# ENERGY METABOLISM IN A HYBRID / MULTI-STRUCTURED URBAN INFORMAL SETTLEMENT

Olufolake Abiola Makinde

*Thesis presented in fulfilment of the requirements for the degree of Master of Engineering (Industrial Engineering) in the Faculty of Engineering at Stellenbosch University*

**Supervisors**
Prof Alan C. Brent
Prof Josephine Kaviti Musango

**March 2018**

## Declaration

By submitting this thesis electronically, I declare that the content of the work therein, in its entirety, is my own original work and thought. That I am the sole author thereof (save to the extent explicitly otherwise stated). The reproduction and publication by Stellenbosch University will not infringe on any third party rights and that I have not previously, in its entirety or in part, submitted it for obtaining any qualification.

Date: ………………. March 2018………………….

Olufolake A. Makinde

# Abstract

*Olufolake Abiola Makinde*

*Master's Thesis (Industrial Engineering)*
*March (2018)*

Municipalities and governments at different levels are faced with the challenge of establishing energy policies and strategies for urban informal settlements that are mostly located in marginal areas. This study undertook a literature review to examine the challenges of energy access and provision in urban informal settlements from a resources' flow perspective. This was achieved by reviewing the concept of urban metabolism with a specific focus on energy flows in urban areas; examining the relevance of the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolisms (MuSIASEM) approach; and, identifying gaps and limitations of assessing energy metabolic patterns of an urban informal settlement. MuSIASEM approach is of relevance because it recognises all factors and characteristics of urban informal settlement in order to provide comprehensive data for their analysis. This approach is one of the appropriate methodologies for examining and understanding energy metabolism in urban informal settlements, because MuSIASEM analyses the society under investigation across various scales, and at different hierarchical levels. The approach then proposes an energy accounting method to measure the quantity of energy required (in demand) by the society in relation to what is available, what is produced and what is consumed. MuSIASEM also defines the energy flow characteristics expressed in terms of the funds generated and flows metabolised in the system.

The results of the study show that the energy metabolisms in urban informal households are affected by different variants in the households among them:

i. The different building structures (typologies) present in urban informal settlements, with each building typology exhibiting different characteristics across both their household profile as well as energy consumption;

ii. The type or composition of household profiles given that urban informal settlements are characterised by different household profiles where change in household type will in turn increase the energy consumption pattern in the household.

iii. The energy fuels type or classification used for household energy services and household activities. Whereas, urban informal settlement households are faced with problems of supply inequality and energy poverty.

iv. The appliances used in households, where increase in households' energy consumption is proportion to the consumption pattern based on the different hours of usage for their household appliances

The implication for applying the MuSIASEM approach is to understand urban informal settlements' energy consumption from a different scale of analysis in order to not only generalise the informal settlements' challenges to just energy access but also the provision of infrastructure. The aim here is to understand factors that affect households' energy demand and consumption as well as the reality of materials in the settlements. Such understanding would provide insights into how to address the challenges surrounding urban informal settlements' development while implementing effective and sustainable policy interventions in such settlements.

The study also presents the consumption behaviour and patterns in urban informal settlements arguing on their relevance for decision/policy makers, urban modellers, for utilities planning and implementation towards an inclusive sustainable development and growth. The analysis provides insight into energy consumption complexities, challenges present in urban informal settlement, which can guide in planning, and addressing specific energy related intervention.

**Keywords:** MuSIASEM, Urban Metabolism, Energy Metabolism, Informal Settlement, Urban Systems, Household Energy, Urban Slums, South Africa.

# Opsomming

*Olufolake Abiola Makinde*

*Master's Thesis (Bedryfsingenieurswese)*
*March (2018)*

Op alle vlakke, word munisipaliteite en regerings gekonfronteer met die uitdaging om energie beleide en strategieë te vir stedelike informele nedersettings, hoofsaaklik in gemarginaliseerde areas, te bewerkstellig. As deel van hierdie navorsing, is 'n literatuurstudie onderneem vanuit 'n hulpbron-vloei perspektief om die uitdagings weens energie toegang en voorsiening in stedelike, informele nedersettings te ondersoek. Dit was bereik deur die konsep van stedelike metabolisme te hersien, met 'n spesifieke fokus op energie vloeie in stedelike areas; deur die toepaslikheid van die Multi-Skaal Geïntegreerde Analise van Maatskaplike en Ekosisteem Metabolisme (MuSIASEM) benadering te ondersoek; en deur gapings en beperkings in bestaande energie metaboliese patrone van stedelike informele nedersetings te identifiseer. Die MuSIASEM benadering is van belang omdat dit al die faktore en eienskappe van stedelike informele nedersettings herken, en voorsien sodoende omvattende data vir die analise. Hierdie benadering is 'n toepaslike metodologie vir die ondersoek en verstaan van energie metabolisme in stedelike informele nedersettings omdat MuSIASEM analises die samelewing onder ondersoek plaas oor verskillende skale, en teen verskillende hiërargiese vlakke. Die benadering stel gevolglik 'n energie rekeningkundige metode voor om die hoeveelheid energie aanvraag deur die samelewing, in verhouding tot wat beskikbaar is, wat gegenereer word en wat verbruik word.

MuSIASEM definieer ook die energie vloei eienskappe in terme van die fondse wat daardeur geskep word en vloeie wat gemetaboliseer het in die stelsel.

1. Die verskillende gebou strukture (tipologie) teenwoordig in stedelike informele nedersettings, met elke gebou tipologie wat verskillende eienskappe demonstreer n terme van beide hul huishoudelike profiel en energie verbruik;
2. Die tipe, of verbruik, van huishoudelike profiele, gegee dat stedelike informele nedersettings gekarakteriseer word deur verskillende huishoudelike profiele, waar verandering in huishoudelike tipe op sy beurt die energie verbruiks patroon daarbinne verander.

3. Die energie brandstof tipes of klassifikasie wat gebruik word in huishoudelike energie dienste en huishoudelike aktiwiteite; waar stedelike informele nedersettings huishoudings gekonfronteer word met probleme van voorsienings ongelykheid ene energie armte.
4. Die toestelle wat in gebruik is binne huishoudings se energie verbruik, is in verhouding tot die verbruiks patroon, gebasseer op die verksillende ure van verbruik vir daardie huishoudelike toestelle.

Die implikasie vir die toepassing van die MuSIASEM benadering is om stedelike informele nedersettings se energie verbruik van 'n ander skaal van analise te verstaan, om sodoende nie slegs die stedelike informele nedersettings se uitdagings tot energie toegang te veralgemeen nie, maar ook die voorsiening van infrastruktuur. Die doel van hierdie navorsing was om faktore wat huishoudelike energie aanvraag en verbruik, sowel as die werklikheid van materiale in nedersettings, te verstaan. Die begrip hiervan sal insig verskaf oor hoe om die uitdagings rondom stedelike informele nedersettings se ontwikkeling, en ter gelyk die implimentering van volhoubare en effektiewe beleide in hierdie nedersettings. Die studie wys ook die verbruiks gedrag en patrone in stedelike informele nedersettings, en argumenteer oor die relevansie vir besluit/beleids makers, stedelike modelleerders, vir diensverskaffer beplanning en implimentering vir inklusiewe, volhoubare ontwikkeling en groei. Die analise verskaf ook insig tot die energie verbruik kompleksiteite en uitdagings teenwoordig in stedelike informele nedersettings, wat beplanning en spesifieke energie-verwante intervensies kan lei.

**Sleutelwoorde:** MuSIASEM, Stedelike Metabolisme, Energie Metabolisme, Informele Nedersetting, Stedelike Stelsels, Huishoudelike Energie, Stedelike Krotbuurte, Suid-Afrika.

# Dedication

*To my amazing mother, Mojirike Makinde*

*&*

*My loving brother, Oluseyi Abiodun Makinde*

## Acknowledgements

All glory and honour be unto God, my Father, my strength and help in everything.

