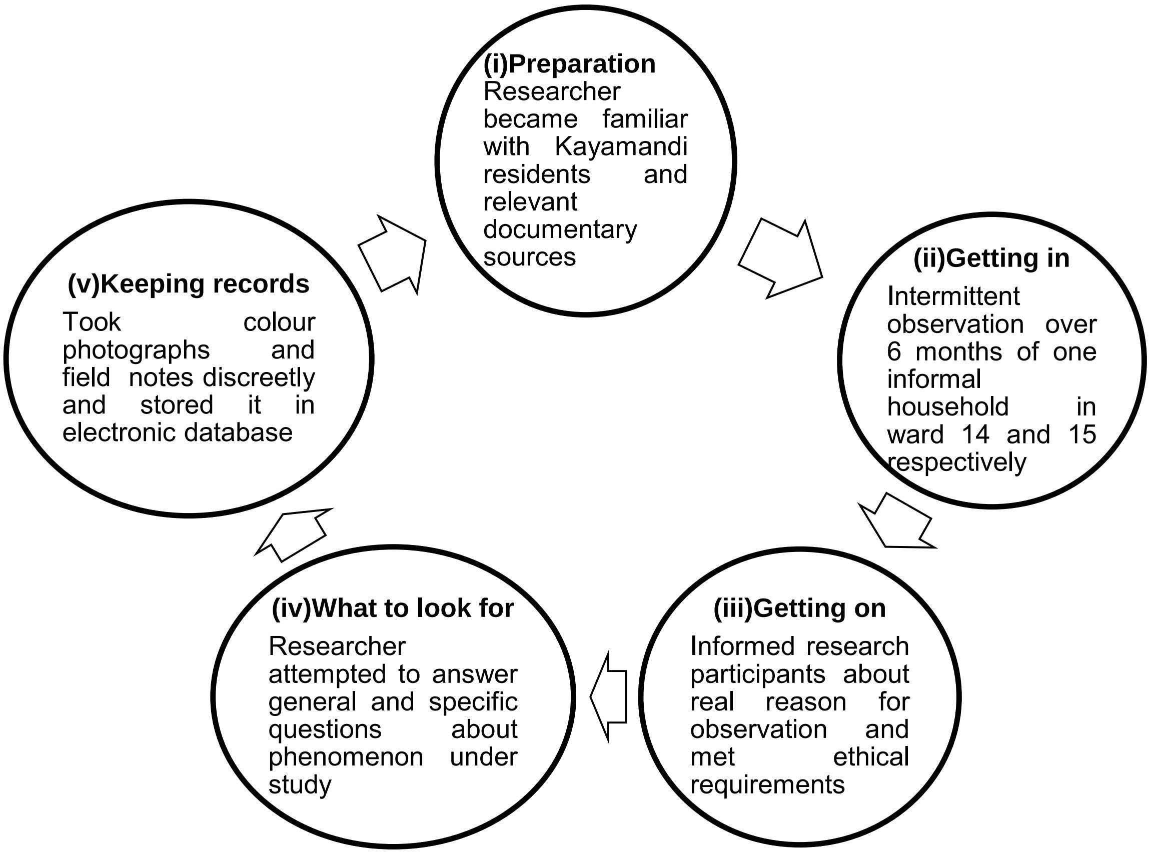

Figure 3.5: Summary of the research methodology employed for direct observation

(i) Preparation

The researcher familiarised himself with a few residents of Kayamandi from January to March 2015 to gauge whether this case study was feasible. The researcher engaged in intermittent observation over a longer period of time. Several documentary sources such as government publications, corporate publications and relevant journal articles were consulted for information on the energy flows of urban informal households (Ahmad & De Oliveira, 2015; DoE, 2013).

(ii) Getting in

One informal household in municipal Ward 14 and one in municipal Ward 15 allowed the researcher to spend 10 days between March and August 2015 in their dwelling to do observations. These intermittent observation sessions allowed the researcher to return at a later date and attempt to make sense out of a phenomenon that at first did not make sense to him. The head of the household in Ward 14 was a municipal employee at Stellenbosch Municipality, and the head of the household in Ward 15 was an employee in the hotel and catering industry in Stellenbosch.

(iii) Getting on

The researcher was honest about his reasons for spending time in their households and informed the research participants that he was doing it to answer one of the research questions of his master's degree study. He supplied both households with hard copies of the consent to participate in research form (see Appendix D) as well as Stellenbosch University's Framework Policy for the Assurance and Promotion of Ethically Accountable Research.

(iv) What to look for

Even though this data collection tool was employed to assist in answering the first research question, *"What are the current energy flows of urban informal households in Kayamandi?"* the researcher remained open to unexpected information. During these observation periods, the researcher asked himself both general and very specific questions about the phenomenon under study.

(v) Keeping records

The researcher took photographs and field notes in a very discreet manner. The field notes were taken in private and not in the presence of research participants. The field notes were transcribed at a later stage. Colour photographs were taken with a Samsung cellular phone in the absence of research participants. A professional camera would have been a distraction and might have forced the research participants to alter their behaviour with regard to what fuel type or energy carrier the researcher wanted them to use for cooking, lighting, water heating, space heating and to operating household appliances. All the field notes and photographs were stored in an electronic database.

3.3.2 Research question 2

To what extent can renewable energy technologies contribute to the provision of energy services in urban informal households?

3.3.2.1 Semi-structured interview

Bryman *et al*. (2014) states that in a semi-structured interview the researcher has a list of questions on fairly specific topics to be covered, often referred to as an interview guide, but the interviewee has leeway in how to reply. Jalil (2013:15) corroborates this and says that this data collection method is "a purposeful exchange between two people to uncover perspectives, experiences and insights on a phenomenon". In this study, the questions in the semi-structured interview asked to what extent renewable energy technologies could provide energy services such as lighting, cooking, water heating, space heating and operating household appliances for urban informal households in Kayamandi.

Bryman *et al*. (2014) list several benefits of using a semi-structured interview, including that it can be used in a wide range of contexts where the researcher has a series of questions on an interview schedule but is able to vary the sequence of questions. Even though in this study the researcher planned to pose the same five questions to all interviewees in the same sequence, the order of the questions had to be rearranged during four interviews because research participants started to talk about questions had were not yet been posed to them. This flexibility allowed the interviewees to be more confident in expressing their views.

In addition, the questions in a semi-structured interview tend to be more broadly framed than those in a structured interview schedule (Bryman *et al*., 2014). For instance, the second question in the semi-structured interview that reads, *"How does your stakeholder group- school/industry/policy- and decision makers/public administration/civil society/intermediaries/finance- engage in the processes of promoting renewable energy technologies to specifically urban informal households?"* is not specific with regard to meaning and was answered in a wide range of ways by the interviewees. Equally, Mattes *et al*. (2015) maintain that semi-structured qualitative interview is an appropriate research method to capture the complex multi-layered character of local change processes. The current study focused on the energy infrastructure transition of urban informal households; the semi-structured interview was a suitable data collection tool to answer the second research question.

Taking a contrary view, Jalil (2013) states several disadvantages of this data collection tool including that it is time-consuming and expensive. All the interviews in this study except one, took place within close range of where the researcher was based, and the length of each interview was limited to 45 minutes. The 10 interviews were completed over a period of three months. It took three months to interview all the research participants because of their unavailability due to family or work commitments. One interview was administered online.

Moreover, during semi-structured interviews, the researcher is susceptible to interview bias and may seem intrusive to the respondent. All interviews in this study were recorded with a cellular phone in order to review recordings for a detailed analysis. All respondents were made aware of the recording during the introduction to the interview process which read, *"I will be taking notes as well as audiotape this interview and will be happy to send you a types copy of my notes tomorrow…"* All interviews took place in a quiet and private setting to make research participants feel at ease. The introduction to the interview also reminded interviewees of their right not to participate in and complete the interview, which made the interview process non-intrusive.

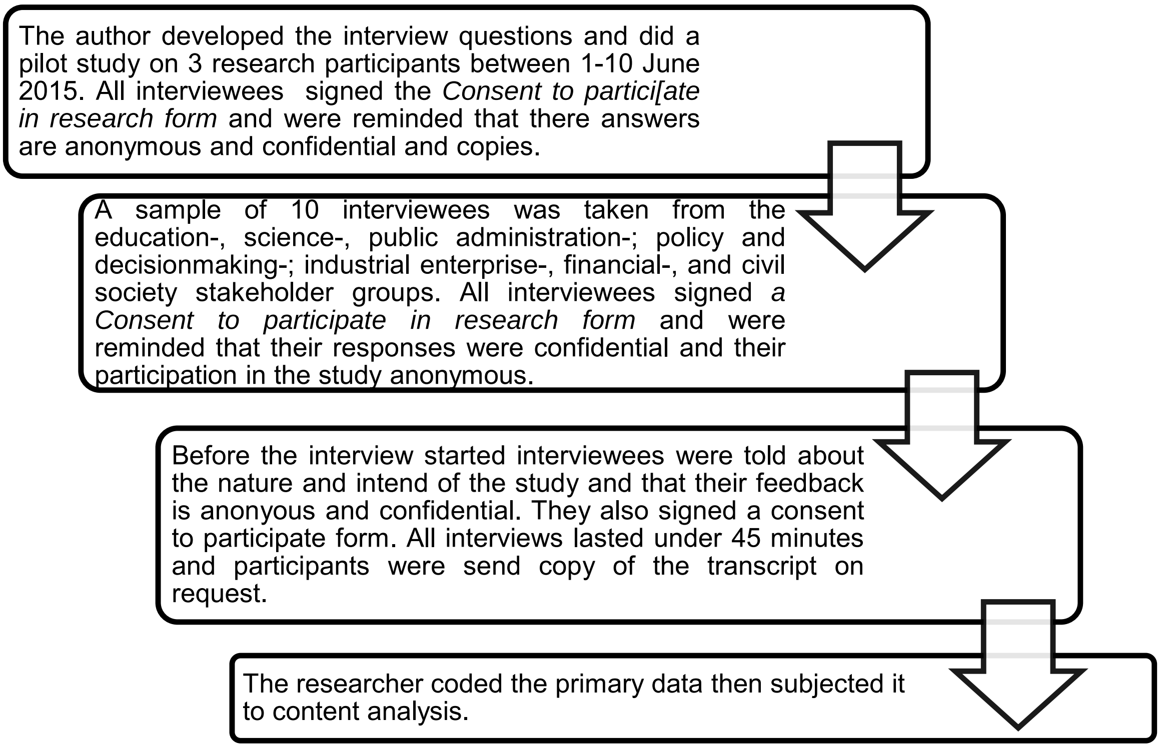

Figure 3.6: A summary of the research methodology employed to interview a widerange of stakeholders that were affiliated to Kayamandi

Kvale and Brinkmann (2015) acknowledge that research interviewing is not a standardised procedure and recommend seven steps to carry out the semi-structured interview process, which were modified in the current study to design, and administer the interviews and analyse the primary data that was derived.

(i) Themes of the interview

The two themes of the semi-structured interview were the following:

(a) The practicality and financial viability of urban informal households of the use of DRE technologies as alternative and/or supplementary energy carriers for cooking, lighting, water heating, space heating and the operation of household appliances.

(b) The current role of the financial-, civil society-, industry-, intermediaries-, education and science-, policy and decision-makers-, and public administration stakeholder groups that enhances or supresses the sustainable deployment of DRE technologies to urban informal households.

(ii) Designing the interview questions

The semi-structured interview in this study consisted out of open-ended questions (Appendix B). Bryman *et al*. (2014:380) describes an open-ended question as "a question employed in an interview schedule or self-completion questionnaire that does not present the respondent with a set of possible answers to choose from." Basically, Bryman *et al*. are thus saying that open-ended questions allow respondents to answer in whatever way they wish to.

Several researchers suggest that this question type has several advantages. For example, respondents are able to answer in their own terminology, which makes expressing their views easier. In addition, these question types are useful for exploring new areas or ones that the researcher has limited knowledge of. This study was the researcher's first attempt at a master's research project, and compared to the questionnaire, the semi-structured interview was easier to develop, administer and analyse.

One of the limitations of open-ended questions is that they are time-consuming (Bryman *et al*., 2014). The researcher carried out the study on a full time basis, so time was not a limitation. Since the interview was shortened after the piloting phase from eight to five questions, all the interviews lasted between 30 and 45 minutes, which was well below the 60 minutes that the researcher had requested from the research participants. All interviewees were transcribed verbatim immediately after the interview had been completed.

The content of the interview questions was informed by the literature review of the study as well as by energy industry conferences and informal conversations that the researcher had formed part of. The literature review explored socio-technical transitions, energy-related theories, the benefits and definitions of energy access, and various DRE technologies that could provide energy services to urban informal households. In addition, the researcher attended an Energy Efficiency Forums that was hosted by the Cape Town Municipality and Africa Utility Week 2015. The researcher also had informal discussions with urban informal households, energy experts, academics and entrepreneurs in the energy field regarding the extent to which

DRE technologies could serve as an alternative and/or supplementary energy carrier for urban informal households.

A pilot study formed part of designing the semi-structured interview for various reasons. Bryman *et al*. (2014) defines a pilot study as a, “a short preliminary study to determine how well your research method works”. Bryman *et al*. (2014) state that, a pilot study is a trial run to gauge the effectiveness of the chosen research method. Several authors argue that a pilot study ensures that the questions and the research instrument function well holistically (Bryman *et al*., 2014; Yin, 2011). The pilot study included three research participants who all worked or lived in Kayamandi. One high school teacher, an NGO and a municipal official formed part of the pilot study. Piloting testing the interview gave the researcher experience and built confidence in using it. The pilot study also allowed the researcher to determine whether participants would be comfortable with all the questions and to detect whether respondents lost interest at certain junctures during the interview. Consequently, the questions that were not understood and the questions that were not answered became apparent. These questions were reworked or removed from the interview. Eventually, the interview questions were scaled down from eight to five questions.

(iii) Sampling procedure

Snowball sampling and convenience sampling were the two non-probability sampling types that were used to select respondents for the semi-structured interview. After piloting and editing the semi-structured interview, prospective interviewees were identified by the researcher from the *Community Needs Assessment and Asset Mapping Profile of Kayamandi* report that outlines the various active organisations and the services that they provide and identifies community leaders and economic and business ventures (Du Plessis *et al*., 2012).

Furthermore, the researcher consulted with the Division of Community Interaction at Stellenbosch University which manages numerous community programmes in Kayamandi on potential civil society bodies, educators, and policy and decision makers that could be interviewed. In addition, the ward plans of municipal wards 14 and 15, which covers Kayamandi, were consulted to identify the names and contact numbers of ward committee members who could be potential interviewees for this study (Stellenbosch Municipality, 2013a).

Table 3.1: Semi-structured interview participation and response rates

Stakeholder group	Contacted	Did not respond	Interviewed	Answered questions online	Answered questions via telephone	Participation rate
Education and science	2	1	1	0	0	50%
Industry	3	1	1	1	0	66.7%
Policy and decision makers	2	1	0	0	0	0%
Public administration	3	0	3	0	0	100%
Intermediaries	2	1	1	0	0	50%
Finance	4	3	1	0	0	75%
Civil society	3	3	2	0	0	66.7%

Table 3.1 illustrate that 19 interviewees, including teachers, NGOs, entrepreneurs, municipal officials, and energy technology manufacturers and distributors who were based in Kayamandi and surrounding areas of Stellenbosch were contacted. The average participation rate was 58.3% ranging from 0% for the policy and decision maker stakeholder group to 100% for the public administration stakeholder group.

(iv) Interviewing

The interview started with an introductory question in order to encourage participants to share their experiences with renewable energy technologies that could provide energy services in urban informal households. Several authors have contended that questions may not follow the exact order outlined on the schedule and that the wording may be changed by the researcher. Seeing that the majority of the participants were not native English speakers this happened often. In such instances, I rephrased the questions in order for the interviewees to understand what information I tried to obtain from them. Furthermore, during the interviews, the researcher did not lead the interviewees with biased, assumption-loaded questions (Bryman *et al*., 2014; Jalil, 2013).