The author hereby expresses appreciation and acknowledges the contribution of the following individuals:

- Prof Josephine Kaviti Musango who acted as one of my study leaders. Prof Josephine is an inspiring mentor, who is dedicated and has an open door policy. She provided guidance, comments and inputs during the course of this research.
- Prof Alan C. Brent who acted as one of my study leaders.
- Suzanne Smit, who was my co-study leader for sparing her time in order to provide guidance and inputs.
- Prof Alan Brent and Prof. Josephine Kaviti Musango for adding me to their research teams.
- The National Research Foundation (NRF), Grant Number: 99103 for providing financial support to conduct this research.
- Engr. Oluseyi Makinde, my role model, support and brother, for seeing me through this journey not only as a mentor but also financially supporting me.
- To my family and siblings, thank you all for your love and prayer.
- Olanrewaju Philip Sadibo, God bless you.
- My immeasurable appreciation goes out to all those who shared in the experiences and journey of my masters' research among them:
    - Dr. Funlola Olojede; my pastor
    - Richmore Dondoferma
- Additionally, to all those who have participated in the challenging conversations, which have shaped my last two years.

# Table of Contents

# List of figures

# List of tables

## List of Acronyms and Abbreviations

| | |
|---|---|
| DEA | Department of Environmental Affairs |
| DoE | Department of Energy |
| EC | Energy Carrier |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gases |
| GNP | Gross National Product |
| HA | human activity |
| IEA | International Energy Agency |
| LCA | Life Cycle Assessment |
| MDG | Millennium development Goal |
| MFA | Material Flow Analysis |
| MuSIASEM | Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism |
| NDP | National Development Plan |
| NPW | Non-paid work |
| PES | Primary Energy Source |
| PW | Paid work |
| RDP | Reconstruction and Development Programme |
| SDG | Sustainable Development Goal |
| StatsSA | Statistics South Africa |
| TET | Total energy throughput |
| UM | Urban Metabolism |
| UN | United Nations |
| UNDESA | United Nations Department of Economic and Social Affairs |
| UNDESA/PD | United Nations Department of Economic and Social Affairs/ Population |
| UNDP | United Nations Development Programme |
| UNEP | United Nations Environmental Programme |
| UN-HABITAT | United Nations Human Settlements Programme |
| WCED | World Commission on Environment and Development |
| W.H. O | World Health Organization |

# Glossary of terms

**Energy metabolism:** This refers to the analysis of energy flows and their implications to the sustainable development and modelling of a society and/or environment. Energy metabolism provides insights for decision and policy makers interested in infrastructure and resilience planning towards decarbonisation of the environment.

**Informal settlement:** This refers to a "contiguous type of settlement", where residents are characterised as having insufficient and inadequate housing, physical infrastructure and basic services. Such a settlement consists of informal dwellings, housing or shacks, semi-formal dwellings with an extension of backyard shacks. It correlates, to an extent, to dwellings with little or absence of necessities such as infrastructures (energy access, water access and proper waste management system) and services (partly because informal urbanization occurs, in most cases, on un-serviced lands) (UN-Habitat, 2003). However, there is no general definition of informal settlement owing to their complexity, and constant changes as well as their dependency on the local context.

**Multi-Scale Integrated Analysis of Ecosystem and Societal Metabolism (MuSIASEM):** MuSIASEM is an approach used in analysing and characterizing the metabolic patterns of a system such as energy, food, waste and water in relation to the ecological and socio-economic variables. The idea is to consider the societies as metabolic structures that consume funds and flows for their growth and sustenance.

**Multi-structured/Hybrid building structures**: They refer to the different typologies of building or housing present in a society.

**Urban metabolism (UM):** This refers to the field of study used in understanding the urban sustainability. The study provides strategies, through its methodological framework, on how urban areas and cities can improve their materials and resource efficiency (such as food, energy, water and waste).

# Chapter 1 Introduction

## 1.1 Background

We are living in an increasingly globally interconnected world with a population of over 54 per cent of the world living in urban areas (UN-Habitat 2016; UN-Habitat 2014b). Statistics show that back in 1950, only 30 per cent of the total population in the world lived in urban areas (UN-Habitat, 2014b). In the decades to come, there is an expectation of profound change to the spatial and size distribution of the world's population. The continuing urbanization and global growth in the population of the world projects an additional 2.5 billion people in the urban areas by 2050, with approximately 90 per cent of this rise concentrating in Africa and Asia (UN-Habitat, 2014b; United Nations, 2015). This means that the proportion of the world living in urban areas is projected to rise, reaching 66 per cent by 2050 (UN-Habitat, 2014b).The Africa extensive increase in urbanization level is projected to reach 58 per cent by 2050, thereby increasing the number of urban dwellers from 400 million to 1.26 billion by 2050 (UN-Habitat, 2014a; UN-Habitat, 2016).

According to Smit et al. (2017) urbanization places excessive strain on cities, thereby bringing about limitations in planning and management of increased urbanites, demands for employment, housing as well as access to basic services and infrastructures; a case that is becoming unsustainable for cities, most especially, the ones in developing countries (Smit et al., 2017). Most of the economies of urban regions in developing countries are unable to meet these basic needs. Economic growth, dynamics of housing markets, and urban planning, are part of the factors that actively bring about segregation and spatial exclusion, leaving those in the informal economy to provide for themselves employment and housing in this environment (Roy et al., 2014; Amado et al., 2016).

A quarter of the world's population now lives in slums (also referred to as informal settlements, shantytowns, bidonvilles, squatter camps, ghettos, favelas, campamentos and Katchi Abadis), with the majority of slum dwellers emanating from the developing (UN-Habitat, 2010; Guibrunet & Broto, 2015; Smit et al., 2017).. As of 2014, more than 880 million people in developing countries lived and worked slums (UN-Habitat, 2014a; UN-Habitat, 2016b). Although there has been a slight decline in slum population, the highest prevalence of slum conditions is in sub-Saharan Africa where the additional population is projected to end up living in slums (UN-Habitat, 2014b).

It is the case that as cities are saturated with inhabitants and productive activities, they add up to about three-quarters of global resource consumption and environmental impacts, for example, the emission of greenhouse gas GHG (UNEP, 2013). This has implications for policy makers, who need to provide basic resources (such as food, water, energy) as well as the social and economic services, which include employment (jobs), education, health, infrastructure and technology, to this added population (UN-Habitat, 2016). Nevertheless, in many situations, it has been reported that informal settlements are not part of the planning system (Guibrunet & Broto, 2015; Smit et al., 2017). In planning for the future of cities, however, urban planners require a better understanding of the general demographical changes, particularly, the growth in and of informal settlements (Smit et al., 2017).

Smit et al. (2017) have also indicated the need for considering the city as a complex system, with informal settlements as a subsystem, as it may improve inferences about current and/or future resource requirements. This is to say that when plans are implemented for informal settlements, they should not be based on a 'one size fits all' approach, because such an approach disregards the institutional and social structures that lead to slums creation, thereby only looking at the symptoms rather than the associated causes of their emergence (Smit et al., 2017; Kovacic & Giampietro, 2016). Smit et al. (2017), therefore, argue for a deeper understanding and recognition of these differences in planning for sustainable cities.

According to Smit et al. (2017), the conventional understanding of slums fails to consider energy as an essential dimension to achieving the Sustainable Development Goals (SDGs). As it were, energy is an essential factor for social and economic development[1], and for achieving Sustainable Development Goals (SDGs), such as poverty eradication, improved health service provision, education, and combating climate change (UNDP, 2016). Accompanied by rapid economic growth and improved living standards, the amount of energy needed in an urban area increases rapidly (UNDP, 2016).

At the same time, in order to understand how resources and material flows are closely linked, the social component and processes of cities need to be considered. According to Smit et al. (2017), the concepts of societal metabolism and urban metabolism have become fundamental to the

[1] According the UN (2015) over 1.2 billion people (being one in five people of the world's population) have no access to electricity, of which the majority are concentrated in about a dozen countries in Africa and Asia.

development of sustainable cities and communities. These methods are important in obtaining knowledge on how cities may grow in the future with the increase of more informal settlements, and how the growing population can be supported. It has been contended that societal metabolism can be viewed as analysis of 'metabolism of human society', where; the societal energy and material transformation processes are characterized to support their continuous existence (see for Fischer-kowalski, 1998; Giampietro et al., 2009; Kovacic & Giampietro, 2016; Smit et al., 2017). According to Ferrão & Fernández (2013), urban metabolism could contribute in planning for sustainable urban cities in the developing world (Smit et al., 2017).

Urban metabolism is defined as the "total sum of the socioeconomic and technical processes occurring within cities resulting in their growth, energy production, and in their waste removal" (Kennedy et al., 2007). This definition, however, reflects the concept from an industrial ecology perspective. Currie (2015:37) expanded the concept to refer to *the collection of complex sociotechnical and socioecological processes by which flows of materials, energy, people, and information shape the city, service the needs of its populace, and impact the surrounding hinterland.*

Recent studies have highlighted the need to apply urban metabolism to informal settlements studies, describing informality as an 'integral part of how cities function'. These studies have also stated the need to understand the co-dependency between process of an urban informal system and the configuration of the infrastructure that influences material flows (see for example Attia & Khalil, 2015; Guibrunet et al., 2016; Smit et al., 2017).

Other arguments to validate these claims can also be found, for example, Turok (2015) argues for the need to treat each settlement separately and differently whilst acknowledging their specific characteristics that they carry out in adding to the wider urban system. This requires that urban metabolism studies move beyond the current focus on urban formal, and explicitly consider urban informality. Roy et al. (2014) argue that a process of extracting important patterns of informal urban flows at different scales and levels of hierarchy is important to understand the growth and emergence of slums. Further, Smit et al. (2017) also identify five typologies of urban informal settlements, which need to be planned for differently (see Figure 1-1).

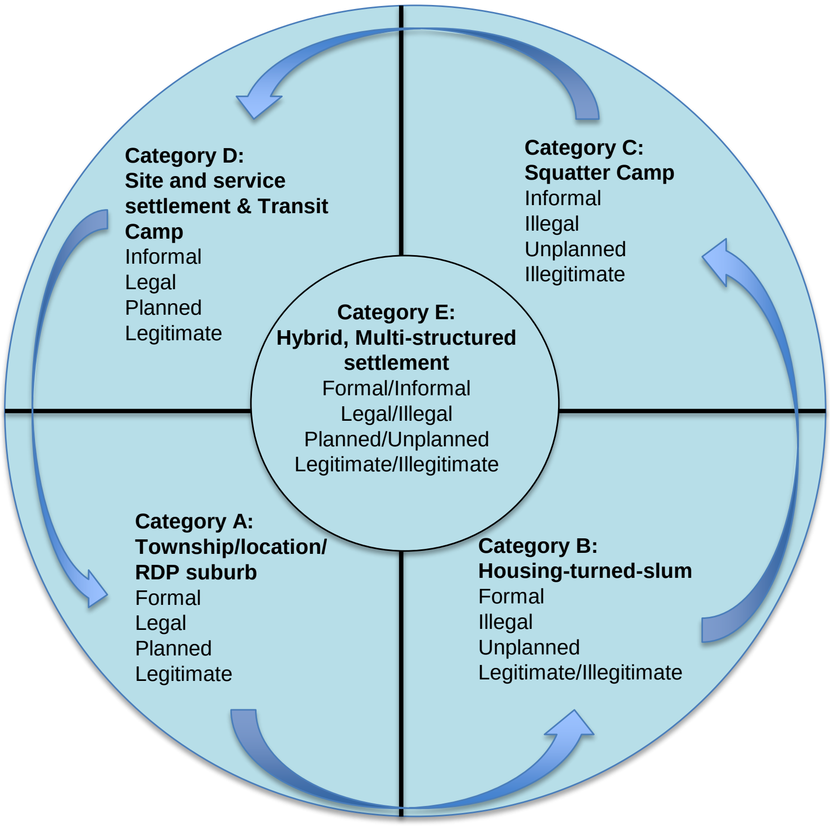



Figure 1-1: South African typology of informal settlements

Source: Smit et al. (2017:113)

This study set out to conduct an energy flow analysis of a hybrid, multi-structured urban informal settlement, from a metabolic perspective, in order to provide an in-depth understanding of energy flows in a hybrid/multi-structured informal settlement. According to Smit et al. (2017), the Category E settlement type consists of a variety of structures, including RDP or formal public housing, hostels as well as informal housing structures such as backyard shacks and freestanding shacks. Smit et al. (2017) indicate that although these types of settlements start out as formal and legal, over the years, they may change to consist of other types of housing because of overpopulation and overcrowding, lack of influx control and lack of adequate maintenance of the settlement. According to Smit et al. (2017), they find that such settlements span both Formal/Informal, Illegal/Legal and Planned/Unplanned physical characteristics and dimensions. Given their dimensions, the classification combines Category A to D, which forms a new Category E. This type of category includes; the legitimacy dimension and how they may be positioned in terms of how to approach policy and their decisions (Smit et al., 2017). A different study is currently underway, which will consider the energy metabolism of the different categories of informal settlements (Smit et al., 2017). In order to achieve an urban plan that is sustainable, however, the reality of materials of urban informal settlement requires analysing.

## 1.2 Research Problem

There is limited empirical data or research on energy metabolic patterns in multi-structured urban informal settlements in South Africa and elsewhere. The dearth of empirical data is attributable to the fact that informal settlements are undervalued or neglected in energy metabolism discussions within the South African context as is elsewhere. The danger of overlooking the informal settlement implies that with the rise in urbanization, urban planners (including energy policy makers and strategy planners) are unable to capture the increasing growth in population with the resultant challenges in providing basic services to this sector.

Additionally, existing studies fail to examine the energy metabolism of urban informal settlements within the multi-structured (hybrid) context, by analysing the energy metabolic patterns within the informal settlements while looking at the different household typologies and building structures.

It is the case that informal settlements are a real phenomenon and their energy metabolic patterns require better inclusion and consideration. Understanding such patterns is essential towards sustainable development planning in informal settlements while connecting this development to the sustainability of cities and/or urban areas.

## 1.3 Rationale and significance of study

Within the contexts of urbanization, resource and material usage, depletion and unavailability as well as climate change, South Africa is looking towards better energy planning and distribution in informal settlements. Included in this consideration are alternative energy, sustainable and inclusive energy policy, environmental stability and sustainability as well as social fairness in development. This study is, thus, appropriate and relevant to support energy planning in an urban informal context.

Arguably, informality and the reality of its everyday experiences presently are both ignored and/or undervalued in planning and policies for urban energy. By recognising the activities in informal settlements and their contribution towards sustainable development, this study may, therefore, assist in expanding the current perspectives as well as inform future energy planning, policy implementation and development in informal settlements.

This study also contributes to the body of knowledge on urban metabolism, informality, energy metabolism, and energy flow and consumption, which can lead to well-informed policy-making and planning, suitable for achieving the Sustainable Development Goals (SDGs), most specifically Sustainable Development Goal 11[2] on Sustainable Cities and Communities. (UNDP, 2016)

The study may therefore benefit different stakeholders:

- It can potentially inform planning and policy when addressing needs and supporting activities within informal settlements.
- International organizations concerned with socio-economic development and sustainability of the environment may use the study as a guide for further research and information.
- The study is relevant to the academic field as well as local, national and international importance as it will contribute to practice and theory of assessing the metabolic flow of energy in a hybrid (or multi-structured) urban informal settlements, as well as aid city regions within which they are situated.
- Municipalities, that are responsible for providing energy services, may be able to gain greater understanding on the energy consumption, profile, and characteristics of a hybrid multi-structured urban informal settlement.

## 1.4 Research objectives

The overall aim of this study was to analyse energy flows and total energy consumption from different household types and building structures in an urban informal settlement. In order to achieve this aim, associated objectives were formulated as follows:

1. To describe the multiple household structures in an urban informal settlement, using a specific case study;
2. To examine the energy flows in the multiple housing structures in the case study; and
3. To examine the energy consumption of different household profiles for the multiple structures in the case study.