(v) Addressing issues of reliability

According to Kvale and Brinkmann (2015) reliability relates to the dependability and fidelity of the research findings. The researcher took several precautions to ensure that the findings were dependable. The researcher used no leading questions during the interview that might have influenced the answers from participants. The interview took place and was transcribed on the same day to prevent any information from being lost. Interviewees were also informed that they had the right not to participate in the interview and that their feedback was anonymous and would be treated as confidential.

(vi) Data analysis

Coding is a key aspect of content analysis and involves the attachment of one or more keywords to a text segment in order to permit later identification of a statement (Kvale & Brinkmann, 2015). Coding was used to organise the semi-structured interview text of this study and to work out the implicit meanings of what was said. Furthermore, this tool was used to provide structure and give overviews of extensive interview texts. The coding of the primary data of the semi-structured interview was concept driven in that it used codes that had been developed in advance by the researcher from the literature review.

Content analysis was used to analyse the data. This technique was used to code the meaning of the texts into categories that made it possible to quantify how often specific themes were addressed. The frequency of themes were correlated and compared to other measures.

3.4 Summary

This chapter described and justified the research design and methodology that were used in this study. The methodological triangulation approach used a case study to investigate the fuel types that urban informal households used for various energy services. The case study data gathering method consisted of a questionnaire, direct observation and semi-structured interviews. The questionnaire and direct observation were the data collection tools to answer the first research question and the semi-structured interviews were used to collect data to answer the second research question.

CHAPTER FOUR: RESULTS

4.1 Introduction

In this chapter, the results of the study are discussed with various goals in mind. The primary data collected to answer the research question was analysed by means of descriptive statistics, and the results are depicted pictorially using Sankey diagrams. The primary data that was collected to answer the first research question were analysed by means of content analysis. In this chapter, the researcher attempts to explain the results of the study and propose reasons for these results. Discussions include real-world applications and the potential consequences of these results.

4.2. Research question 1

What are the current energy flows of urban informal households in Kayamandi?

4.2.1 Cooking

Figure 4.1 is a Sankey diagram that illustrates the fuel types and energy carriers that are primarily used by the sample of informal households in Kayamandi. The primary energy carriers and fuel types that are used for cooking by these households are electricity, paraffin, firewood and gas. The majority of the sample of informal households in Kayamandi (58%) use electricity as a primary energy carrier for cooking. About 24% of the households use paraffin, 12% use gas, and 6% use fire wood as a primary fuel type for cooking.

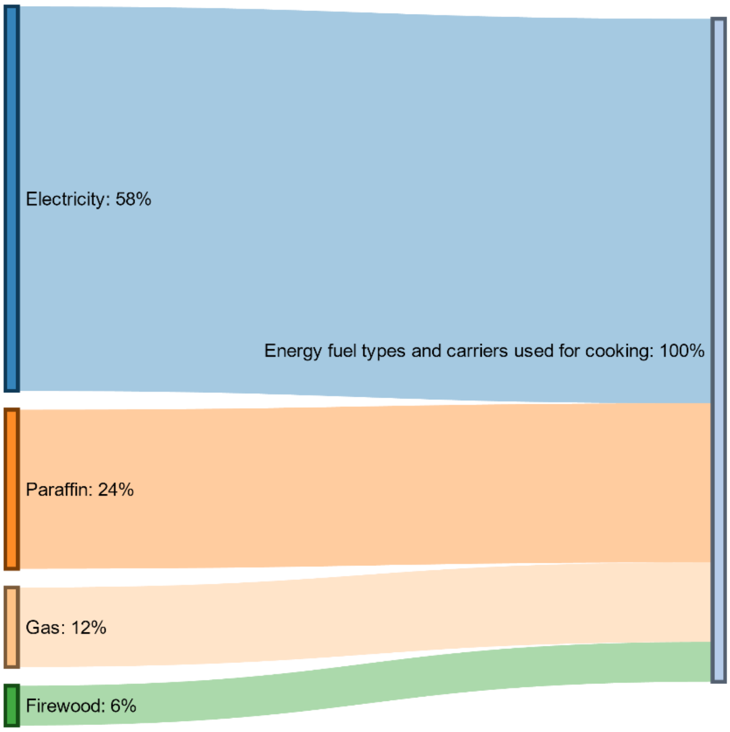

Figure 4.1: Sankey diagram that illustrates the primary energy fuel types that informal households use for cooking

Of the 29 households that use electricity as a primary energy carrier to cook, 20 own two-plate electric stoves. The other 9 households make use of four-plate electric stoves with an oven. These households cook on average 2 meals a day, which range from 30 minutes for popular dishes such as *mielie pap* (maize porridge) to three hours for samp and beans. Sixty percent of these informal households receive electricity connection from neighbouring households or from illegal connections that are attached to streetlights or electrical boxes. These electricity connections provide inconsistent and unreliable electricity to these informal household. Furthermore, strong winds and rainy weather cause electricity interruptions which necessitates the use of alternative fuel types to cook with. The above-inflation rise in electricity prices also forces these households to use alternative fuel types to cook.

Twelve informal households use paraffin stoves, 6 informal households use gas and two informal households use firewood to cook with. The 12 informal households that use paraffin as a primary fuel type for cooking use gas and fire wood as alternative fuel types for cooking. At times retailers run out of paraffin stock and these households are forced to use firewood or gas if they can afford it.

The use of paraffin to cook by these 12 informal households is important because it raises health concerns since the combustion of paraffin could lead to respiratory and cardiovascular diseases (Lay *et al*., 2013; Zulu & Richardson, 2013). Mainali *et al*. (2014) suggest that the severity of these diseases depend on several factors for instance the stove types, whether the room is ventilated or not and the period of time that people are exposed to the fumes. Ultimately, the morbidity caused by the use of paraffin to cook causes a loss in productivity and income-generating opportunities, which impedes economic development.

All six informal households that use gas as a primary fuel type alternate it with paraffin and firewood when gas is not available for cooking. The main reason why these households cannot access gas at times is unavailable supplies at retailers during volatile periods of electricity supply when the demand for gas increases. Likewise, when the price of gas increases some households opt for alternative fuel types.

Table 4.1: Frequency table showing the primary fuel types used for cooking by informal households

Fuel type/ energy carrier	Number of households	Percentage
Electricity	29	58
Firewood	3	6
Paraffin	12	24
Gas	6	12
Solar system	0	0
Coal	0	0
Generator	0	0
Other	0	0
Total households	**50**	**100**

Table 4.1 indicates that firewood is used by three households as a primary fuel type for cooking; they perceive it as a ‘free’ resource because they harvest it from nearby woodlands at no charge. According to a study by the Department of Energy, cooking with firewood is associated with a higher child mortality rate, diminishing maternal health and a general disease burden from smoke (DoE, 2013). Moreover, women and children are mainly responsible for the time-consuming activity of wood collection in a household, which affects schooling and other productive activities. Consequently, the income-generating capability of these households could decrease and their dependence on firewood for cooking is a key contributor to being trapped in poverty (Burke & Dundas, 2015). Despite the fact that firewood is not a popular choice for a

primary or secondary fuel type for cooking, the overwhelming majority of informal households in the study confirmed that they made use of firewood or coal when they prepared food at social events, for instance traditional ceremonies and barbecues. Although the use of firewood for cooking by informal households seems trivial, it is crucial in terms of today's concerns over the empowering of women and poverty eradication. Replacing wood with a cleaner energy fuel type may improve the health of women and children and afford them more time to focus on income generating activities and education which may improve the socio-economic conditions of their homes.

Table 4.1 indicates that none of the households in the sample uses a solar system, a generator, coal or any other fuel type than electricity, wood, paraffin and gas as a primary fuel type or energy carrier for cooking. Generators are relatively expensive, and one needs diesel or petrol to operate it. Thus, the cost of operating a generator may be a reason why none of the households uses it to operate a cooking device. Coal is used to prepare meat at infrequent social gatherings by several of these households.

Therefore, the multiple fuel use model (see Section 2.4.3) is observed in the majority of households. The 29 households that use electricity as a primary energy carrier to cook with use paraffin, gas, firewood or a combination thereof as alternatives if electricity is inaccessible. These findings of households using various fuel types and energy carriers for cooking challenge the work of earlier researchers who advocated the energy ladder theory (see Section 2.4.1). These findings also challenge the goal of many cities that want to be completely dependent on renewable energy for energy services

4.2.2 Lighting

Figure 4.2 illustrates the various fuel types and energy carriers that are primarily being used by the sample of informal households in Kayamandi for lighting. The Sankey diagram illustrates that 50% of the informal households in the sample use electricity as their primary energy carrier for lighting. Twenty-four percent of the sample indicated the uses of paraffin, 20% use candles and 6% use solar lights as a primary fuel type or energy carrier for lighting.

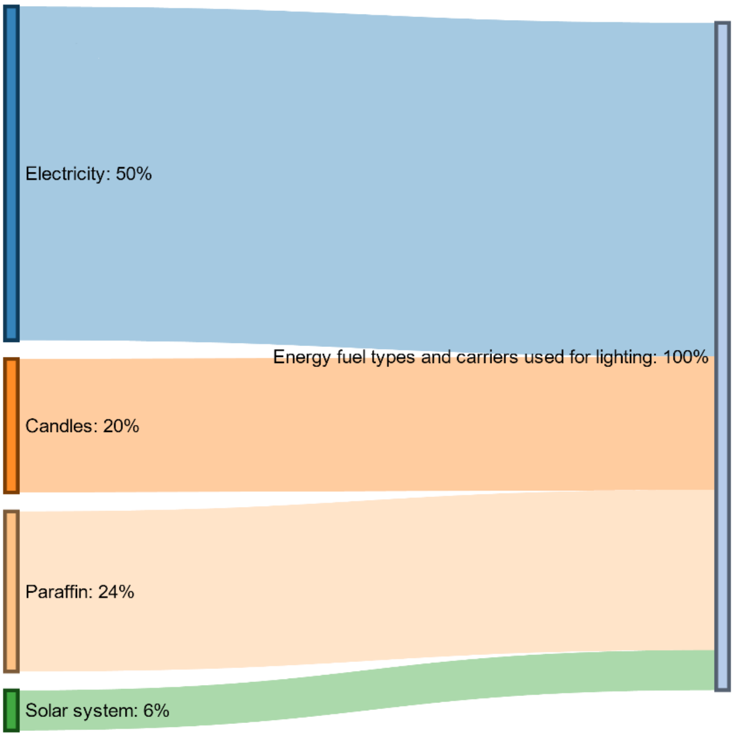

Figure 4.2: Sankey diagram that illustrates the primary fuel types that informal households use for lighting

All 25 households that use electricity as a primary energy carrier for lighting use paraffin lamps and candles as secondary and alternative fuel types on a regular basis. All 25 of these households use candles when electricity is inaccessible to provide lighting while 18 of them also stock paraffin lamps as a secondary fuel type for lighting.

Twenty-four percent of the informal households in this sample use paraffin as a primary fuel type for lighting. Despite the flammable nature of paraffin and the fact that it causes chronic indoor air pollution it remains a very popular alternative fuel type for lighting. As an illustration, 74% of the 50 informal households in the sample stock it and use it as a potential back up for lighting services.

Despite the fact that only 20% of the 50 informal households use candles as a primary source of lighting, the majority of the sample stock and use it from time to time. The rapidly increasing price of electricity causes some of the households to use paraffin and candles up to 50% of the time. Even though candles are responsible for starting numerous fires in informal households, the relatively lower price of this fuel type makes it an appealing primary and secondary source to provide lighting for informal households in Kayamandi. What is more, candles are available at most local shops, unlike gas and paraffin that are stocked by select retailers.

The lights of cellular phones are used as a means as a guiding tool and to steer away from any safety hazards. The lights of the phones are used indoors to help find candles or paraffin lamps or keys. Outside, the phone light is used to help guide the person to a water tap or a toilet facility. Residents also use the light to steer their path to and from work or late at night.

Table 4.2: Frequency table showing the primary fuel types used for lighting by informal households

Fuel type/ energy carrier	Number of households	Percentage
Electricity	25	50
Candles	10	20
Paraffin	12	24
Dry cell batteries	0	0
Gas	0	0
Solar system	3	6
Car batteries	0	0
Generators	0	0
Total households	**50**	**100**

According to Figure 4.2, three informal households in the sample use solar energy to operate their lights. One of the three households uses an SHS that operates two lights. The other two households use a solar light which battery they charge during the day in order to provide light for them at night. Both these households use the solar lights as an outside light to deter burglars from breaking into their dwellings at night. They received these solar lamps from a donor, and thus far they have been effective in deterring burglars. This discovery will have significant implications for reducing the crime rate in Kayamandi which is one of the major challenges in the area (Stellenbosch Municipality, 2013a).

All three informal households that use solar lights use paraffin and candles as secondary fuel types to provide lighting, specifically during winter months when the sun rises later and sets earlier. These solar systems will then have to work much longer hours because of the extended hours that informal households need lighting services.

Seventy-four percent of the 50 informal households do not have a window in their structure. Very little natural daylight therefore enters their dwelling during the daytime.

As a result, the use of a fuel type or energy carrier is necessary to see in the dwelling during the day if the main door cannot be opened due to adverse weather conditions or potential safety threats. Even though many of the households without windows in their dwellings are aware of the health and financial implications of this oversight, the threat of burglars gaining access through the windows override these concerns.

In short, households that experience a lack of access to clean, reliable, and safe lighting suffer socially and economically. It limits the productivity of these households contributes to carbon emissions and causes chronic illness due to indoor air pollution (Pode, 2013).

4.2.3 Water heating

The Sankey diagram below illustrates the various fuel types that the sample of informal households uses for water heating. According to Figure 4.3, approximately 58% of the households use electricity, around 24% use paraffin, 12% use gas and 6% use firewood.

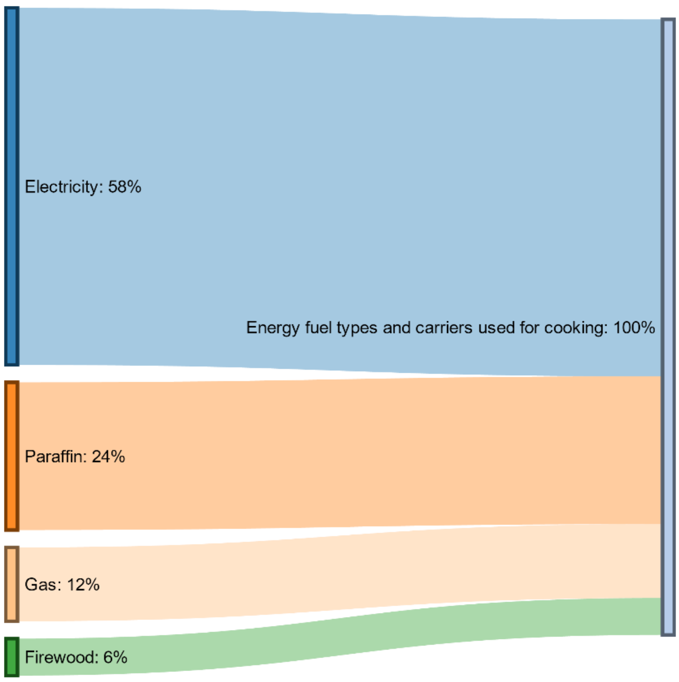

Figure 4.3: Sankey diagram that illustrates the primary fuel types that informal households use for heating water

Nineteen of the households that use electricity to heat water use an electric kettle and the other 10 households use their electric stoves. It is possible that households view the heating of water in an electric kettle as quicker and more economical as opposed to heating water on an electric stove. Eighteen of these households use paraffin stoves to heat water in the absence of electricity while eight households use gas as an alternative to electricity.

Owing to the increasing cost of electricity, many households use paraffin and gas stoves for certain periods during the month to heat water. The ever-present threat of power-cuts causes many households to keep paraffin and gas on standby to heat water, which is essential for preparing for work or school.

Table 4.3: Frequency table showing the primary fuel types used for heating water by informal households

Fuel type/ energy carrier	Number of households	Percentage
Electricity	29	58
Firewood	3	6
Paraffin	12	24
Gas	6	12
Solar system	0	0
Coal	0	0
Generator	0	0
Other	0	0
Total households	**50**	**100**

There is a real sense of community amongst people in Kayamandi and water is often shared with neighbours with no electricity access. Most households admitted that they have a cordial relationship with their neighbours who supplied them with boiling water at times.

4.2.4 Space heating

In the construction of informal households, material that has poor insulation capability, for example corrugated iron, is often used. The roofs of the overwhelming majority of the dwellings of the sample have nail holes and gaps between the sheets of corrugated iron, which causes leaks when it rains and allows cold winds to blow into the dwellings. This escalates the heating costs of informal households because the heat escapes from the dwellings at a very high rate. Consequently, devices such as electric heaters, paraffin heaters and *imbawula* (see below) are constantly running in order to replace lost heat and neutralise the cold coming in from outside.

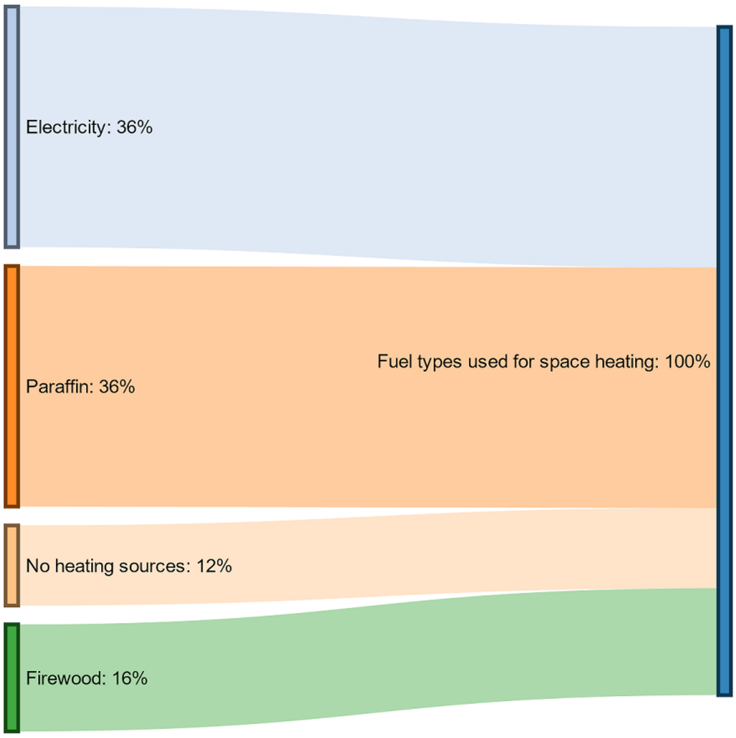

Figure 4.4: Sankey diagram that illustrates the primary fuel types that informal households use for space heating

Figure 4.4 indicate that an equal amount of households (36%) use either electricity or paraffin as a primary fuel type or energy carrier to heat their homes. Firewood is used by 16% of the households while 12% of the sample does not have any sources for heating. The 18 households that use electricity as a primary energy carrier for space heating make use of electric heaters. This appliance is primarily used in the colder seasons as well as early mornings and late afternoons. Twelve of the 18 households that use electricity as a primary energy carrier for space heating use paraffin as an alternative source to heat their homes, and the rest use firewood.

Paraffin heaters were found to be the primary source for space heating for 36% of the households because they are quick and effective at heating a home. The danger of the device falling over is very high, and this often results in a fire that destroys many homes. Paraffin heater also often doubles as a source for heating water and cooking food. Fifteen of the 18 households that use paraffin as a primary fuel type for space heating use firewood or coal as an alternative space heating source.

Table 4.4: Frequency table showing the primary fuel types used for space heating

Fuel type/ energy carrier	Number of households	Percentage
Electricity	18	36
Firewood	8	16
Paraffin	18	36
No sources for space heating	6	12
Total households	**50**	**100**

Eight informal households burn firewood in a metal can with ventilation holes (see Table 4.4). When the wood is burnt until it is hot coals, the resident of the informal household brings these indoors in order to heat up the home. The use of this device, which is commonly referred to as an *imbawula,* has numerous safety concerns. For instance, it can start a fire if it is knocked over, and it poses a safety threat to unsupervised minors and it or releases toxins that cause indoor air pollution. Even though most users are aware of and have suffered from these detrimental effects, they use *imbawulas* to heat their dwellings because the wood is gathered for 'free' and the metal can be recycled.

The discussion of firewood that informal households use for space heating addresses larger matters namely health, economic development and environmental destruction. The indoor combustion of firewood could cause respiratory and cardiovascular diseases in the residents of informal dwellings. Unhealthy people tend to be less productive and will not be able to take advantage of all income-generating opportunities; thus, they will ultimately make less money In addition, the use of firewood for space heating raises concerns about deforestation which could lead to the erosion of valuable topsoil (Lay *et al*., 2013).

The six households that do not use any carrier or energy fuel type to heat their homes keep themselves warm in various ways when the temperature drops. Warm clothing and blankets are common sources for keeping themselves warm inside their homes. This is also a secondary means of keeping warm for many other households, to keep warm especially during winter evenings. In addition, one household has two hot water bottles that it uses to keep warm at night. These six households lack funds to acquire fuel to heat up their homes.

4.2.5 Operating household appliances (radio, television, refrigerator, and iron)

4.2.5.1 Radio

The Sankey diagram below illustrates the primary fuel types and energy carriers that informal households in Kayamandi use to operate their radios.

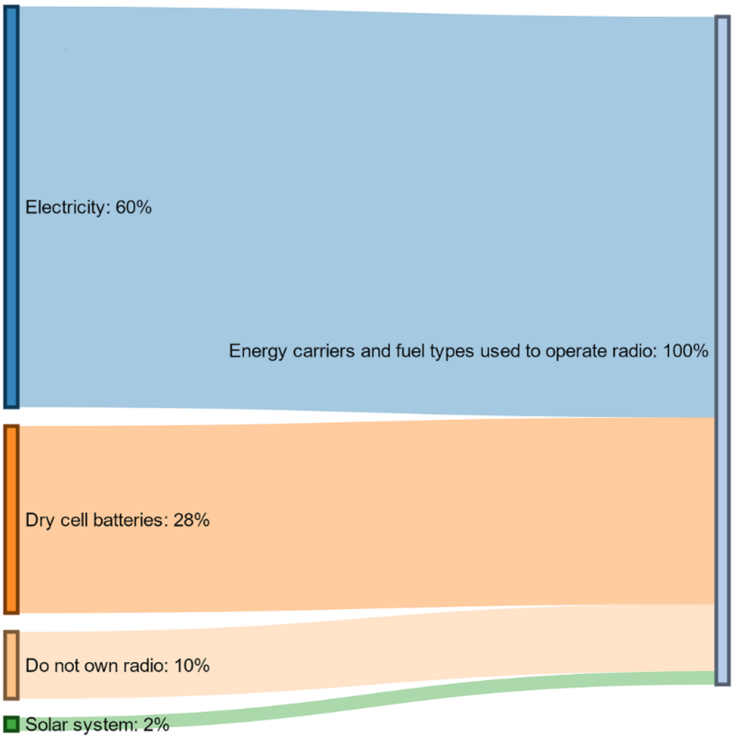

Figure 4.5: Sankey diagram that illustrates the primary fuel types that informal households used to operate their radios

The figure illustrates that 60% of the sample of informal households use electricity, 28% use dry cell batteries and 2% use a solar system as primary energy carriers to operate their radios. It also indicates that 10% of informal households do not own a radio.

From the 30 informal households that use electricity as a primary energy carrier to operate their radios, 13 use dry cell batteries as an alternative source when electricity is inaccessible. The remaining 17 households have no alternative means to operate their radios in the absence of electricity. However, many indicated that they use their cellular phones as a secondary radio if the electricity is unavailable to operate their main radio.

Table 4.5: Frequency table showing the primary fuel types used to operate radios by informal households

Fuel type/ energy carrier	Number of households	Percentage
Electricity	30	60
Dry cell batteries	14	28
Solar system	1	2
Do not own a radio	5	10
Total households	**50**	**100**

From the 5 households that that do not own a radio, 3 said that they primarily made use of their cellular phones when they wanted to listen to radio broadcasts. Many store multi-media files such as videos and songs on their cellular phones, which serves as a mobile entertainment station. Two of these households use their own electricity supply to their household to charge their cellular telephone batteries and one pays a neighbour an amount of R5.00 to charge his cellular phone battery. Some also stated that they were fearful of theft of household appliances such as radio and Hi-Fi sets from their badly secured dwellings and preferred to use the radio function of their cellular phones.

According to Table 4.5 one household use a solar system to operate a radio and various other household appliances. The owner of the informal dwelling stated that had received the SHS from his employer in 2014 and operated his radio, television and two lights with the system.

4.2.5.2 Television

The Sankey diagram below indicates that 62% of the informal households in the sample operate their television sets with electricity and that 14% use car batteries. A solar system is used by 2% of the households and no other carrier or energy fuel type is used by the households to run their television sets.

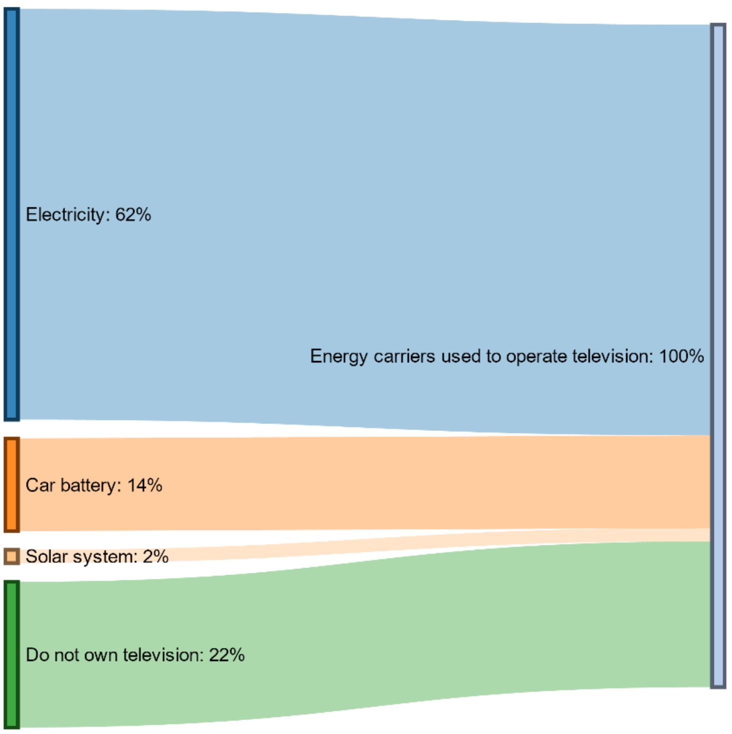

Figure 4.6: A Sankey diagram that illustrates the primary fuel types that informal households use to operate their television sets

Table 4.6: Frequency table showing the primary fuel types used to operate television sets by informal households

Fuel type/energy carrier	**Number of households**	**Percentage**
Electricity	31	62
Car batteries	5	10
Solar system	1	2
Households with no television set	13	26
Total households	**50**	**100**

4.2.5.3 Refrigerator

The Sankey diagram below illustrates that 50% of the sample of informal households use electricity as the primary carrier to operate their refrigerators while 50% do not own a refrigerator.

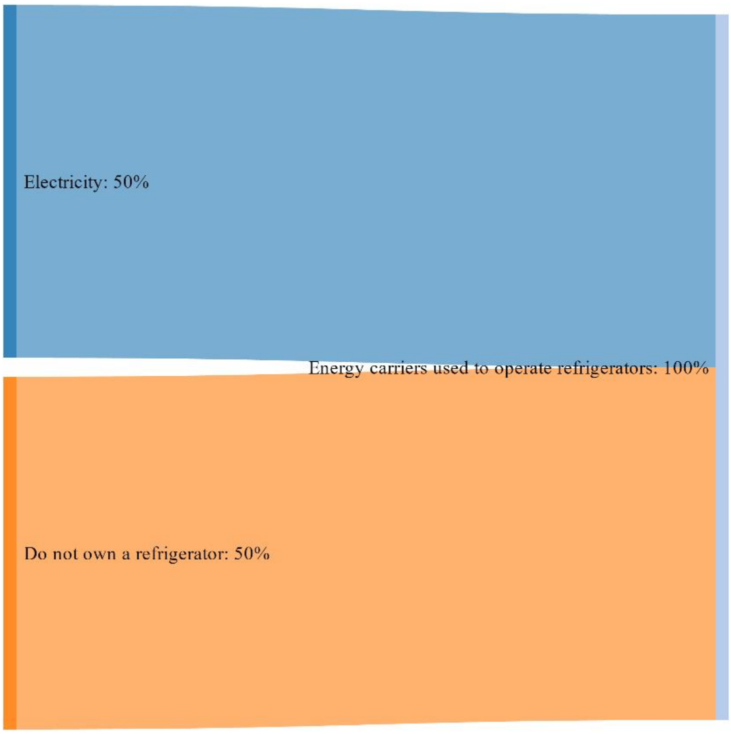

Figure 4.7: Sankey diagram that illustrates the primary fuel types that informal households use to operate refrigerators

All the households with refrigerators stated that they did not use an alternative energy carrier or fuel type to operate their refrigerators when electricity was inaccessible. Of the 25 informal households that did not own a refrigerator, 14 indicated that they regularly requested neighbours or employers to store their perishable food.

Table 4.7: Frequency table showing the primary fuel types used to operate refrigerators by informal households

Fuel type/ energy carrier	Number of households	Percentage
Electricity	25	50
Households with no refrigerators	25	50
Total households	**50**	**100**

In addition to refrigerators being relatively expensive compared to other household appliances, it is likely that the operation of a refrigerator 24 hours a day will cause a marked increase in the electricity expenses of the household. Accordingly, many informal households would not acquire a refrigerator.

4.2.5.4 Iron

The Sankey diagram illustrates that 50% of the informal household sample use electricity as an energy carrier to operate their irons. The rest of the sample does not own an iron.

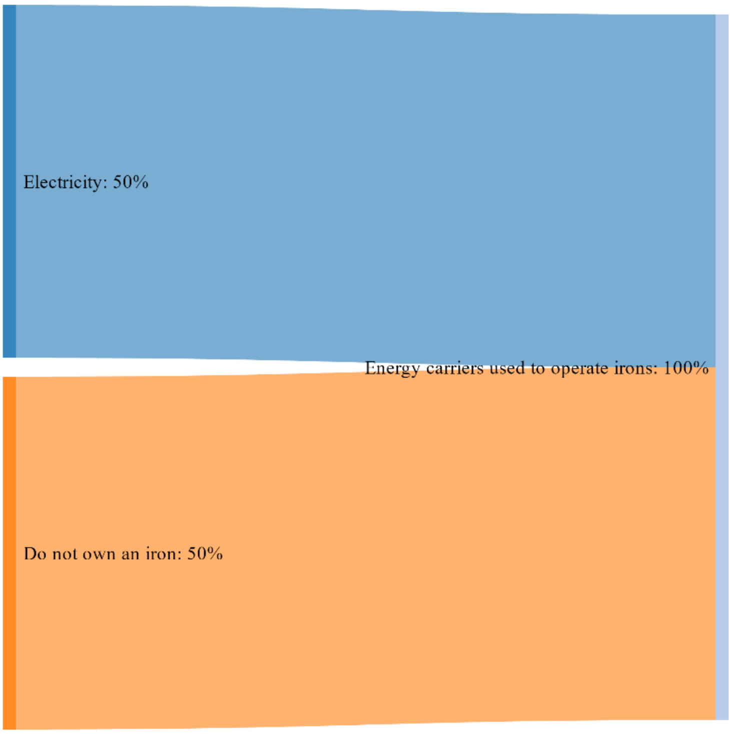

Figure 4.8: Sankey diagram that illustrates the primary fuel types that informal households use to operate irons

Of the 25 households that do not own an iron 10 indicated that they share an iron with a nearby neighbour or family member.

Table 4.8: Frequency table showing the primary fuel types used to operate irons by informal households

Fuel types/energy carriers	Number of households	Percentage
Electricity	25	50
Households do not own an iron	25	50
Total households	**50**	**100**

4.3 Household expenditure on fuel by type

This section scrutinises the financial expenditure per month on the various energy services of the 50 informal households that formed part of the study sample. First the financial expenditure was analysed in terms of various fuel types and energy carriers of the 31 informal households with access to the main electricity grid. Then the expenditure on the various energy fuel types and carriers on informal households with no electricity access was examined.