## 1.5 Ethical Considerations

This nature of this study required direct and deep interaction with the participants in the process of collecting data. Therefore, the appropriate steps were followed to ensure ethical guidelines in

[2] SDG goal 11 prescribes "inclusive, resilient, safe and sustainable" cities (UN-Habitat, 2016)

research were adhered to in upholding the privacy, rights, anonymity and confidentiality of the participants. The following sub-sections describe how ethical compliance was met while conducting this research.

**a) Informed consent**

The researcher informed the participants – household resident - on the purpose of the research, the nature of data collection method and the scope of study before starting with the data collection process. In line with this, during the face-to-face interview, each participant was also presented with a copy of consent form to be signed (see approved format in Appendix A).

**b) Harm and risk**

In this study, the researcher assured that no participants were in any way placed in a situation that might be deemed harmful physically, psychologically or otherwise.

**c) Confidentiality, privacy and anonymity**

In compliance with confidentiality, and to ensure anonymity of the participants in the study the names, addresses (location and house information), identifiers as well as personal information of the interviewees are not disclosed. The participants are referred to using numbers/codes and housing structure names throughout the document (except where the community zone or section name was stated).

In addition, while analysing the data and in writing of the results of the findings, participants' anonymity was ensured by use of codes and numbers as identifiers for each households and participants. The participants were also not required to put their names on the questionnaires as a confidentiality measure. For safety purposes, the questionnaires collected were given to the supervisor for safekeeping.

**d) Voluntary participation**

Finally, each participant was informed that to take part in the study was voluntary and each had the right to not take part or discontinue participation if they ever felt they did not want to continue. It was made clear that the study was solely for academic purposes and no one was forced to participate.

## 1.6 Research design and methods

This study adopted a case study design and employed both qualitative and quantitative data collection methods. A mixed methods approach was used in order to collaborate data and provide an opportunity for results validation in a more rigorous manner (Brewer et al., 1999).

The research design involved examining a hybrid case study with its typology informed by Smit et al. (2017) Kayamandi, described has a hybrid multi-structured slum, is a typical example of an urban informal settlement that has multiple housing structures and different household typologies.

The informal activities and energy metabolic patterns' data for the hybrid informal settlement was collected. A questionnaire was prepared in line with the research objectives and problem statement. Identification of research participants was followed by a pilot test (conducted to measure the level of response and validate the questionnaire). Data was collected using self-administered questionnaires along with face-to-face interviews with each of the participants. Other methods used in data collection involved; observation and documentation, including various activities on energy flow and consumption in informal settlements, as well as photographic documentation of household typology and building structures (refer to chapter 4). Data analysis was carried out in order to provide information about the energy metabolic patterns in the hybrid urban informal settlements.

Data was analysed using statistical data analysis on Microsoft excel, for mapping out each of the household energy consumption patterns, different energy mixes (classification and fuel types) present and used in each household, household total energy throughput, and the whole systems' energy consumption (refer to chapter 4).

The results obtained provides empirical evidence that can inform literature on the energy metabolism of a hybrid urban informal settlement. An understanding of the gaps in energy metabolism study and analysis in urban informal settlement as well as how their energy flow influences cities sustainable development (see Figure 1-2).

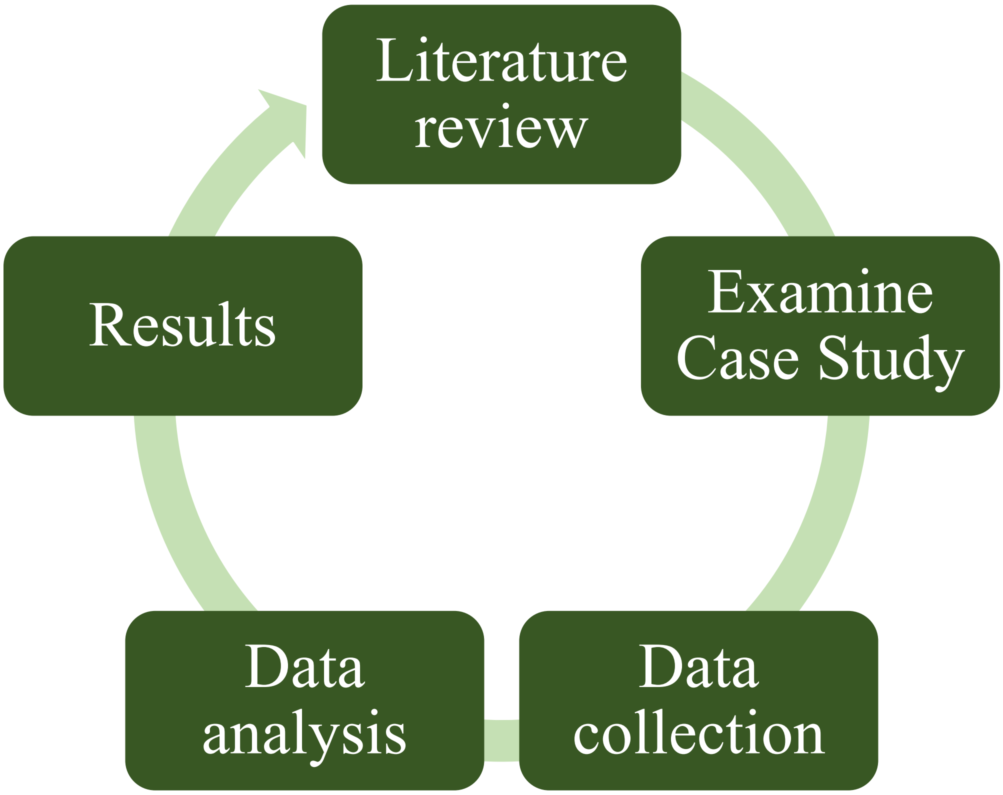



Figure 1-2: Research Strategy

### 1.7 Scope and limitations of the study

In this study:

- Only the urban informal settlement energy flow was considered. The analysis of the whole (city) economy was not accounted for.
- The study is limited to one urban informal settlement type, namely: a hybrid multi-structured settlement type.
- The focus of the study was mainly on energy usage, energy expenditure and household appliances in an urban informal settlement household.
- The analysis of the data obtained excluded human activity.

## 1.8 Layout of the thesis

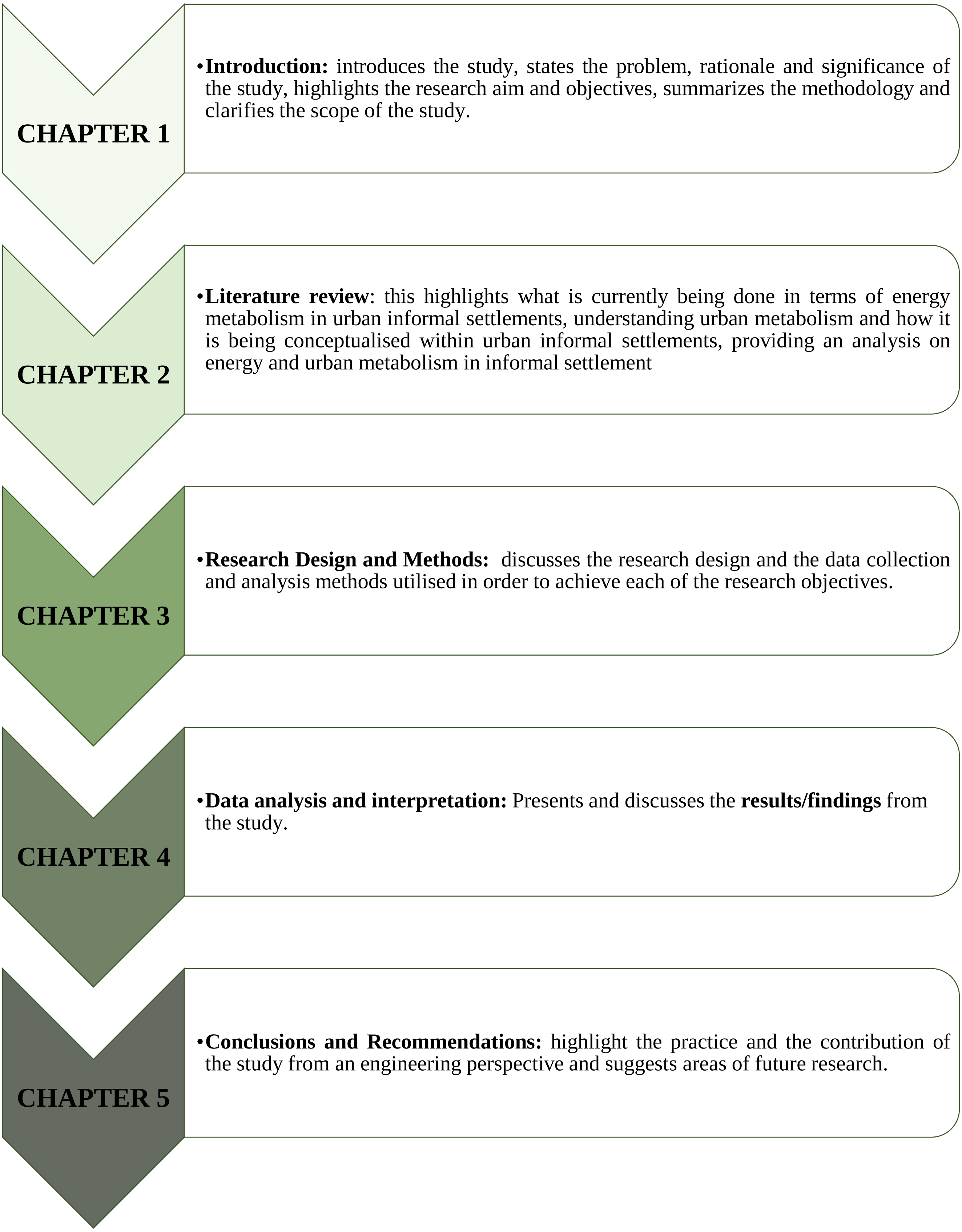



Figure 1-3: Organization of the Research Study

# Chapter 2 Literature review

## 2.1 Introduction

This chapter discusses the literature reviewed for purposes of this study. The literature review took the form of an exploratory research, which, according to Churchill & Iacobucci (2004), provides the foundation of a good study. It has to be normally flexible, unstructured and qualitative (Aaker & Joachimsthaler, 2000; Burns & Bush, 2002) and serves as an input to further research (Malhotra, 2004). Exploratory research provides insights and comprehension of an issue or situation while helping to determine the most appropriate data collection methods, research design, and subject selection process[3].

The exploratory research was executed by reviewing available literature from preceding studies from various sources, namely books, proceedings papers, journal articles and conference papers. In addition, unstructured interviews with experts, followed by a formal approach of pilot test using the survey instrument (questionnaire) provided information on literature gaps and required information for inclusion in this section.

The study followed an exploratory investigation into urban metabolism concepts and the various methodological approaches for energy metabolic flow analysis. In addition, the preliminary literature review provided i) the basis from which a case study was selected, namely a hybrid multi-structured urban informal settlement relevant to the study; ii) the appropriate research tools; and iii) the techniques required for describing the different household types and building structures in urban informal settlement.

Firstly, the chapter explores the phenomenon of slums as an effect of urbanization and presents the conceptualisation and typology of slums in (becoming or emerging) in the South African context (refer Figure 2-1). Secondly, the chapter reviews the concept of urban metabolism, which has become a way of understanding materials and resource flows (both in their demand and in consumption), and as a tool in analysing the metabolic pattern of a society. Thirdly, the chapter defines energy metabolism and discusses the concepts thereof in relation to how the metabolism is characterised in urban informal settlements. The chapter closes with a discussion of the approach taken to create an understanding of the societal metabolism and energy flow patterns of

[3] The research design, data collection method and case study was described in Section 3

an informal settlement. Here, information on the material reality of the informal settlement, which may affect policy planning and implementation in this settlement in order to have inclusive decision-making and move towards achieving sustainably developed cities and liveable environments is provided. The figure below (fig. 2.1) provides a snapshot into the organization of the literature reviewed.

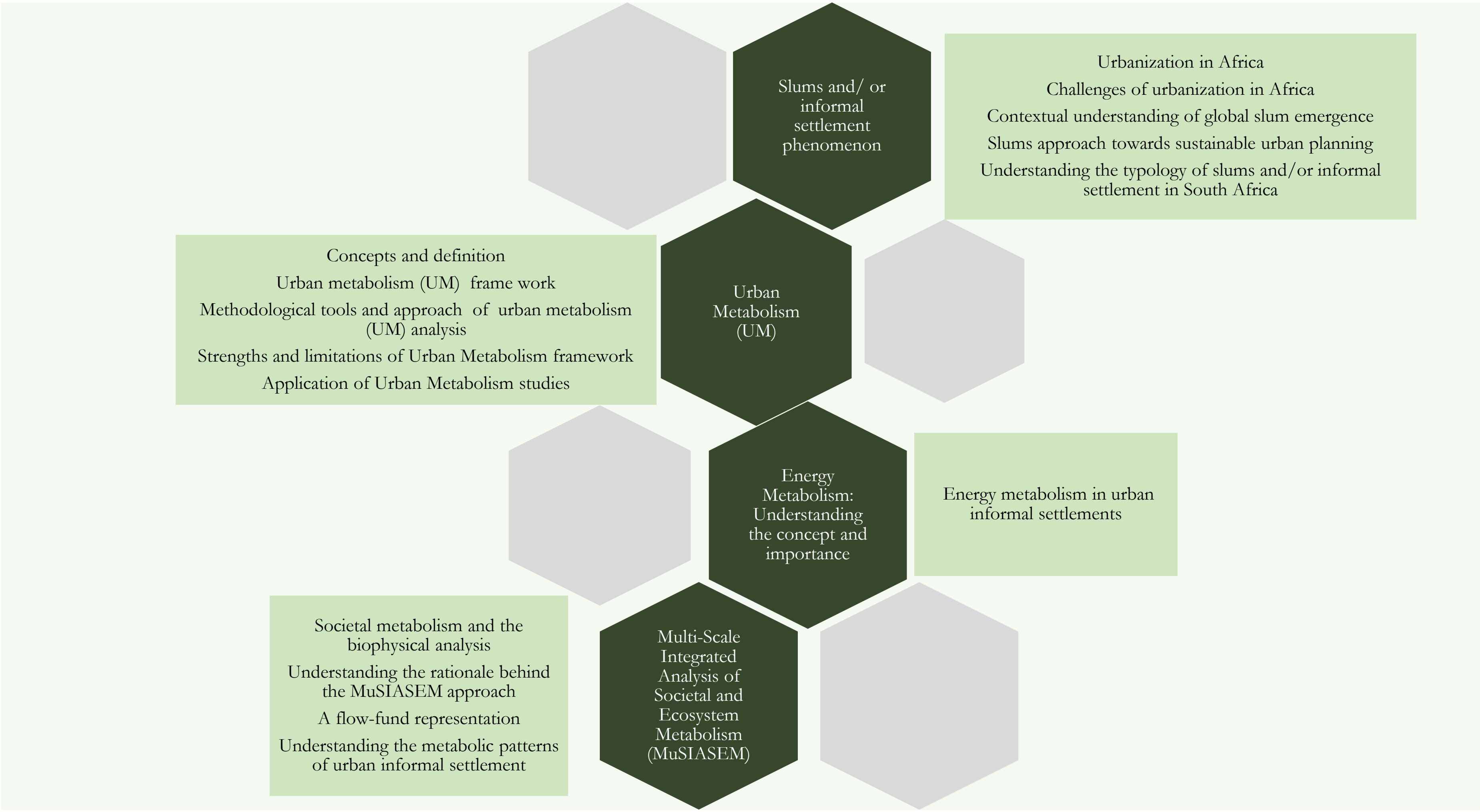



Figure 2-1: Organization of Literature review

## 2.2 Urbanization and urban informal settlements

The global sustainability movement and sustainable development of cities have been continuously developing concepts. The World Commission on Environment and Development (WCED) coined what has become the most frequently quoted definition of sustainable development thus:

> *Development that meets the needs of the present without compromising the ability of the future generations to meets their own needs* (WCED 1987:204)

Cities are complex systems and are largely responsible for 75 percent of the global resource consumption (Pacione, 2009). Cities also represent 2.7 per cent of landed areas of the world, and are responsible for 75 per cent of the world's energy use (consuming both direct and indirect energy such as fuel, food, water supply etc. Cities also produce more than 70 percent of greenhouse gas emissions (Ash et al,. 2008; UN-Habitat, 2016).