4.3.1 Financial expenditure on energy carriers and fuel types per month of informal households with electricity access

The 31 informal households with access to electricity spend on average R473.00 per month on electricity for cooking, lighting, water heating, space heating and operating household appliances. Table 4.9 indicates that the average cost of electricity is R175, paraffin R113, gas R75, candles R55, firewood 30 and dry cell batteries R25 per month.

Table 4.9: Financial expenditure on fuel types and energy carriers of urban informal households that have access to electricity

Fuel types/energy carriers	The average amount in Rand (R) spent per month by the 31 informal households with electricity access
Paraffin	113
Gas	75
Candles	55
Firewood	30
Electricity	175
Dry Batteries	25
Amount	**473**

The electricity cost per month amongst the 31 informal households varies between R0 and R620. Three respondents said that they paid a monthly all-inclusive rent to the owner of the property where there dwelling was erected. Thus, they were unsure of the exact cost of this unrestricted access to electricity every month. The electricity cost of eight households is more than R 500. These high cost could be ascribed to property owners inflating electricity prices.

4.3.2 Financial expenditure on fuel types and energy carriers per month of informal households with no electricity access

The 19 informal households that do not have access to electricity spend an average of R526 on firewood, paraffin and gas for cooking, lighting, water heating, space heating and operating household appliances. The average cost of paraffin is R185, gas R115, candles R85, dry cell batteries R56, firewood R50, and car batteries R35 per month.

Figure 4.10: Financial expenditure on fuel types and energy carriers of urban informal households with no electricity access

Fuel types/Energy carriers	**The average amount in Rand (R) spent per month by the 19 informal households with no electricity access**
Paraffin	185
Gas	115
Candles	85
Firewood	50
Solar System	--
Dry Batteries	56
Car batteries (charging)	35
Amount	**526**

Informal households that operate their television sets with car batteries purchased them second hand for R 350. They recharge these batteries on a monthly basis and pay R 35.

The household that make use of a solar system for lighting and household appliances had to replace a wire which cost R50 in January 2015. Other than that, the household has not had to pay any other maintenance fees for the SHS. The one household has not had to spend money on alternative fuel types or energy carriers to provide lighting as the solar lights provide all the light that they need.

4.4 Research question 2

To what extent can renewable energy technologies contribute to the provision of energy services in urban informal households?

4.4.1 Cooking

None of the interviewees had any experience of DRE technologies that provide a cooking service, in particular to urban informal households. Even though awareness campaigns about the dangers of cooking with commonly used fuel types such as paraffin, firewood and gas take place on a regular basis in Kayamandi, no stakeholder group actively promotes renewable energy technologies that could provide cooking services to informal households. Respondent 3, a social worker in Kayamandi, said that these campaigns focus on informing people about the dangers of cooking with these fuel types but that they provides no cleaner, safer and more affordable alternative energy carriers or fuel types that specifically informal households can use to cook with.

All the interviewees highly doubted the practicality and financial viability of DRE technologies that could be used for cooking in urban informal households, specifically in Kayamandi. Respondent 4 suggested that even if a technology, for example solar cookers, was financially accessible to informal households the storage of the devices in relatively small dwellings of between 12 and 20 m^2 as well as the residents' long working hours prevented the uptake of this solar technology.

> The small area of shacks is not suitable for solar cookers that look very big to me. To be stored in a shacks... some people work long 12 hour shifts as petrol attendants and security guards so they leave their homes before the sun rises for the early shift which starts at 6 or 7 and return home after sunset. This is the reality of many residents in Kayamandi... So even if they could afford a solar cooker it would be a waste of money because they won't be able to use it before sunrise when they have to leave for work and at night when they get home after dark…

Despite the fact that various stakeholder groups in Kayamandi do not view solar cookers as a viable option for cooking, many informal households with no electricity supply are interested in this technology for cooking. Approximately 60% of the 19 informal households in this sample with no access to electricity said that if they had the financial means, they would use a solar technology for cooking. This would replace of gas, paraffin and wood. Many housewives admitted that it was embarrassing for them to cook their meals with paraffin and firewood, especially on a Sunday when many households cook big, traditional family lunches.

These findings have important consequences for the potential deployment of solar cooking technologies in urban informal households. It is important that manufacturers and retailers of solar cooking technologies expose potential end consumers to alternative cooking devices to build familiarity and trust. Researchers should also involve target markets from the inception of the design phase to factor in the unique needs and circumstances of various markets. Accordingly, these efforts may build trust in these solar cooking devices and could persuade community members and various stakeholders that with a few lifestyle changes, it is practical for them to cook with solar energy devices.

The benefits of cooking with solar energy, such as improved indoor air quality and a potential savings should be stressed during these awareness campaigns. This should specifically be of interest to the Department of Health because of the potential to reduce pulmonary infections. Even though there is evidence that government departments that are involved in disaster risk management do spread awareness about the safety risks using paraffin, gas and firewood as fuel, they could also emphasise solar cooking technologies that may provide cooking services. Thus, it is highly likely that informal households in Kayamandi will consider using DRE technologies for cooking if these efforts are supported by a wide range of stakeholder groups that are aware of the practicality of certain technologies that could provide this energy service.

4.3.2 Lighting

Several respondents have personally experienced how DRE technologies, in particular SHSs, provide lighting services for urban informal households. Respondent 2 said that his family used a relatively expensive SHS at their homes in both Swaziland and Mozambique for lighting and for operating household appliances. His brother bought this solar system, which allows three lights to run for up to eight hours every day, in South Africa.

> …even though my brother paid a lot of money for the solar system we could do our homework at night and save the paraffin that we normally used for our lights at home. I don't think that this community [Kayamandi] are prepared to pay upfront cash to have a solar system for lighting their shacks so another means of paying will have to be looked at if we want more shacks to use this solar system …

Kayamandi has also been a recipient community of various instances of deployment of DRE technologies that provide lighting specifically for informal households. The NGO that Respondent 1 works for, served as a facilitator to distribute solar lights to informal households in Kayamandi in 2014. Moreover, this NGO advocates stronger ties between civil society bodies and manufacturers and distributors of renewable energy technologies to increase the uptake of specifically, DRE technologies in urban informal households to provide lighting.

> [Name of NGO] partnered with an energy technology manufacturing company to distribute solar lights to informal households in Kayamandi… I saw that these lights made a difference in the community because at night the households that received the solar lights were lit. The distribution of the solar lights was a once-off project that our organisation was involved with. The manufacturing company approached us to act as intermediaries in the process because we were well acquainted with the community members of Kayamandi. Our role in the project was to identify 50 informal households that could use these solar lights.

Respondent 1 also admitted that the uptake and use of these solar lights were extremely popular because many households used the lights to light the area around their houses at night to deter burglars. Many households that had not received solar lights requested to be beneficiaries of the solar light roll out if it happened again. Even though, Respondent 1 was sceptical about how sustainable the deployment of free solar lights would be in the long run, she acknowledged that such projects were a good way to expose households to cleaner energy technologies.

All of the interviewees were aware of the iShack project that has been renting Solar Home Systems to over 1000 informal households in the Enkanini informal settlement since October 2013 (DEA, 2015). These SHSs can provide lighting, charge cellular phone batteries and run a television set for a nominal monthly fee. This fairly basic service can be incrementally upgraded so that households can add other appliances, such as fridges. Full-time, skilled iShack agents that are recruited from the local community are responsible for installing and maintaining these solar systems. The *iShack* project was set up as a large scale demonstration project, funded by the Green Fund, to show that off-grid electricity services for informal settlements can be financially sustainable (DEA, 2015).

It is almost certain that this off-grid electricity service project is financially viable due to the support of the public administration and policy and decision-maker stakeholder groups. A municipal official said that Stellenbosch Municipality has been very supportive in creating a space for the growth of viable alternatives to conventional electricity generation and distribution practices, specifically the iShack project. He said that the municipality's Indigent Policy had been amended to appoint service providers to provide off-the-grid electricity and to pay them the indigent subsidy, which is also known as free basic electricity. A Service Level Agreement was signed in April 2015, where after the free basic electricity subsidy was paid directly to the service provider.

The discussion of solar energy technologies that could potentially provide lighting for informal households addresses larger matters such as the quality of education, health conditions, socio-economic conditions, and a safety conditions. School going children can have more time at night to do their school work without wasting energy fuel types such as candles and paraffin. Solar lights can extend work hours, allowing businesses and individuals to extend their income-generating undertakings and other social activities. The use of solar lights at night can create a safer environment for communities because safety is a big concern on Kayamandi.

In short, it appears that DRE technologies such as SHSs or solar lights could supplement or even replace the commonly used fuel types and energy carriers that urban informal households use for lighting.

4.4.3 Water heating

All the interviewees were familiar with DRE technologies, in particular solar water heaters, which are used to heat water for specifically formal households. Respondent 7, an energy entrepreneur, said that solar water heaters were a popular energy-saving measure in relatively high-income areas, but more recently government had started deploying solar water heaters to low-income formal households. He added that even though solar water heaters did not function optimally on overcast days, this DRE technology provided effective hot water supply with no fuel costs and minimal required maintenance.

The education and science stakeholder group and the civil society stakeholder groups appear to be aware of their responsibility to promote affordable DRE technologies to urban informal households. Respondent 4, a qualified engineer and academic, suggested that ongoing research was taking place to invent financially viable technologies that would fit into the lifestyles of informal households. He said that it was highly unlikely that an informal household in Kayamandi could presently afford to buy a 150 litre solar water heater that cost no less that R13000, excluding the expected installation cost of around R3000. He also suggested that the researchers of energy solutions lessened the appeal for renewable energy technologies by only involving end users close to the end of the project.

> …I think that engineers and inventors should consult the target group that they are designing energy solution for from in the planning phase of their innovation and not at the launch of their products as what is currently happening. This approach will open their eyes early in the design phase to how practical and financially viable their proposed technology solution will be.

There appears to be several difficulties that hinder the use of solar water heaters that could provide water heating services to urban informal households. Respondent 4, a trained engineer and academic, claimed that many of the informal households did not have a reliable water supply. He stated that many informal households obtained their water from communal taps that could be quite a distance from the households.

> …and solar water heaters also require a constant piped water source to function and currently none of the informal households have water piped to their house.

Furthermore the weak building structures that mostly consist of corrugated iron, wood, cardboard, and paper does not seem to be able to support solar water heaters which are normally mounted on the roofs of households. Respondent 4 recommended that 2 litre soft drink bottles be placed on the roofs of informal dwellings during the day in order to be heated by the sun. Respondent 7, an energy entrepreneur, concurred and said that it was too risky to install solar water heaters on the roofs of informal dwellings because of the high safety risk.

> …solar water heaters must be mounted on a roof or some other raised area to function properly. They hold 150-300 litres and therefore must have a secure roof to be mounted to.

A solar water heater that is stationed on the roof of the main formal dwelling on the property where the informal dwelling is situated could be the solution. This situation, however, may lead to conflict between the two households as hot water is limited, especially in the morning when people go to school and work according to a social worker, Respondent 2. Respondent 4 also alluded to the challenge of piping the water from the solar water heater to the informal household in this scenario.

Nevertheless, Respondent 8 said that centrally located buildings with plenty of roof space to fit multiple solar water heaters could generate a great deal of hot water that informal households could collect with insulated containers.

> Rooftops of churches, schools, and community centres can house numerous water heaters which can be provided to residents of informal households…they could pay a small fee that goes towards paying for the initial investment, maintenance cost and labour cost if anyone is needed to work at the hot water distribution point.

Respondent 8, a manufacturer and distributor of renewable energy technologies, pointed out that due to the high cost of the solar water heaters, theft was a concern in Kayamandi.

> …copper piping is very valuable and any system designed with copper has the potential to be a target for theft…

Conversely, Respondent 7 pointed out that installers of solar water heaters usually paint the copper pipes black so that they can absorb thermal radiation more effectively. The black paint disguises the metal, which makes it less likely to be stolen.

In short, it appears that DRE technologies such as single solar water heaters are not practically feasible and financially viable to replace or supplement the commonly used fuel types and energy carriers used by informal households in Kayamandi for water heating. A solar water heater is only practical if the informal dwelling is situated on the property of a formal dwelling on which roof the solar water heater can be installed as the structure of the informal dwelling is usually not strong enough. Otherwise, centrally located multiple heaters could serve a number of informal households with hot water on a daily basis, provided that they have a backup heating system such as gas or electricity for overcast days.

4.4.4 Space heating

None of the interviewees are familiar with DRE technologies that could provide space heating for informal households. According to Respondent 4, most informal households insulate their homes by using cardboard, newspaper and other random materials on the walls and in gaps. These materials are used on the exterior of the dwelling to prevent the wind from entering and the heat from dissipating, especially during winter.

4.4.5 Operating household appliances (radio, television, refrigerator, and iron)

Several research participants believe that DRE technologies can be used to operate household appliances such as televisions, cellular phones, refrigerators and radios. Respondent 3 described how her family that lives in an informal dwelling use a simple SHS to charge cellular phone batteries.

> We have been using a solar system to charge our cellphones and for our television for a number of years now. It saves my parents money that they could spend on food…

She also claimed that her parents preferred to operate their radio with dry batteries rather than the SHS because they switched it on when no one was home to deter potential burglars. She added that this was a common phenomenon in the informal settlement where she lived and that televisions that were operated with car batteries were also left functioning in the absence of the homeowners to create the illusion that someone was home.

Respondent 6, a manager of a factory that manufactures solar systems for households, said that they were actively involved in promoting the uptake of these systems in specifically informal households.

> Our company has partnered with the Department of Environmental Affairs and provide skills to entrepreneurs to sell these solar home

> systems to shack dwellers. These entrepreneurs are operational in many of the black townships where there is a large concentration of informal households. They market and sell these solar systems to these communities...

He also claimed that the modular design of this DRE technology made it possible to operate a television, a refrigerator, a radio and an iron in an informal dwelling.

These findings have important consequences for the broader domain of access to information and fresh food. Households need to be connected to televisions and radios to obtain the latest information about heath, financial and general community matters. The many unemployed people in Kayamandi could have affordable access to information that may result in business opportunities or job opportunities, which would consequently improve their socio-economic conditions. Refrigerators allow households to store a wide variety of food for many days, which could improve the health of the residents.

In short, it appears that DRE technologies, for example a SHS, could supplement or replace the commonly used energy carriers that informal households use to operate their televisions, refrigerators, irons and radios.

4.5 Summary

It is clear that in the majority of informal households electricity is the preferred energy carrier to provide energy services. Apart from electricity, firewood, paraffin and gas seems to be the most used fuel types for cooking, lighting, water heating, space heating and operating household appliances. These commonly used fuel types and energy carriers have detrimental social and environmental impacts on informal urban households and do not support modern economic development. The Sankey diagrams illustrate that approximately 60% of informal households in the sample of access to some type of electricity. All households use more than one fuel type for various energy services, confirming the multiple fuel use model in urban informal households in Kayamandi. Informal households spent between 10% and 15% of their income on electricity, paraffin and gas.

It appears that lighting, operating household appliances and water heating are the only energy services that can either be provided or supplemented by DRE technologies for urban informal households. There appears to be some practical concerns around the use of solar cookers for cooking purposes and DRE that can provide space heating for urban informal households are unknown.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The objectives of this study were to identify the fuel types and energy carriers that urban informal households commonly used for lighting, cooking, space heating, water heating and operating household appliances as well as to identify the roles of stakeholders that might increase the uptake of DRE technology on a local level by urban informal households. Chapter 5 outlines the key contributions and findings of this study by summarising the current energy use as well as the extent to which renewable energy technologies can contribute to the provision of energy services in urban informal households. This chapter also highlights the roles that the different stakeholder groups can play that form part of the strategy to enhance the uptake of DRE in urban informal households. A number of limitations and areas of improvement and considers a variety of topics for future research.

5.2 Current energy use in urban informal households

It is important to understand the fuel and energy carrier choices of household in order to design policies that could support the energy transition process. Electricity is the energy carrier of choice for the majority of urban informal households to provide them with energy services such as cooking, lighting, water heating, space heating and operating household appliances. The price of fossil fuel-generated electricity is increasing at above-inflation rates, making it more and more unaffordable for many informal households many of whom are unemployed. Nevertheless, the subsidies that the fossil fuel generated electricity sector enjoys and the exclusion of externalities still result in an artificially low price, making this energy carrier affordable to many informal households.