Although urbanization now defines our society, it acts as an important factor contributing to socio-economic development. As such, urbanization has very visible negative effects on the ecosystems, materials and resource consumption, biodiversity and increasing threat caused by pollution to public health (UN-Habitat, 2016), one key effect has been the increase in the spread of urban informal settlements and/or slums (UN-Habitat, 2003).

Urban informal settlements are mostly located in marginal areas, with their presence in most world cities. Given this informality, therefore, environmental policies as well as infrastructural transition and construction require a detailed and effective way of understanding how informal settlements and their activities play a role in shaping urban sustainability.

With the continuous influx of new urban settlers to cities, there is an increase in the need for adequate service provision (e.g. education and health), infrastructure (e.g. public transport, housing, and waste management) as well as employment (jobs). With the potential and drastic increase in population and productive activities, however, cities are faced with the challenges of balancing resource distribution and social equity as well as resource scarcity at global scale.

Urban informal settlements need not be viewed based on statistics and maps, but rather, as entities that require and consume resources, and where urban dwellers' everyday experiences influence resource consumption (Guibrunet & Broto, 2015). From this viewpoint, in order to understand urbanization as well as resource and material flows in urban areas or cities, it requires focusing on the urban informal settlements in cities.

Furthermore, the ecological consequences of urbanization extend beyond the boundaries of cities; as urban inhabitants rely on extracting, transferring and delivering energy, water and food from large source regions (Wackernagel & Rees, 1996). The different urbanization trends have significant impacts on the global environment, but are still poorly understood (Bettencourt et al., 2007), yet such an understanding is necessary for transitioning into urban sustainability (Clark et al., 2017).

## 2.3 Slums and/or informal settlements phenomenon

This section explores the global perspectives on slums (or informal settlements), by exploring their definition and characteristics as described by United Nations Human Settlements Programme (UN-Habitat, 2010b). To understand these characteristics, however, an understanding of the definition of informality is required.

Informality refers to a range of spatial organisational patterns, economic exchanges and social relations. Informality emerges in a diversity of settings, from fast growing South East Asian cities to cities in which urbanization reflects the growing influence of global markets in Africa (Guibrunet & Broto, 2015).

Informality has also been defined as urban services provided outside of government regulatory outlines, tax systems and public interferences (such as employment, housing and infrastructure) (UN-Habitat, 2009). Informality is very significant because, it not only characterises a significant part of the current and future economy of urban regions of several world cities but also relates to the many ways in which city dwellers live every day (i.e. the day-to-day activities of urban or city dwellers).

Urban informality can also be seen as a fundamental part of the modern narratives of urbanization (Roy, 2005). Informality, which often describes activities and practices that occur within the city in response to the day-to-day requirements of urban dwellers, usually occur from the bottom of the society chain to the top, rather than occur within a legal or institutional outlines and/or governmental policy plan.

With informality often misunderstood and/or misinterpreted, the World Bank provides its definition as the prolific activities that are "concealed deliberately" from the government or state (Schneider et al., 2010). The exclusion of informal settlements, however, has become a self-revealing prediction, which often results in ineffective and disadvantageous policy-making.

However, the case research on the significance of activities and processes that occur in urban informal settlements and how their contribution towards urban sustainability remains lacking. Despite knowing the importance of urban informal activities and processes, and how these shape the city, informality in urban areas are still poorly understood and under-represented in urban research, particularly in the study of urban sustainable development and sustainability.

### 2.3.1 *Urbanization in Africa*

The African continent provides a unique insight into the perspective of urbanization as it is experiencing multiple interconnected transitions concurrently (Smit et al., 2017). In several ways, the patterns of urbanization in Africa are related to those experienced in the present Latin America countries, namely densely urbanized countries dominated by a lone city, often the economic or political capital of the nation (Karekezi & Majoro 2002). For example, the patterns of urbanization in some of the Latin America countries are characterised by one or two capital cities and a high rate of urbanization (as seen in countries such as Colombia, Chile and Bolivia) whilst similar patterns are emerging in African nations such as Zimbabwe-Bulawayo and Harare, and Botswana-Gaborone (Karekezi & Majoro, 2002).

In order to evaluate the emergence of slums in the African context, they need to be considered against the background of urbanization and its effect in Africa. Developing countries are faced with continuous urbanization and Africa is not left out. Despite African urbanization being of importance (Currie & Musango, 2016), discussions on how cities can achieve sustainable development goals generally overlook the African continent (Swilling & Annecke, 2012; Parnell & Pieterse, 2014). This has led to few strategies emerging on the ways to assess and plan for Africa's overstrained and fast growing cities) (Cobbinah et al., 2015).

Recent studies point to urbanization as one of the key factors contributing to urban development in Africa. Urbanization is seen to constitute a range of factors including demographic (UNDESA/PD, 2012), sociological (Pivo, 1996), ecological (Tavernia & Reed, 2009) and economic (Bao & Fang, 2012) occurrences. Each of these factors has the potential to either improve or slow down the growth and development of urban areas (e.g. cities, megacities, and metropolis) albeit in developed or developing countries.

Considering the unfortunate threat continuous rapid urbanization poses to the sustainable development of urban areas, this development is becoming increasingly impossible in Africa, where urban growth is pervasive (Brockerhoff, 2000; UNEP, 2007; Fox, 2012). In the past, the population of Africa was to a large extent rural. With urbanization rate now averaging at 3.3 percent, however, Africa has turned into one of the fastest urbanizing regions in the world (UNDESA/PD, 2012). An important aspect of urbanization, particularly in the African continent is the growing informal sector, which is mostly characterised with; informal housing, informal activities, urban poor, low-to-medium energy-intensity use (Karekezi & Majoro, 2002).

Recent studies have shown the increasing struggle faced by several urban areas in Africa because of concentrated, unplanned and unsustainable urbanization. For instance, Currie (2015) suggested that the increasing trend of urbanization in Africa is putting a severe strain on urban areas especially in the case of urban poverty and unsustainable resource exploitation, which include energy and land.

Moreover, as the population of urban dwellers continues to increase, this will result in both demographic and socio-economic changes of urban regions, which challenges the policy makers thereby preventing the harnessing of urbanization for sustainable and inclusive growth. One of the defining characteristics of African cities urbanization is informality, with many of the urban dwellers relying on the government (state or municipalities) for their well-being and resources access (Fernández, 2014; Pieterse, 2014).

There are limited studies that have considered the effects rapid African urbanization has on local and global resource requirements (see for example Njoh, 2003; Brückner, 2012; Cobbinah et al., 2015a). Planning for African urban sustainability is generally framed following conceptions of successful cities of the Global North, that omit the reality of informal living and informal economic systems prevalent in developing countries (Watson, 2009), particularly in African cities (UN-Habitat, 2014a). In this regard, Smit & Musango (2015) provided one of the first attempts at linking informal economy to green economy plan in South Africa.

### 2.3.2 *Challenges of urbanization in Africa*

Although urbanization provides the potential for making cities more prosperous and play a role towards the development of countries, many world cities are grossly unprepared for the multidimensional challenges that urbanization poses (UN-Habitat, 2016).

According to Parnell & Pieterse (2014) & Currie (2015), the key themes, which show the effects and challenges of urbanization on African countries present in many of their cities, are as follows:

- Those that result from urban growth and reinforce increasing residency in slums and informal settlements, majorly from circular migration of residents
- Challenges presented in providing urban services
- Climate change
- Insecurity; such as tenure and land insecurity
- Exclusion from policy planning, giving rise to inequality
- Increasing pressure on the supply of energy and the natural environment, which requires a better understanding of the relationship between urbanization and energy consumption
- The challenges in Urban Metabolism (UM) assessment in African cities are mainly scarcity of data at the city level, thus leading to difficulty in tracking flows in informal system. In addition, there is a lack of a standard approach to carrying out UM as well as cities nature as opened.

### 2.3.3 *Contextual understanding of global slums emergence*

As society continues to urbanize, there is a continuous increase in segregation of the economy. With informality (in the form of settlement and slums), a result of continuous unplanned urbanization, it is very useful to recognize how the emergence and phenomenon of slums is viewed globally. This would help in providing a way of understanding the slum phenomenon in the form of their characteristic conditions and categorization.

The term slum can be used in describing a large range of low-income settlements and/or housing with poor living conditions (UN-Habitat, 2003). Slums mainly consist of a densely populated urban area usually characterized by low standard housing (inclusive of both structure and services). The definition combines the essential characteristics of slums, which are sub-standard and densely populated (mainly attributed to its spatial and physical characteristics). According to the generic definition of slums, they are usually identified as an equal or integral part of cities (UN-Habitat, 2003).

Slums are largely (to a great extent) a result of the physical and spatial manifestation of urban poverty, where the fundamental importance of this fact has not always been put into consideration in past policies, which aimed at eradication or slums upgrade. Future policies, therefore, need to look beyond the physical dimension of slums by addressing the underlying problems such as urban poverty (UN-Habitat, 2003). This means that policies aimed for slums should seek to provide support towards urban poor livelihoods by enabling the activities of the informal sector to grow as well as linking low-income housing development to income generated in these slums (UN-Habitat, 2003).

Slums are inclusive of informal settlements, which are now turning into a very visible presence of urban poverty within cities in developing countries. Other definition of slums is given as parts of cities that are mostly neglected consisting of poor living conditions and housing (World Bank & UNCHS Habitat, 1999) . Slums have been referred to using different names such as favelas, bidonvilles, kampong and tugurios, with each sharing the same characteristics of living conditions (UN-Habitat, 2003). Housing or dwellings in many of these settlements usually differ from one another ranging from a simple shack to a more formal housing structure. Accessing infrastructure and basic services are either limited or badly deteriorated (UN-Habitat, 2003; UN-Habitat, 2010b).

The characteristic conditions of a slum household as described by UN-Habitat (2003 ; 2010)is shown in Table 2-1 and relates to a deficiency in any of the following:

i. Improved water system access
ii. Adequate living areas (usually overcrowded and of high-density
iii. Improved sanitation system access
iv. Quality of structures and lack of durable dwellings, and
v. Tenure security (UN-Habitat, 2010).

Table 2-1: Indicators and threshold for providing slum definition[4]

Source: (Smit et al., 2017)

| Characteristics | Indicator | Definition |
|---|---|---|
| Accessible to water | Improved drinking water system and or sources<br>(MDG indicator 7.8)<br>(SDG goal 6.1) | A settlement household has an improved drinking water supply system, if there is at least 20 litres consumption per day, this at less than 10 percent of its household income. With the water from these sources described as follows:<br>● Piped water connected into the dwellings, plot or yard<br>● Borehole/ tubed well<br>● Stand pipe/ Public tap water system.<br>● A properly dug well, well-kept and protected.<br>● Water obtained from a protected spring.<br>● Collected rainwater. |
| Accessible improved sanitation | Improved sanitation system and or facilities<br>(MDG indicator 7.9)<br>(SDG goal 6.2) | A settlement household is considered to have an improved sanitation which is accessible to each household member if it is able to use the following:<br>● When connected with an excreta disposal system, either used as a public or private toilet, shared among people from a reasonable number of household.<br>● A pit latrine that is built with a slab;<br>● An improved pit latrine with a proper ventilation;<br>● Septic tank with direct connection;<br>● Composting toilet;<br>● Sewers with pipe (for pouring to flush or flush the toilet) |

[4] Where the first two indicators in Table 2-1 may be linked to SDG 6, whereas the only reference to the notion of slums pertains to SDG 11 Sustainable cities and communities, and in particular to SDG 11.1, which refers to the upgrading of slums (UN-Habitat, 2016). As for the last three indicators, these are not explicitly mentioned in the SDGs.

<table>
<tr><td>Housing or dwellings of durable quality</td><td>a. Location<br><br>b. Structure permanency</td><td>A house or dwelling is considered durable if it is built on a location that is non-hazardous. A hazardous location is the following:<br>● Areas that are geographically unstable, which are usually prone to earthquakes, landslides and flood.<br>● Garbage dumpsites;<br>● Highly industrial polluted areas;<br>● Unprotected high risk zones (such as airports, railroads, energy transmission lines).<br>The permanency of structures is determined by:<br>● Construction quality (example is the materials used for floor, wall and roof);<br>● Compliance with local building codes, bylaws and standards.</td></tr>
<tr><td>Overcrowding</td><td>Sufficient living areas</td><td>A house is considered to have sufficient living areas for its household people if not more than three people per liveable room.</td></tr>
<tr><td>Tenure security</td><td>Security of tenure</td><td>This is when a household has an effective protection by the state against arbitrary forced and unlawful evictions through:<br>● A documented evidence, which can be used as proof, such as formal title deed to tither land or residence<br>● De facto or perceived protection from forced evictions</td></tr>
</table>

Whilst providing basis for slum estimates according to its definitions (Bakers, 2008; UN-Habitat, 2010; UN-Habitat, 2015b; UN-Habitat, 2015a; UN-Habitat, 2016; Smit et al., 2017), Smit et al. (2017) describe them as failing to incorporate the key basic characteristic conditions for defining or measuring slums as "access to clean and modern energy". Majority of slums and/or informal settlements are mainly situated on the periphery of cities, many of which are lacking formal energy access. Those with access are mostly through illegal connection (e.g. indirect connection to neighbours) (Sustainable Energy Africa, 2014).

Furthermore, there are other relating factors that contribute to the creation of slums, as provided by Smit et al. (2017), namely (i) income inequality (ii) lack of economic growth and opportunity (iii) in-migration (iv) poverty (v) lack of affordable housing and (vi) weak governance (Amado et al., 2016; UN-Habitat, 2003). It is also the case that when analysing the urban slum, certain qualifying number of characteristics, definition and its attributes require consideration (see Table 2-2).

Table 2-2: Main categorisation for spatial analysis of slum

| | |
|---|---|
| Origins and age | Slum estates<br>Historic city-centres slums<br>Recent slums<br>Consolidating informal settlements |
| Size and scale | Small slums<br>Medium-sized slum estates<br>Large slum settlements |
| Location | Peripheral<br>Central<br>Scattered slum islands |
| Development dynamics | Slums upgrade<br>Development led by the communities and or individuals<br>Communities that lacks incentives for improvement<br>Intervention-led improved slums |
| Spatial forms, vulnerability and legality | Informal<br>Illegal |

Source: (UN-Habitat, 2003 in Smit et al., 2017)

According to (Smit et al. 2017), other dimensions and analysis through which slums are generally defined are:

i. based on their physical characteristics; which relates to the household typology, access to infrastructure and services;
ii. according to their social characteristics, which is mostly based on employment, income and economic activity; and
iii. legal characteristics, which relates to ownership of land and planning regulations adherences (Srinivas, 2015; Turok, 2015).

Other further attempts at analysing slums include referencing them as unsafe and unplanned areas (Khalifa, 2011).

Further, Smit et al. (2017) argue that the conventional categories of slums fluctuate between Illegal and Legal, Informal and Formal, and Unplanned and Planned. As such, Smit et al. (2017) were able to provide conceptualized four distinguishable types of settlements as shown in table 2-3 below.