The multiple-fuel use model is evident in households of different socio-economic statuses that were part of this research. The secondary fuel types used by most used by households for the various energy services are paraffin, gas and firewood. This finding challenges the work of earlier researchers who have long assumed that an increase in household income will stop the use of primitive fuels such as firewood.

It is highly probable that the use of various fuel types and energy carriers for energy services is influenced by the above-inflation electricity price increases, unreliable electricity supply and cultural preference for a specific fuel type for a particular energy service. For instance, many South African households prepare meat in the open air with firewood, coal or gas even if they have access to electricity. In addition, many households view firewood as a 'free' source of energy and a means to save money.

Even though the health and safety risks of using paraffin, gas and firewood for cooking, lighting, water heating, and space heating are known to most informal households these fuel types are most commonly used as primary and secondary fuel types.

Owing to the lack of insulation of informal dwellings, keeping the homes warm is a challenge. The increasing price of paraffin makes the perceived 'free' source, firewood increasingly likely to be used as a means to heat their homes. As a result of the lack of money to acquire fuel types or energy carriers to heat their homes, several informal households only use warm clothing, blankets and hot water bottles to stay warm.

Despite the fact that many informal households are aware of the benefits of DRE, technologies there is a small uptake of these technologies such as SHSs and solar lights. Solar lights are often used to promote safety and security and enable households to save money.

5.2.1 Sankey diagrams

The Sankey diagrams created for this study show the ratio of primary fuel types and energy carriers that urban informal households use for the respective energy services namely cooking, lighting, water heating, space heating and operating household appliances.

The Sankey diagrams reveal the current preference of informal households for electricity as a primary energy carrier for cooking, lighting, water heating and operating several household appliances. Paraffin appears to be used by a similar number of households as electricity for space heating. Paraffin is also used extensively by large proportion of households for cooking, lighting and water heating.

The Sankey diagrams also depicts the extensive use of fuel types such as paraffin, firewood and gas for cooking, lighting, water heating and space heating. These illustrations can be used to plan the increasing deployment of renewable energy technologies in urban informal households.

The Sankey diagrams could assist in identifying areas where renewable energy technologies can be incorporated into the energy portfolio of urban informal households in order to reduce the environmental and safety hazards caused by the commonly used fuel types and energy carriers. In addition, these Sankey diagrams can increase awareness amongst civil society stakeholders about energy concerns and improve their ability to contribute to domestic energy challenges and needs. In addition, the diagrams could help researchers, policy and decision makers, and public administrations to understand the energy flows of urban informal households for the various energy services. Besides, they can also help simplify energy issues for concerned citizens, civil society bodies and environmental NGOs.

5.2.2 Financial implications

Informal households with access to the main electricity grid spend on average R 473 per month on all energy carriers and energy fuel types while informal households with no access to electricity spend R526 on numerous fuel types. This is between 10-15% of the urban informal household income and represent an exorbitant amounts considering South Africa's high unemployment rate.

5.3 Extent of renewable energy technology contributions to the provision of energy services in urban informal households

5.3.1 ECOlite solar home system

It is highly likely that an ECOlite SHS could provide urban informal households with several energy services such as cooking, lighting, water heating, space heating and operating numerous household appliances. The SHS's practical design is highlighted by the modularity of the technology that allows households to add extra PV panels if they want to operate more appliances.

The multi-pronged business plan enhances the sustainable deployment of the ECOlite SHS in specifically low income areas. Employing the local youth as agents to market and sell this technology in the target market builds trust amongst prospective users. This strategy could also alleviate the high unemployment rate. The numerous strategic relationships that the manufacturing company has with government and private entities increase the capacity of the company to continuously improve the design of this technology and also to help more informal households to gain access to clean energy.

5.3.2 SolarTurtle

The SolarTurtle is able to provide urban informal households with a lighting service and to operate many household appliances. Central locations such as school premises or churches could be used to house this technology for easy access by community members. The female-headed operation is able to curb the unemployment in Kayamandi. However, the distance that people have to travel to collect their batteries may be a safety hazard, specifically in the morning or after dark. The amount of space needed to house these SolarTurtles could also be a challenge to find.

5.3.3 Solar water heater

A single solar water heater is impractical to fit onto an informal dwelling due to its poor construction. A centralised solar water heater that can accommodate the warm water needs of many informal households can be placed on the roofs of schools. Local residents can be employed to see to the functioning and maintenance of this central water heater. However, the distance that users may have to walk to access the hot water may be a safety concern.

5.3.4 Solar bottle bulb

The solar bottle bulb is a practical way for informal households to light their dwellings during the day by using recycled and environmentally friendly material. This simple technology comes with no safety risks and only needs replacement after five years of use. Urban informal households can save money when they install a solar bottle bulb in their dwelling.

5.4 Strategy to increase DRE technology deployment

The following responsibilities of the various stakeholder groups could increase the deployment of DRE technologies in urban informal households:

Education and science

The benefits of using DRE technologies could be included in the curricula from pre-primary to high school level. School children could also help to familiarise their families in the targeted communities by manufacturing DRE technologies at school that can be used for various energy services. Teachers could attend regular workshops and give input on how to include DRE technologies in the school curriculum. Renewable energy researchers should properly consult with the communities during the feasibility stages if they want to improve or design a new DRE technology.

Industry

The increasing financial investment of private companies in off-grid energy solutions that target low income households, such as urban informal households, may be mutually beneficial for all parties. Private companies could provide initial capital outlay for renewable energy projects in exchange for a percentage of the project revenue and profits.

Policy and decision makers

Municipal councillors need to be informed of all activities around the deployment of DRE in his ward and inform his constituency of these programmes timeously. A ward committee member could also be appointed the energy champion in the municipal ward to help steer awareness campaigns around the deployment of DRE technologies.

Public administration

Municipalities could play a pivotal role in coordinating all the research, awareness campaigns, and the roll-out of DRE in localities. They are perfectly positioned to stay in touch with all stakeholders and an accessible point of entry for organisations or individuals with new proposals around the deployment of DRE technologies. Municipalities can also create awareness about the benefits of using renewable energy technologies. Relevant government departments could also provide policy support and guidance and purchase all excess electricity that is generated by renewable energy projects.

Intermediaries

Due to the small-scale of the transition process Intergovernmental Organisations may play a secondary supporting role by giving policy advice or helping to raise additional funding for the deployment of DRE technologies in localities. However, the transition process could be led by locals.

Finance

Various financial models could be employed to increase access to renewable energy technologies such as ‘fee-for-service’, cross-subsidisation, and end-user microfinance. Commercial banks, for example, could rent solar home systems to customers and in localities where more than 20 people work for an employer, a mass purchase of DRE should be discounted.

Civil society

Community involvement in renewable energy projects could stimulate a bottom-up approach to finding sustainable energy solutions. Concerned citizens should play a leading role in advocating for cleaner, more affordable energy technologies in their communities. Community groups could invest some of their own money in renewable energy projects and take ownership of these initiatives. Community members could also provide labour to construct renewable energy projects as well as maintaining these technologies when in operation.

5.5 Limitations of study

The research produced unique and useful results. However, the study was not without its shortcomings that could have influenced the results and findings. This study investigated the energy use of informal households in an urban setting. The majority of research participants in the questionnaire and semi-structured interview were male. The small sample of fifty households that the questionnaire was administered to could also be seen as a weakness. Informal households that formed part of an established informal settlement did not form part of the sampling frame for administering the questionnaire. This study investigated the extent to which distributed solar energy technologies could provide energy services for urban informal households.

5.6 Recommendations for future work

A similar study can be conducted with more research participants. A study to investigate the energy flows in urban formal households, as well as rural households may also be considered. A study can be conducted to investigate to what extent other renewable energy technologies such as biogas and wind energy can be used to provide energy services to urban informal households. There is also a need to do research on how renewable energy technologies can leapfrog in informal economies. A study on the loss of productivity and income-generating opportunities due to ailments caused by indoor air pollution in urban informal households can also be conducted.

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Appendix A: Questionnaire

Dear Respondent

Thank you for being part of this study that is titled Energy infrastructure transitions in urban informal households in South Africa. As part of my Master of Philosophy studies, I would like to ask you to please complete the following short questionnaire. Your responses are confidential and anonymous. The questionnaire consists of three sections. In the first section, I would like to ask you some questions about the fuel types that you use in your household for lighting, cooking, water heating, space heating and for operating household appliances. The second section of the questionnaire looks into the amount of money that you spend on the energy fuel types that you use for the various services. The questionnaire ends with a few questions about how the availability of renewable energy systems would affect your energy fuel type choice for various energy services. This research is conducted in accordance with Stellenbosch University's Framework Policy for the Assurance and Promotion of Ethically Accountable Research and I will furnish you with an electronic or hard copy of this document upon request. Do you have any questions regarding the study before we begin?

1. How many people form part of this household, counting yourself? ______________
2. What is the size of this dwelling? ______________
3. What fuel types do you use for lighting in this household?
4. What is the proportion of fuel types that you use for lighting in this household?
5. What is the quantity of each marked fuel type that you use for lighting in this household?

	3. Mark all fuel types used for lighting with an X	4.Proportion of fuel types that are used for lighting	5.Quantity of fuel types that are used for lighting
a. Paraffin			
b. Gas			
c. Candles			
d. Solar system			
e. Electricity			
f. Dry cell batteries			
g. Car batteries			
h. Generator (petrol/diesel)			
i. Other (specify)			
Don't know			
Total		**= 100%**	

6. What fuel types do you use for cooking in this household?
7. What is the proportion of fuel types that you use for cooking in this household?
8. What is the quantity of each marked fuel type that you use for cooking in this household?

	6. Mark all fuel types used for cooking with an X	7.Proportion of fuel types that are used for cooking	8.Quantity of fuel types that are used for cooking
a. Paraffin			
b. Gas			
c. Solar system			
d. Firewood			
e. Coal			
f. Electricity			
g. Car batteries			
h. Generator (petrol/diesel)			

i. Other (specify)			
j. Don't know			
Total		**= 100%**	

9. What fuel types do you use for heating water in this household?
10. What is the proportion of fuel types that you use for heating water in this household?
11. What is the quantity of each marked fuel type that you use for heating water in this household?

	9. Mark all fuel types used for the heating with an x.	**10. The Proportion of fuel types that are used for heating water.**	**11. Quantity of fuel types that are used for heating water.**
a. Paraffin	01		
b. Gas	02		
c. Coal	03		
d. Firewood	04		
e. Solar geyser	05		
f. Electricity - electric geyser	06		
g. Electricity - electric kettle	07		
h. Electricity - electric stove/hotplate	08		
i. Generator (petrol/diesel)	09		
j. Other (specify)	10		
k. Don't know	98		
l. Not applicable - water is never heated in the household)	99		
Total		**= 100%**	

12. What fuel types do you use for heating rooms and keeping warm in your household?
13. What is the proportion of fuel type(s) that you use for heating rooms and keeping warm in this household?
14. What is the quantity of each marked fuel type that you use for heating rooms and keeping warm in this household?

	12. Mark all fuel types used for heating rooms and keeping warm with an X	**13. Proportion of fuel types that are used for heating rooms and keeping warm.**	**14.Quantity of the fuel that is used**
a. Paraffin	07		
b. Gas	02		
c. Coal	03		
d. Firewood	04		
e. Solar system	05		
f. Electricity	06		
g. Car batteries	08		
h. Generator (petrol/diesel)	09		
i. Blankets (not electric)	10		
j. Warm clothing	11		
k. Hot water bottle	12		
l. Other (specify)	13		
m. None of the above	14		

n. Don't know	98		
Total		**= 100%**	

What fuel types do you use to run the following appliances in this household?

	15. Radio/Hi-Fi			**16. Television**			**17. Fridge**			**18. Iron**		
	a)Mark X	b)Proportion	c)Quantity	a)Mark X	b)Proportion	c)Quantity	a)Mark X	b)Proportion	c)Quantity	a)Mark X	b)Proportion	c)Quantity
a. Paraffin										01		
b. Gas										02		
c. Coal										03		
d. Firewood										04		
e. Solar System	05			05			05			05		
f. Electricity	06			06			06			06		
g. Dry cell batteries	07			07			07			07		
h. Car batteries	08			08			08			08		
i. Generator (petrol/diesel)	09			09			09			09		
j. Other (specify)	10			10			10			10		
k. Don't know	98			98			98			98		
l. Not applicable – no appliance	99			99			99			99		
Total		**= 100%**			**= 100%**			**= 100%**			**= 100%**	

Thank you so much for your participation thus far. We are moving on to the second section of the questionnaire that deals with your household's financial expenditure on energy. I assure you once again that your responses are completely anonymous and confidential.

19. On average, how much does your household spend each month on the following fuel types?

	Energy cost
20. Paraffin	R
21. Gas	R
22. Candle	R
23. Coal	R
24. Firewood	R

25. Solar system	R
26. Electricity	R
27. Dry cell batteries	R
28. Car batteries	R
29. Generator (petrol/diesel)	R
30. Other specify	R
31. Household expenditure on energy per month (Total)	**R**

Thank you so much for your participation thus far. We are moving on to the final section of this questionnaire that explores how the availability of renewable energy system would affext your fuel type choice for various energy services.

32. If you are provided with a Decentralised Renewable Energy Systems, such as a Solar Home System, that could provide you with services which energy fuel type would you replace?

Fuel types	**Mark with X**
Paraffin	01
Gas	02
Coal	03
Firewood	04
Electricity	06
Dry cell batteries	07
Car batteries	08
Generator (petrol/diesel)	09
Other (specify)	13
None of the above	14
Don't know	98

33. If you are provided with a distributed renewable energy system, such as a solar home system, that can provide you with energy services, which energy service would you replace?

Mark with X					
Energy services	Cooking	Lighting	Water heating	Space heating	Household appliances

34. Is there anything else that you would like to mention?

Thank you so much for your time and feedback. It is much appreciated. I assure you once again that your responses are completely anonymous and confidential. Thank you very much for your participation.

Appendix B: Semi-structured interview questions

Dear Respondent,

Thank you so much for agreeing to be interviewed as part of my Master of Philosophy studies. The topic of this study is *Energy Infrastructure Transitions in Urban Informal Households in South Africa*. It is hoped that the findings of this study can highlight distributed solar energy technologies as an alternative and supplementary provider of energy services such as cooking, lighting, space heating, water heating and operating appliances in urban informal households.

I will be taking notes as well as audiotaping this interview and will be happy to send you a typed copy of my notes tomorrow so that you could verify that the responses that I have ascribed to you are accurate. This research is conducted in accordance with Stellenbosch University's Framework Policy for the Assurance and Promotion of Ethically Accountable Research, and I will furnish you with an electronic or hard copy of this document upon request. You have the right not to participate in this interview and also not to complete the interview, if you do not wish to do so. Do you have any questions regarding the study before we begin?

1. Could you describe in as much detail as possible what experiences you have had with distributed renewable energy systems, such as solar home systems that may have assisted in providing energy services namely cooking, lighting, water heating, space heating and operating household appliances?

2. How does your stakeholder group – school/university/industry/policy- and decision maker/public administration/civil society/intermediaries/finance - engage in the process of promoting renewable energy technologies to specifically urban informal households?

3. In your opinion, what more can your stakeholder group do to facilitate the deployment of distributed renewable energy systems to urban informal households?

We are almost done; we just have two questions left. Thanks so much for your participation thus far.

4. What concerns does your stakeholder group have about the uptake and use uptake and use of distributed renewable energy systems by urban informal households?

5. Is there anything else that you would like to mention?

Thank you so much for your time and feedback. It is much appreciated. I assure you once again that your responses are completely anonymous and confidential. Would you like me to send you a typed copy of the interview, so that you could check the accuracy of the responses that I have ascribed to you?

Appendix C: Consent to participate in research form

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jou kennisvennoot • your knowledge partner

Topic: Energy Infrastructure transitions in urban informal households in South Africa

You are asked to participate in a research study conducted by Mr Ebenaezer Appies (BA Environmental Management, Postgraduate Diploma in Sustainable Development), from the School of Public Leadership at Stellenbosch University. You were selected as a possible participant in this study because you form part of one or more of the following stakeholder groups:

i. inhabitant of an urban informal household
ii. education and science (schools, universities, research institutions)
iii. industrial enterprise
iv. policy and decision-makers
v. public administration
vi. civil society
vii. intermediaries (labour unions, chambers of commerce)
viii. finance (banks, funding schemes, venture capital)

1. PURPOSE OF THE STUDY

The preliminary investigation suggests that limited consideration has been given to the energy infrastructure transition process from traditional to modern fuel types. Thus, we do not use the opportunity to incorporate renewable energy technologies that function in more efficient and cleaner way into the process. This also prevents the increase of access to these modern, cleaner energy technologies. Therefore, the purpose of this study is to explore whether the regional innovative system approach to sociotechnical transitions can enable access to renewable energy technologies that can provide energy services for urban informal households. The associated research questions are:

i. What are the current energy flows of urban informal households in Kayamandi?
ii. To what extent can renewable energy technologies contribute to the provision of energy services in urban informal households?

2. PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:

(i) Meet with the researcher for 20-30 minutes at a venue of your choice.
(ii) Answer questions that the researcher poses regarding the energy infrastructure transition in urban informal households in Kayamandi.

3. POTENTIAL RISKS AND DISCOMFORTS

There are no risks associated with this research.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

There are no known personal benefits that would result from your participation in this research. This research may, however, help us to understand the role of the different subsectors in creating an environment where increased access to modern energy technologies such as renewable energy technologies for urban informal households is realized.

5. PAYMENT FOR PARTICIPATION

There is no payment for participating.

6. CONFIDENTIALITY

Any information that is obtained during this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by assigning an identification code to every interviewee. All research records obtained will be kept locked in the office of the researcher's supervisor (Dr Josephine Musango). The interview might be audio-taped and you have the right to review/edit the tapes. The tapes will be locked in the office of the researcher's supervisor where no one will have access to the tapes.

You can choose whether to participate in this study or not. If you volunteer to participate, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions that you do not want to answer and still remain in the study. The researcher may withdraw you from this research if circumstances arise that warrant doing so.

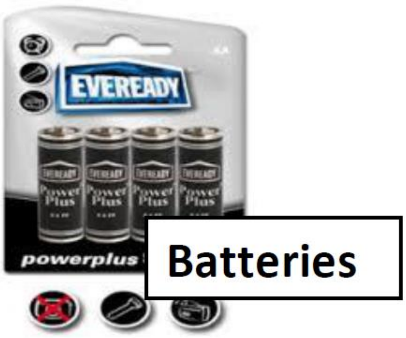
7. IDENTIFICATION OF RESEARCHERS

If you have any questions or concerns about the research, please feel free to contact the researcher at 071 750 4279 or email ebenappies@gmail.com or his supervisor, Dr Musango at Josephine.Musango@spl.sun.ac.za

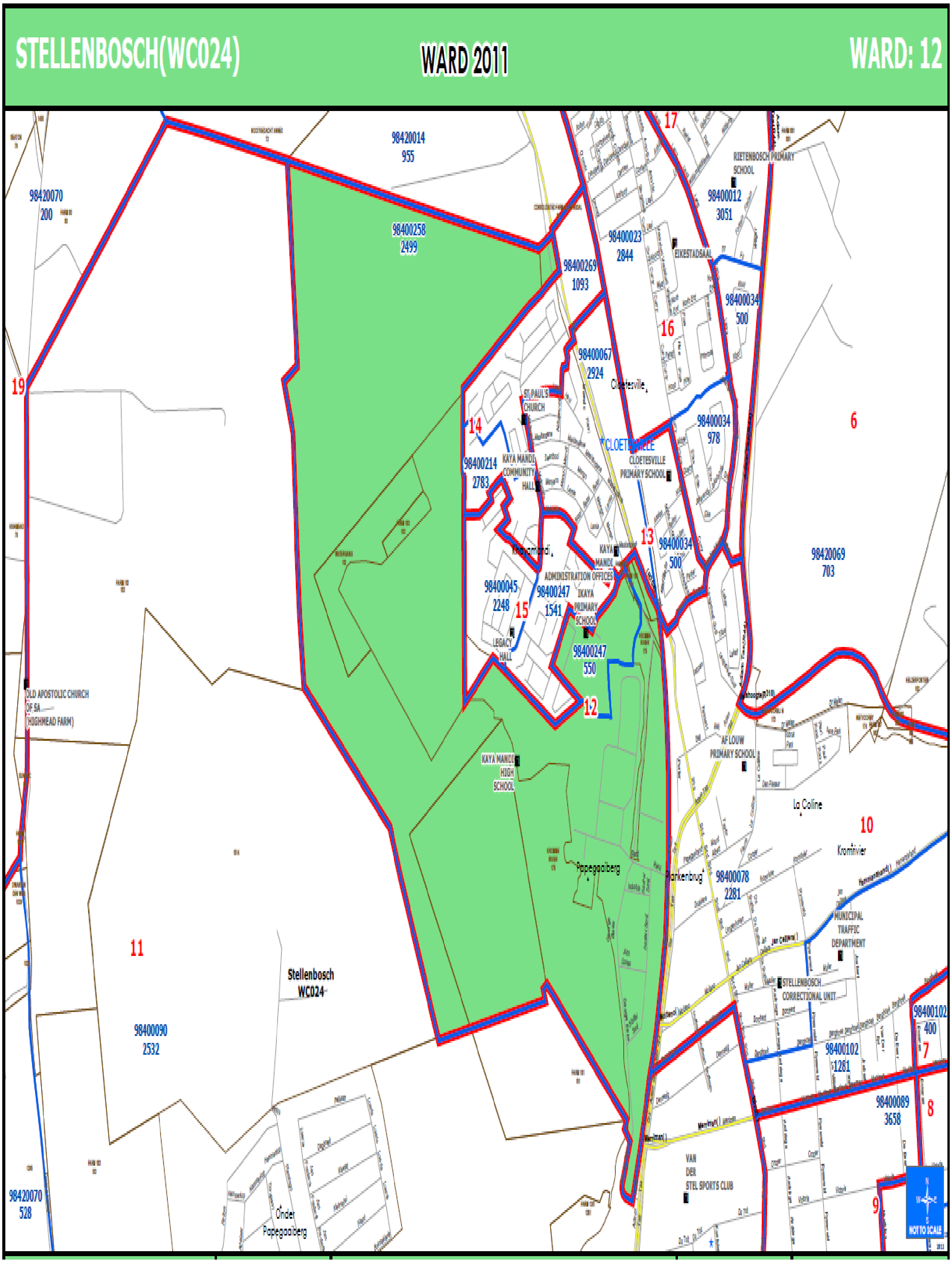
8. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

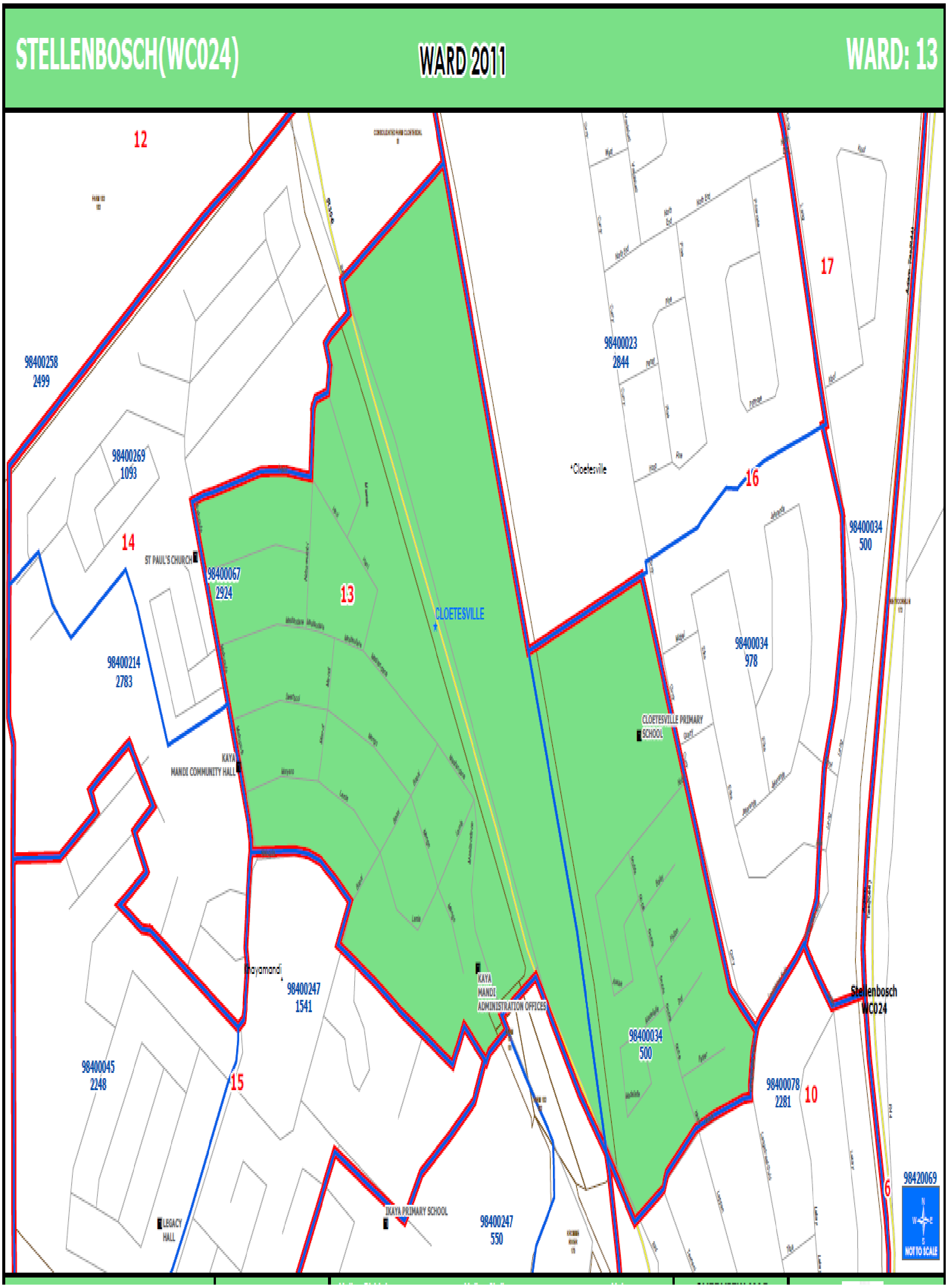
Appendix D: Visual aid displaying energy fuel types and energy carriers



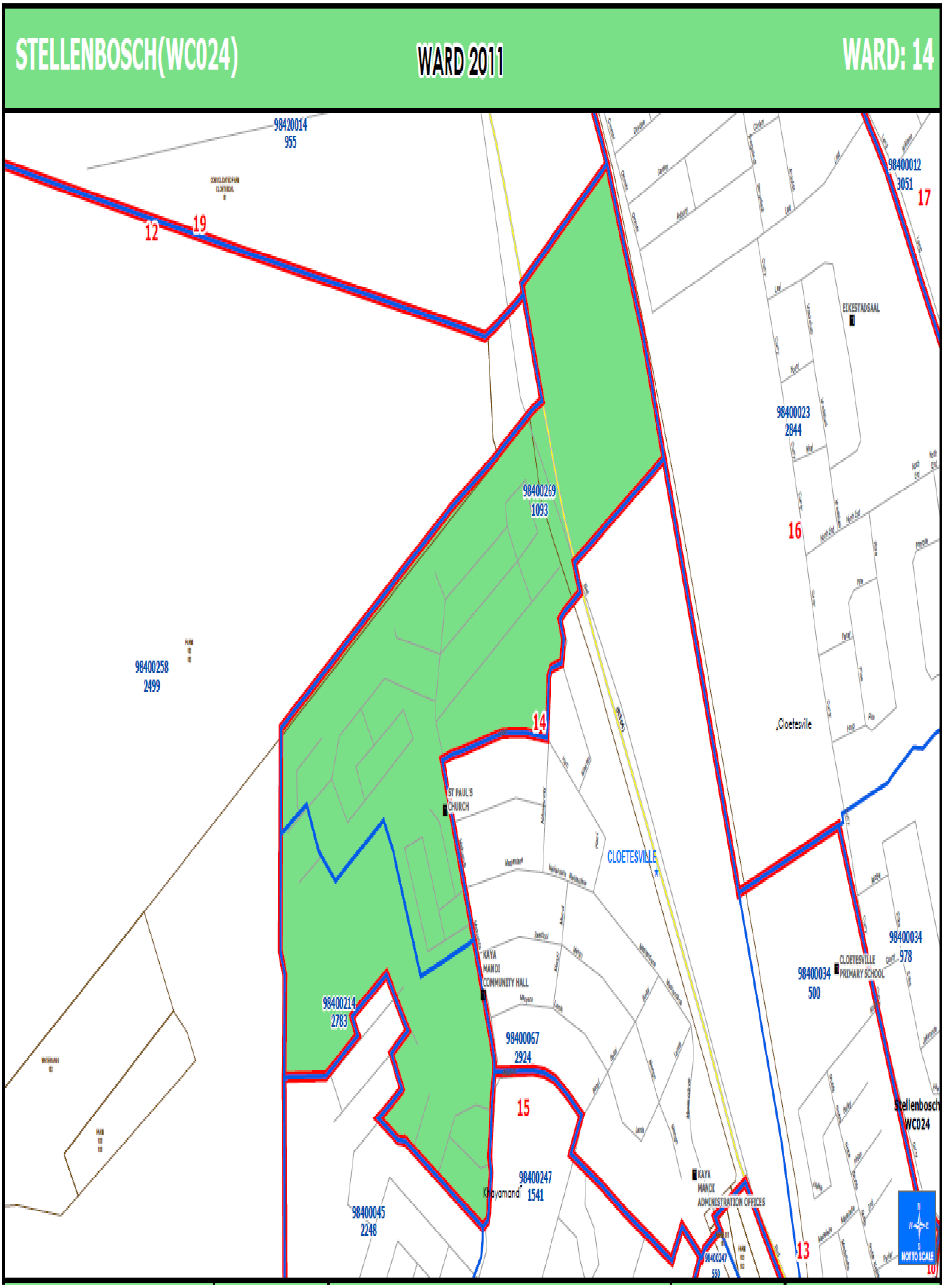
Appendix E: Ward 12 boundary in Stellenbosch Local Municipality



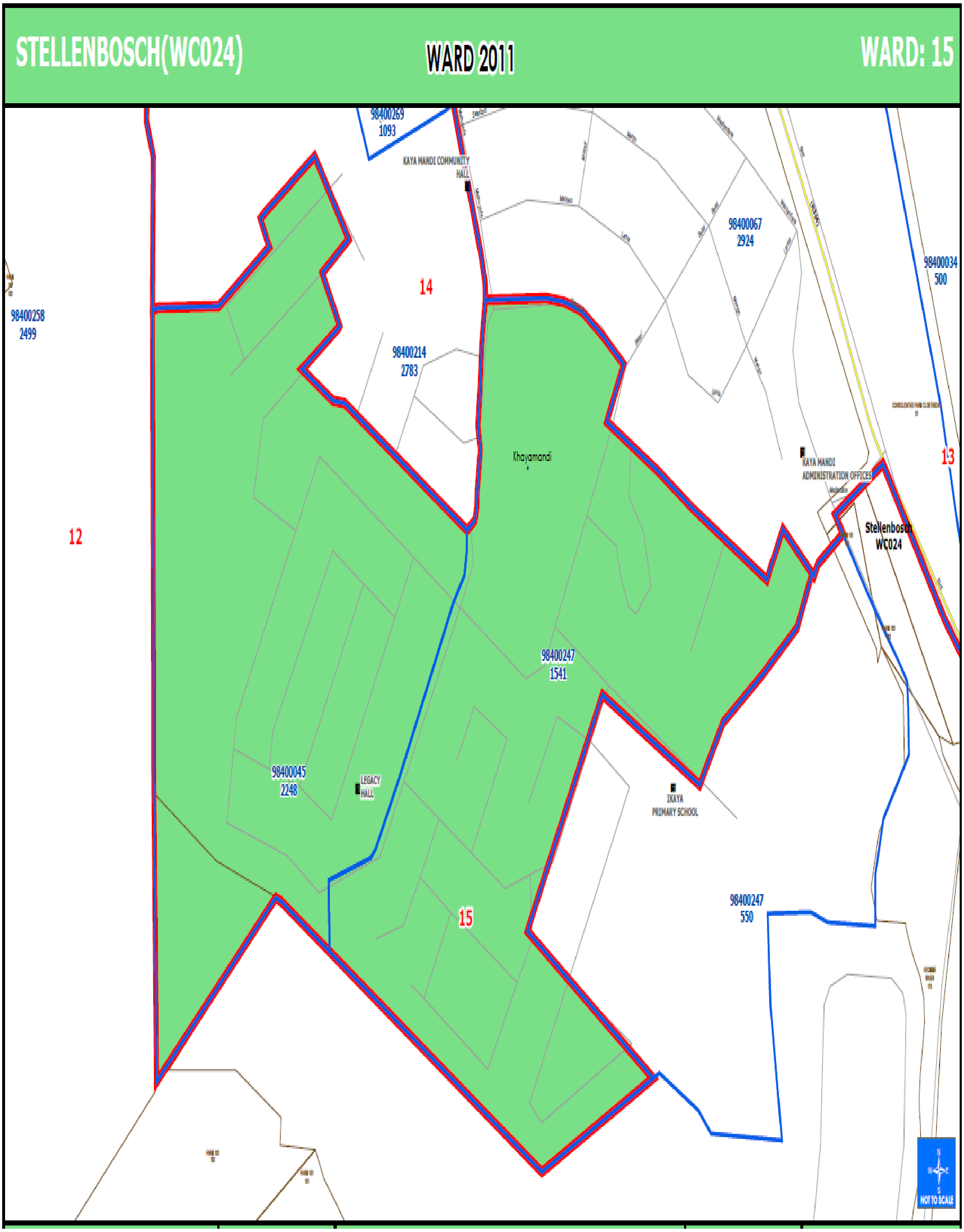
Appendix F: Ward 13 boundary in Stellenbosch Local Municipality



Appendix G: Ward 14 boundary in Stellenbosch Local Municipality



Appendix H: Ward 15 boundary on Stellenbosch Local Municipality



Appendix I: Renewable energy solutions

In this section it is argued that renewable energy technologies, in particular distributed PV electricity generators, can serve as alternative and/or supplementary sources that provide energy services such as cooking, lighting, water heating, space heating, and the operation of household appliances for urban informal households. It first looks at the regulatory framework and the drivers of the renewable energy industry in South Africa. Next, it discusses PV and ends with an analyses of wide-ranging technologies that could provide services such as cooking, lighting, water heating, space heating, and operating household appliances.

Renewable energy technologies

Hancock (2015) notes that renewable energy consists of a broad range of sources and technologies, namely hydro-electricity, ocean energy, wind energy, solar energy and bio-energy. Some renewable energy sources, for example hydro-electricity, are less favoured due to the release of greenhouse gases, for example methane, as well as the displacement of people from their land due to the construction and operation of dams that enable the generation of hydro-electricity. In contrast, wind and solar energy are regarded as more environmentally friendly (Hancock, 2015; Newell & Mulvaney, 2013). Most countries have enacted policies to regulate and promote renewable energy technologies in the power generation, heating, cooling and transport sectors. These are driven by the need to mitigate climate change, reduce dependence on imported fuels, develop more flexible and resilient energy systems, and create economic opportunities (REN21, 2015).

Regulatory framework

Electricity in South Africa is a regulated sector and is primarily overseen by the National Energy Regulator of South Africa and the DoE. Through the Integrated Resource Plan, the DoE is responsible for planning the source and quantity of electricity to be generated for the country in the future. The National Energy Regulator of South Africa is responsible for licensing and adjudicating the prices of these generation sources.

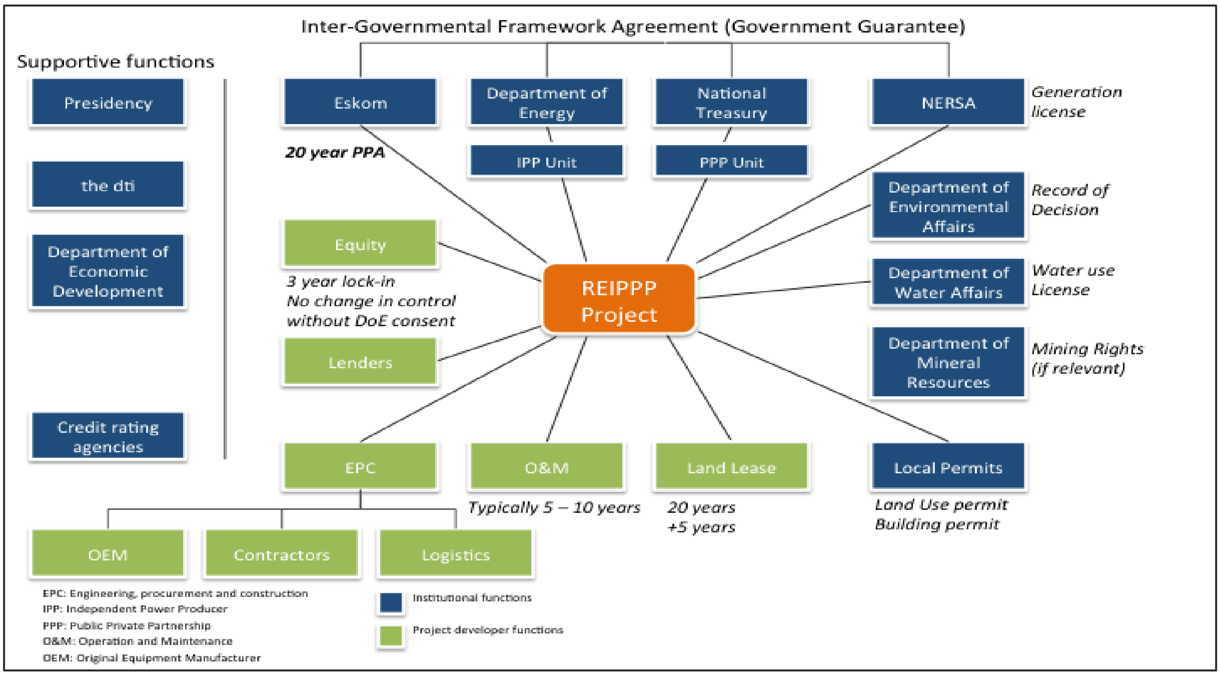


Figure 1: Implementation programmes of the Renewable Energy Independent Power Producing Programme
Source: Milazi, 2014

Figure 1 show that many other government departments in South Africa also play a role in executing these plans (Milazi, 2014). The National Treasury makes sure that these programmes are affordable and that government gets value for its investments. The Department of Environmental Affairs issues environmental authorisations in order for these programmes to go ahead. The Department of Trade and Industry sets and implements industrial policies to ensure that local content is prioritised and control imported products. The Department of Public Enterprises is a shareholder in Eskom and advances local procurement (Milazi, 2014). Besides, the Presidency and the Department of Economic Development perform a supporting function in the Renewable Energy Independent Power Producing Programme.

Drivers of renewable energy in South Africa

According to the Milazi (2014) there are various causes behind the increasing interest in renewable energy technologies. Additional capacity to generate electricity is needed in order to avert supply-demand disruptions. Renewable energy can reduce climate change by contributing towards the carbon emission reduction targets of South Africa. Reduction in coal dependence of the energy sector enhances energy security and diversifies the energy mix. The number of jobs that renewable energy technologies can potentially create is considerably more than the number created by coal-generated electricity. Since South Africa has a relatively high unemployment rate of approximately 25%, the growth in the PV industry could help alleviate this challenge (Statistics South Africa, 2016).

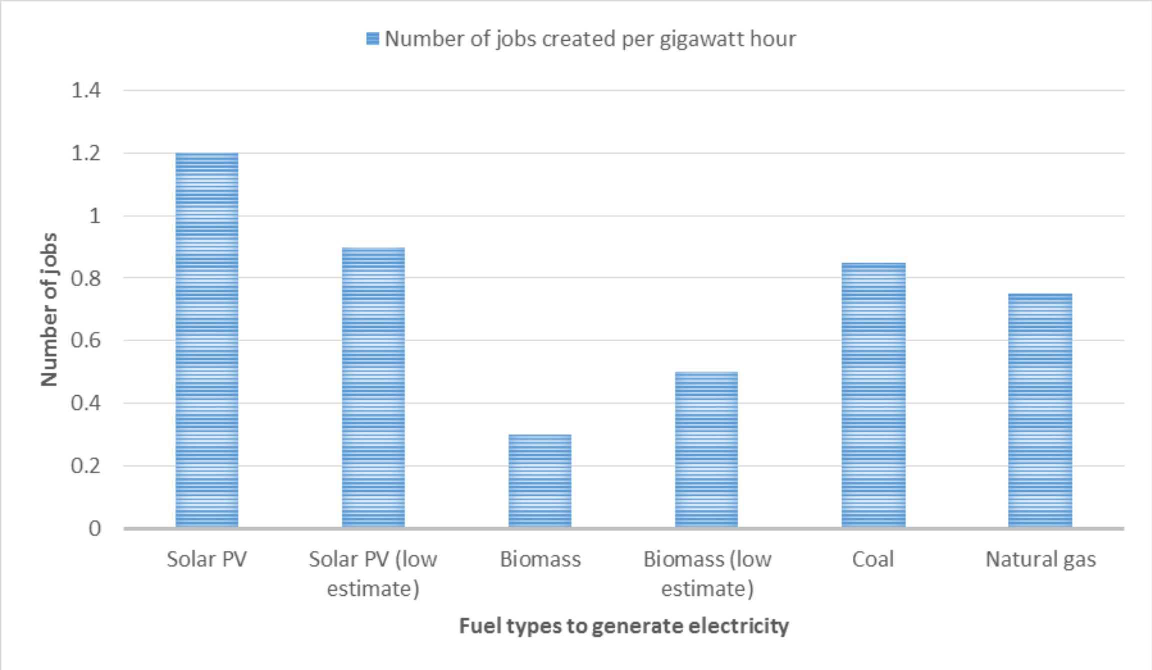


Figure 2: Estimated number of jobs per gigawatt hour that various energy technologies can create
Source: Adapted from Practical Action, 2014

Figure 2 above illustrates the estimated number of jobs per gigawatt hour that can be created from PV systems, biomass, coal and natural gas. It is clear that the use of PV systems to generate electricity creates relatively more jobs than coal, biomass and natural gas. It is highly likely that the large-scale deployment of small-scale PV electricity generators may lower the high unemployment in South Africa. These findings are corroborated by the Renewable 2015 Global Status report that noted that PV technology had created 2.5 million jobs, most of which are concentrated in China because of the country being the leading PV manufacturer and because of a growing domestic market (REN21, 2015). PV technology is starting to play a substantial role in electricity generation in some countries as rapidly falling costs have made unsubsidised PV-generated electricity cost-competitive with fossil fuels in an increasing number of locations around the world. In 2014, PV technology marked another record year for growth, with an estimated 40 gigawatts installed for a total global capacity of about 177 gigawatts (REN21, 2015).

Photovoltaics

Boyle (2012) argues that PV technology is an ideal way to generate energy for several reasons. Firstly, PV systems have the lowest environmental impact compared to all renewable and non-renewable electricity generation technologies. Secondly, when PV systems operate normally, no emission of pollutants and radio-active substances occur. Lastly, due to the stationary nature of PV modules this technology is mechanically safe and generates no noise (Boyle, 2012). The inclusion of renewable energy technologies, specifically PV technology, into the energy portfolio of urban informal households may have various socio-economic benefits. Numerous researchers suggest that renewable energy technologies, such as small-scale PV electricity generators, are well suited to alleviate the energy demand and supply challenges in developing countries, as outlined in Section 1.2 of this study (Hancock, 2015; Azimoh *et al*., 2014; Lay *et al*., 2013; Pode, 2013). In addition, Zerriffi and Wilson (2010) state that the incorporation of renewable energy technologies into the energy portfolio of households can provide carbon-free electricity that can mitigate climate change and thereby alleviate environmental destruction. Furthermore, Practical Action (2014) suggests that renewable energy technology uptake, in particular of PV technology, has a high employment potential as illustrated in Figure 2. For example, the unemployed can start companies that maintain PV electricity generators.

However, some of the disadvantages of PV technology include the risk of electric shocks and its aesthetics that might not appeal to everyone (Boyle, 2012). Furthermore PV technologies rely on semiconductor technologies that require hazardous chemicals, complex global supply chains and contract manufacturing (Newell & Mulvaney, 2013). Azimoh *et al*. (2014) have also demonstrated that the theft of PV panels as well as the low power quality from these systems makes this technology unappealing. It is thus apparent that PV technologies, despite their numerous advantages, do have a number of shortcomings that may weaken the appeal of these technologies, specifically for urban informal households. However, distributed PV electricity generators, such as SHSs, may be part of the solution to increase energy access to urban informal households in South Africa.

There appears to be certain socio-economic and policy challenges to the energy infrastructure transition to a low-carbon economy. The high upfront costs, the implementation risks and the marginal impact that PV technology may have on carbon mitigation call for a careful calculation of the risks and benefits of these technologies (Lay *et al*., 2013; Pode, 2013; Zerriffi and Wilson, 2010). REN21 (2015) state that the deployment of renewable energy technologies is a political and financial challenge that is compounded by a lack of available financial resources, the high costs of capital and a reluctance on the part of investors, specifically in developing countries.

Solar home systems

An SHS is an amalgamation of a PV module, a charge controller, a battery, and end use appliances (Friebe *et al*., 2013; Pode, 2013). A typical SHS in South Africa is a direct current system that consists of a 50 or 75 watt solar panel, a 100 ampere hour rating, a 12 volt battery pack, a battery safety fuse and a charge controller (Azimoh *et al*., 2014). Lay *et al*. (2013) suggest that an SHS could provide electricity for lighting and other applications. An example of an SHS is provided in Figure 3 below.

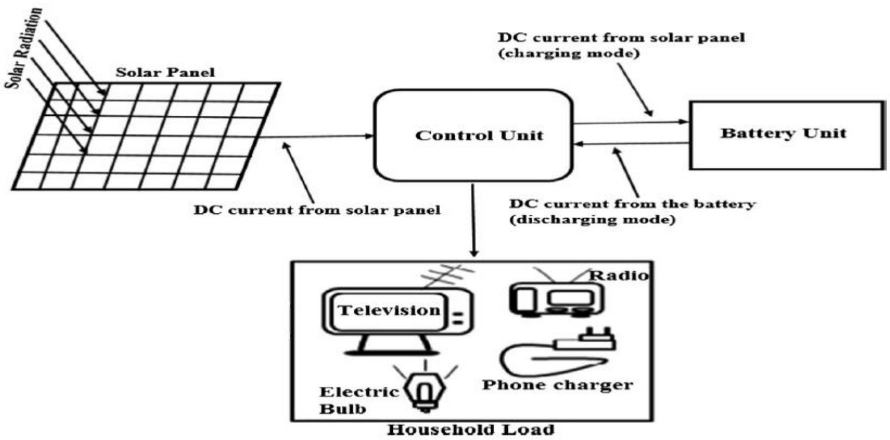


Figure 3: Configuration of a solar home system
Source: Azimoh *et al*., 2014

It is highly likely that the deployment of SHS in rural areas could decrease the migration rate to urban areas (Azimoh *et al*., 2014). For example electrification programmes in remote villages in rural Romania (Fara, Finta & Micu, 1998). This is an important point for cities, specifically in developing countries, that are finding it difficult to cope with the increase in demand for basic services by an increasing population.

The residential sector is the smallest of the three segments of the renewable energy market, both in terms of the installed capacity and the size of typical installations such as SHSs. At the moment most renewable energy consists of rooftop PV SHSs and solar water heater installations (GreenCape, 2015). The embedded generation regulations of larger municipalities such as City of Cape Town, Nelson Mandela Bay and eThekwini have set a precedent for many other municipalities. These regulations enable municipalities to respond to customers whose interests in self-generation are rising. This is an indication of the system's attempt to adapt to the increased uptake of renewable energy technologies such as SHSs (GreenCape, 2015). GreenCape speculates that by 2020 this market will increase to around 100 megawatt of installations per year.

While starting from a low base, the small-scale embedded generation market, that includes SHSs, is showing some very positive trends. The combination of Eskom load-shedding, higher prices charged by the utility and decreasing PV costs has led to significant interest in the small-scale embedded generation market. At the time of writing, the opportunity was largely limited to larger commercial, agricultural and industrial customers whose consumption was high during daylight hours. Currently, the standards, grid requirements and metering costs make these investments prohibitively expensive at a residential level. However, this is set to change within the next few years, with the introduction of a smart metering standard and the National Energy Regulator of South Africa publication of the embedded generation guidelines.

Several factors influence the performance of SHS. Azimoh *et al*. (2014) suggest that dust, pollution and the tilt angle of the PV panel affect the amount of electrical energy that is generated. Furthermore, the inappropriate use and inadequate maintenance of the lead acid battery that forms part of the SHS result in a shorter battery life (Azimoh *et al*., 2014). This should be of interest to organisations that run awareness campaigns about the benefits of solar energy technologies for example SHSs, as well as entrepreneurs that sell SHSs. Poor consumer education may contribute to the incorrect use of SHSs.

It appears that the sustainability of the SHS electrification programme is threatened by the theft of PV panels from households that use these systems. For example, it was found that households in Papa New Guinea reverted to solid-fuel use to meet their energy needs after the theft of their PV panels. The theft of PV panels in Zimbabwe led to households shielding panels with steel bars, which caused shading of the panels that makes the solar system less effective (Azimoh *et al*., 2014).

In South Africa, the two trends emerging that attempt to curb the theft of PV panels are the 24-hour surveillance of PV panels by placing them flat on the ground in front of people's houses during the day to keep them in sight and the use of security lights to illuminate pole- and rooftop-mounted panels at night (Azimoh *et al*., 2014). Azimoh *et al*. (2014) recommend a benchrack mounting system that can allow devices to be taken indoors. This point is potentially of interest to municipalities that may roll out SHS in communities, and financial stakeholder such as, banks and insurance companies that provide funding for these technologies because replacing the stolen panels is likely to make SHS financially unfeasible for households that choose to invest in buying them.

Pode (2013) suggest that in order for low income households to invest in SHSs on a massive scale, the following provisions be made: There should be complete transparency about the cost of the SHS, and it should be affordable. Procedures that monitor and evaluate the functioning of the SHS as well as the satisfaction of the customer should be established. Finally, emphasis should be put on the after-sales services that could improve the quality of the product, build customer loyalty and serve as an extra revenue stream for SHS companies (Pode, 2013).

In Section 2.5 of this study, energy access was defined as follows: "Households and the organisations serving them are able to source clean affordable energy at all times in order to provide energy services such as cooking, lighting, water heating, space heating, and the operation of household appliances." SHSs thus have to enable households to access a sufficient amount of energy and ideally minimise the use of firewood, paraffin, coal and electricity because the multi-fuel theory of energy suggests that households do not replace traditional and transitional fuels but use these in collaboration with electricity (see Section 2.4.3). The RIS approach to socio-technical transitions may address this challenge by allowing active engagement with the financial sector and intermediaries to make SHSs more financially accessible to urban informal households that rely heavily on fossil fuels.

In my view, the large scale uptake of SHSs is able to address most of the concerns regarding health and safety issues when households use firewood, gas, coal and paraffin for various energy services. Furthermore, power outages will not be a threat to urban informal households that uses SHSs and the release of carbon during the electricity generation process will be negligible. The large-scale uptake of distributed PV technology such as SHSs is also able to create numerous job opportunities, as illustrated in Figure 3. It is highly likely that the distributed nature of SHSs could increase electricity access to urban informal households, and for households that are far away from electricity distribution infrastructure, and do not have easy access to commonly used supplemental fuel types.

ECOlite solar system

The ECOlite solar system is a locally manufactured energy solution that targets low-income households in South Africa. The solar system is a modular technology that consists of a PV solar panel, a suspendable controller with a battery, and a lamp. The system is produced in an off-grid, non-electrified facility in Pretoria, South Africa. This modular technology can be primarily used for lighting (The Innovation Hub, 2014).

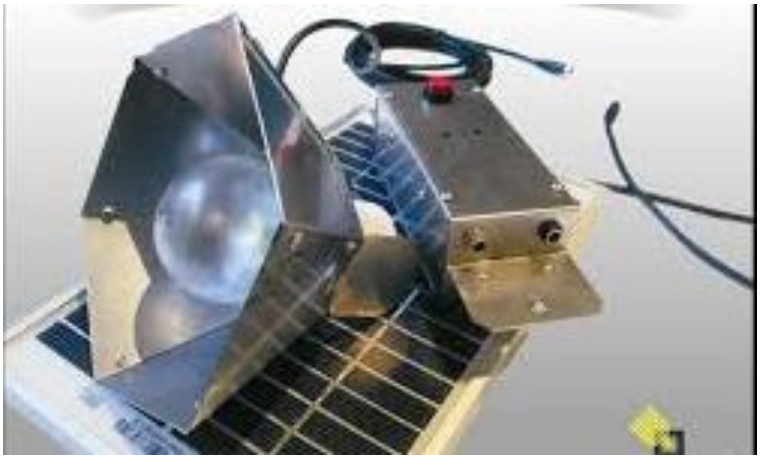


Photo 1: An ECOlite solar system with a solar panel, a suspendable controller with a battery, and a lamp
Source: The Innovation Hub, 2014

Unlike integrated designs, the modularity of this solar system enables more incremental purchases and expansion of the system. For instance, a household that can only afford a solar system to operate its lights initially can upgrade it at a later stage to operate numerous household appliances. Likewise, the modularity of this SHS gives consumers an option to buy only the lamp. The battery/controller portion of the lamp can be charged from a different location or can be charged from a separate solar panel (Meintjes, 2015). According to Meintjes (2015), competitor products are typically made of less durable frames and are also fully integrated, which limits modularity and the option of smaller purchases of different components at a lower price.

According to the Technical Procurement and Assembly Manager of the company, Ecovest, that manufactures and distributes this technology, the main aim with which this technology was designed was to replace the current use of paraffin, kerosene and candles for lighting in low-income areas of developing countries. This technology provides primary energy through sustainable lighting at home. This lighting service adds to security measures at households, prolong the day and enable children to do homework at night (Meintjes, 2015).

The manufacturing capability of Ecovest has been scaled up due to strategic partnerships with local organisations which give the company access to 120 years of experience in the mechanical and electrical engineering fields. These partnerships have improved quality and reduced costs to ensure that the product is reliable and accessible to the majority of South African citizens. Ecovest and its partners have working relations with several government departments in order to create an environment where there products will be deployed in a sustainable manner. The Department of Environmental Affairs has been training entrepreneurs to market and sell this technology to people in low-income areas. Ecovest also works in partnership with the Innovation Hub, the City of Tswane Municipality and the Gauteng Growth and Development Agency to promote the sustainable uptake of the ECOlite solar system in low income areas.

SolarTurtle

The SolarTurtle is a DRE technology that was created to provide energy services for low-income households. The SolarTurtle consist of a 6 metre container that has been converted into a functional solar-powered micro-utility (see Photograph 2). The outside of the container boasts 12 solar panels that total 3.6 kilowatt. These panels are mounted on a unique panel deployment system that is both strong and secure (Van der Walt *et al*., 2015).

Photo 2: Once the two side frames of the Solar Turtle are open struts lift all the panels up and lock them into place
Source: Ugesi Gold, 2014

The SolarTutle is an electricity distribution point that is neatly packaged in a theft resistant shipping container. The container is fitted with a solar battery charging station, which can charge multiple battery packs of different sizes during the day (Van der Walt *et al*., 2015; Ugesi Gold, 2014). The inside of the container holds a 5 kilowatt PV system and a solar battery charging station that can recharge multiple battery packs at once (Photo 3: The SolarTurtle houses a solar battery charging station that recharges multiple bottle battery packs

). These bottled battery packs are carried home to provide basic electricity for lighting, phone charging and other energy-efficient devices.

Photo 3: The SolarTurtle houses a solar battery charging station that recharges multiple bottle battery packs
Source: Ugesi Gold, 2014

The SolarTurtle business plan includes a wide range of elements such as micro-franchising, PV panels, batteries instead of electrical cables and a secure container to provide a sustainable energy solution to low-income households. This technology can operate as a small or micro for-profit business in low income areas to provide energy services such as lighting and operating household appliances. This distributed solar energy technology do not need access to the national grid, nor does it rely on large-scale generation capacity located far from the site of consumption (Van der Walt *et al*., 2015). Even though the SolarTurtle is intended for rural electrification programmes, I am of the opinion that this technology could provide various energy services in urban settings too.

Due to the SolarTurtle's distributed nature, it has several advantages. This technology avoids the risk of cable theft, which is a common problem for South African energy service providers. Since the SolarTurtle does not require transmission infrastructure, set-up time and costs are saved. After the battery packs are charged in the container, they are then taken back to households where they are used to operate electrical appliances such as lamps, radios and televisions. In addition, it is possible to station the SolarTurtle on any centrally located, accessible premises of institutions that are regularly patronised by community members, for instance schools, churches and local clinics.

In my opinion the SolarTurtle would be a very practical way to increase energy access to urban informal households. The social business model that employs local women would facilitates the sustainability of the renewable energy access as the community will have some ownership over the electricity generation utility. The absence of electric cables will further facilitate energy access and remove the possibility of cable theft that is so common in South Africa which increases the reliable supply of clean energy. The high upfront cost that many households cannot afford for SHS is avoided. This is a good example of a created community power systems that can increase energy access.

Solar water heaters

Boyle (2012) states that a rooftop solar water heater is a flat plate pumped system that consists of the following three elements:

i. A collector panel that is sprayed black or coated with a selective surface to maximize solar absorption. The panel is covered with a single sheet of glass or plastic and the whole assembly is insulated at the back to cut heat losses.
ii. A storage heater with a capacity between 100- and 350 litres that contains an electric immersion heater for winter use. The tank is insulated all round with glass fibre and/or polyurethane foam. The hot water from the panel circulates through a heat exchanger at the bottom of the tank.
iii. A pumped circulation system to transfer the heat from the panel to the store. Sensors detect when the collector is becoming hot and switch on an electric circulating pump (Boyle, 2012).

Solar water systems can be constructed to be direct or indirect systems (Mkhize, 2016). Direct systems are more efficient and can operate optimally in non-frost areas for example along the coast. When direct systems are installed in colder areas, they will be susceptible to frost damage which could result in burst pipes and panels. Standard indirect systems require anti-freeze solution to protect the solar collectors from freezing (Mkhize, 2016).

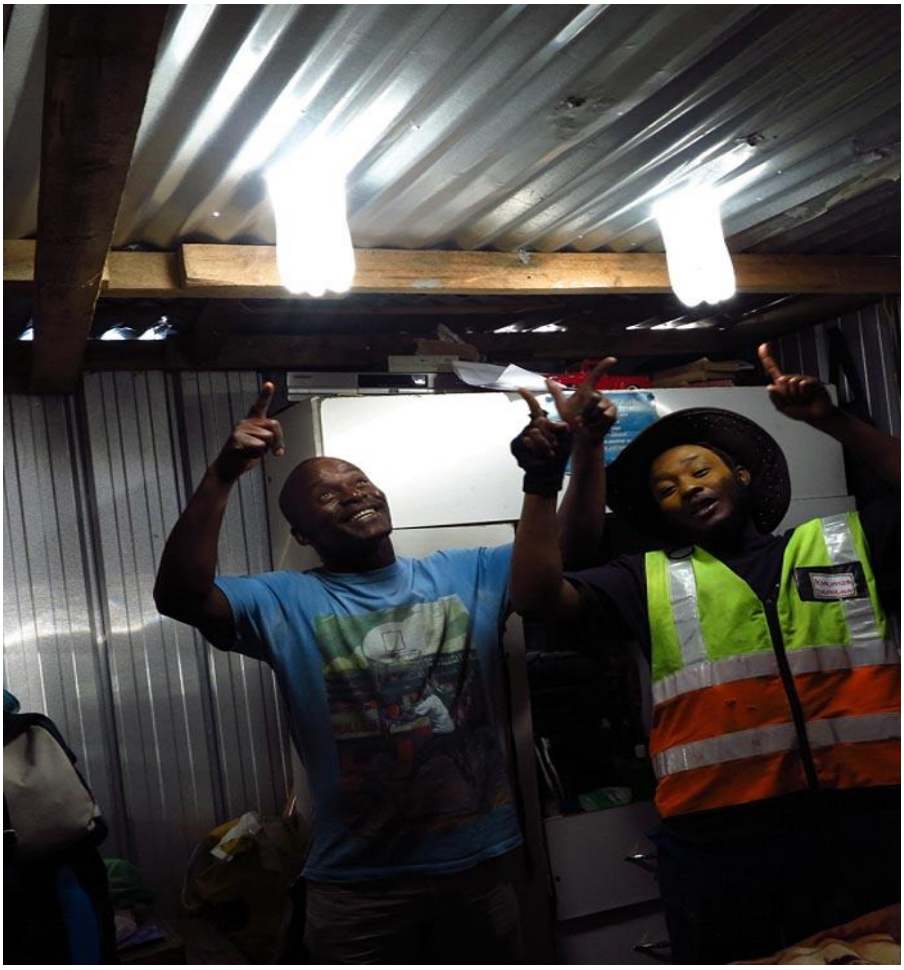
A South African company that manufactures solar water heating solutions, Solar Beam, are producing a patented low-pressure, direct and frost-free solar water heating system that is able to operate anywhere in South Africa (Mkhize, 2016). This direct solar water heating system is efficient in frost and non-frost areas and is manufactured

100% in South Africa. These direct low-pressure systems are more effective because the water that is heated in the panel is the same water that is found in the tank (Mkhize, 2016). In addition, the new Solar Beam low-pressure direct solar collector caters for frost expansion with no serious damage to the panel, which increases its value for money.

Solar Beam's low-pressure system meet government's requirement regarding local manufacture in excess of 70% local content of both tank and solar collector and can be erected in 30 minutes which adds to the value of the design. Above all, the system does not require any mounting structures as it lies flat on a pitched roof (Mkhize, 2016). Many will probably disagree with the assertion that solar water heaters are an effective technology in light of the many failed evacuated tube low-pressure solar heating systems that were installed in low-income households between 2010 and 2012. These 100% Chinese-manufactured imported products are extremely fragile as a hail storm can result in the destruction of the glass tubes. In addition, these solar heating systems were not easy to install and developed numerous leaks because they were not designed for South African climatic conditions (Mkhize, 2016).

Solar bottle bulbs

A solar bottle bulb is a plastic bottle filled with bleached water installed in the roof of a building so that daylight from outside is refracted through the water into the room, providing the equivalent brightness of a 40-60 watt incandescent lamps, depending on the weather conditions (Wang *et al*., 2015). The first solar bottle bulb was developed in Brazil when this country was looking for an alternative to electric lighting during an energy crises that caused power failures. The recycled materials and clean resources that are used for this eco-friendly technology include a polyethylene terephthalate bottle of 1.5 or 2.0 litre capacity, a galvanised iron sheet, rubber sealant, bleach, and filtered water (Wang *et al*., 2015).



Photograph 4: Solar bottle bulbs installed in an informal household in Joe Slovo township in Cape Town
Source: Mahala, 2012

The solar bottle bulb is easy to create and is increasingly being used all over the world especially in developing countries. It has certain benefits and disadvantages (Wang *et al*., 2015; The Jungle Gym, 2011). It uses cheap and locally available materials that provide sufficient lighting for low-income households during daylight. The bulb does not produce any harmful pollutants and also reduces the dangers from faulty and temporary electrical connections that cause devastating fires. However, the solar bottle bulb does not perform well in overcast and rainy weather. Besides, the water needs to be replaced every five years and, obviously, without any provision for energy storage, the bulb will not work at night. (Wang *et al*., 2015).