Table 2-3: Settlement types (with their categories and characteristics).

| Categories | Settlement types characteristics | Definitions |
|---|---|---|
| A | Legal, Formal and Planned | These types of housing or building structures are usually formal with proper adherences to all legal requirements and the spatial aspects of the settlement are planned. |
| B | Illegal, Formal, Unplanned | The housing or building structures are initially formal, but because of overcrowding and or overpopulation as well as lack of proper maintenance, it fails to adhere to legal requirements in terms of health and safety and building regulations. |
| C | Illegal, Informal, Unplanned | The structures of the building or housing are informal, which contravenes all legal requirements and planning regulations. |
| D | Legal, Informal, Planned | The structures of the building or housing remain informal, with the infrastructure formally provided and the layout of the settlement are planned. |

Source: (Smit et al., 2017)

Smit et al. (2017) suggest that these categories are very essential and useful in order to recognise the physical, infrastructural and legal dimensions and characteristics of slums, and to provide a typology through which an in-depth analysis of slums can develop. (Smit et al. (2017) go on to argue that although these categories provide the basis of understanding the phenomenon of slums, they provide little explanation into their persistency and growth of slum phenomenon in urban development.

Other characteristics and factors, therefore, require consideration in the dimension and analysis of the slum phenomenon. This is because the type of settlement may change over time especially when connected to the different transitions happening on the African continent.

### 2.3.4 *Slums approach towards sustainable urban planning*

Slums are universally perceived as either a challenge or problem (Nuissl & Heinrichs, 2013). It is, thus, largely accepted that slum existence calls for 'urban planning' political action. According to Smit et al. (2017), the approach to urban planning and policy of slums are diverse, and often contradicts one another in terms of their characterisation, whether the problem is about slums itself and how they and their dwellers should be treated (see also Hunter & Posel, 2012; Nuissl & Heinrichs, 2013; Turok, 2015) .

Furthermore, Smit et al. (2017) suggest that when there is little or no external governmental support towards the improvement of slums livelihood, and slums are not integrated into the wider urban environment. It had been argued that there is a long term effect of intergeneration disadvantage and inequality; which is constant leading to lack of attention to slums as well as lack of inclusion in urban planning and policy (see for example Amado et al., 2016; UN-Habitat, 2015c; UN-Habitat, 2015b; UN-Habitat, 2015a).

Smit et al. (2017) argument points to the need to understand informal settlements through a systems-oriented approach by considering them as:

- 'integral parts of the city', which are occupied by resourceful and motivated citizens, not as an isolated squatter camp inhabited by desperate and destitute (Turok, 2015)
- affecting opportunities and the standard of living of their dwellers, and
- influencing or influenced by the perspectives of development of societies and cities in which they occur (Nuissl & Heinrichs, 2013).

It is also the case that if cities are considered as a complex system (example is provided by (Schandl & Capon, 2012) with their subsystem an informal settlement, it is possible to make inferences about both their current and future interactions particularly relating to their resource requirements (Smit et al. 2017). This is a contrast with the analysis of slums provided by UN-Habitat (2003) (as described in Table 2-1), which assumes and conceptualises slums as homogeneous, and suggests that a one-size-fits-all is appropriate. Smit et al. (2017), however, argue that this type of approach negates the multidimensional and opposing contextual realities of slums, particularly in relation to their transitioning. The slum analyses, as described in Table 2-3, are based on their physical, legal and geographical characteristics, disregarding the social and institutional structures leading to slum creation, with focus on the symptoms rather than the cause of their emergence (Kovacic & Giampietro, 2016).

In light of this discussion, and in order to make plans towards developing sustainable cities, it would necessitate a deeper recognition and understanding of the various differences.

### 2.3.5 *Understanding the typology of slums/informal settlements in South Africa.*

The continued growth and presence of informal settlements with access to little or no infrastructure and services, most of which are found in the largest cities is one common phenomenon in South Africa (Chenwi, 2012). According to UN-Habitat, there are about three slum households present in ten urban homes (UN-Habitat, 2010a). Notwithstanding, this rise in informal settlement are a result of economic and social exclusion, poverty, marginalisation, social inequality and discrimination (Huchzermeyer et al., 2006).The reasons as to why these settlements exist or were formed differ. Some have established the result of bourgeoning informal settlement as slowness in state-subsidized low-cost housing delivery (Huchzermeyer et al., 2006; Skuse & Cousins, 2007).

According to Smit et al. (2017), the emergence of slums in South Africa is closely linked to the political and social history of the nation. They trace the emergence of slums in South Africa as giving rise to a number of settlement types, namely (i) Housing-turned slum; (ii) Township, RDP neighbourhood, Location; (iii) Transits camps; (iv) Squatter camps; (v) Service and Site informal settlements; (vi) Hybrid, multi-structured settlements (Smit et al., 2017).

Smit et al. (2017) also point out that the number of existing settlement types exist between legal and illegal; formal and informal; and planned and unplanned. When considering the political context of slums in South Africa, it can be categorised further based on the notion of Legitimacy/Illegitimacy (Smit et al., 2017).

The typology of settlements in South Africa, builds on the conventional framework as provided by (Smit et al., 2017) settlement types which is summarized in Table 2-4:

Table 2-4: Settlement types in South Africa

| Slum Type | Description |
|---|---|
| 1. Township, Location, RDP neighbourhood | They are referred to as a formal housing structures, established by the government for control and regulation (Harrison, 1992)). They can however be described as a Category A type of settlement, which is Legal, Formal, Legitimate and Planned. |
| 2. Housing turned slum | According to UN-Habitat (2003), these settlement type evolved from the "hostel" housing structures. The settlement types have been described according to Chenwi (2012)as different from the traditional type of informal settlement.<br><br>Although, they may have been planned initially as Category A settlement types (Legal, Formal, Legitimate and Planned). They however now form a different category of settlement, which is Category B: Illegal, formal, Illegitimate and Unplanned. |
| 3. Squatter camps | They result from land invasion at a gradual process of occupation and incremental growth (UN-Habitat, 2003). They are different from the site and service settlement type, in which the settlements are mainly focused on the illegal occupation of lands and/or buildings.<br><br>However, as they are considered an unwanted settlement type, they were classified according to Smit et al. (2017) as Category C type of settlement i.e. Illegal, Informal, Illegitimate and Unplanned. |
| 4. Site and Service informal settlements | This settlement type refers to those that are informal housing, which were constructed in the context of 'site and service' schemes (Harrison, 1992)<br><br>They have legal tenure as they were constructed and provided by the government in order to clear backlogs on housing provision. However, they are categorized as legal but an informal settlement type, with Category D: Legal, Informal, Legitimate and Planned. |
| 5. Transit camps | They are areas where the government relocates people living in shacks, pending the time the municipality can allocate a formal housing. Although temporary, but mostly controversial, as there is no timeline before reallocation of housing thereby displacing the dwellers from their work opportunities and communities (Turok, 2015).<br><br>They are similar to site and service in nature, as Category D: Legal, Informal, Legitimate and Planned. |
| 6. Hybrid or multi-structured informal settlements | These settlement types evolved from the different categories of settlements over the years from the legal/illegal, formal/informal, and planned/unplanned slum dimensions.<br><br>Initially, such settlements comprised of hostels type of housing structures, later including an addition of formal RDP and public housing. |

Source: (Smit et al., 2017)

Smit et al. (2017) suggest that the emergence of Hybrid, multi-structured settlement types has been due to lack of proper maintenance and overcrowding resulting in their deterioration, with the settlement initially planned comprising of formal housing structure as seen with Category A settlement type (legal, formal, planned settlement).

Further, Smit et al. (2017) describes the hybrid multi-structured settlement type as comprising of both the illegal/legal, informal/formal, and unplanned/planned category aspects. These were further categorized as comprising of Category A to D, having formed a new Category E: Legal/Illegal, Formal/Informal, Planned/Unplanned, and Legitimate/Illegitimate. These settlement types may be categorised further into:

- Backyard shacks: are generally informal housing structures (mostly built from corrugated iron sheets) erected at the backyard of a formal housing or residential properties. They are seen in formal legal townships or RDP neighbourhood; and
- Freestanding shacks informal settlements: are clusters or groups of informal housing structures, built on tracts of land within a formal township, or between townships in buffer zones, on an undeveloped plot of land, on vacant land formally owned by coloured Asian or white areas, and on tribal lands which are close to urban areas (Smit et al., 2017).

Effective and sustainable urban planning and services provision, inclusive of informal settlement or slums and its hinterland, the categories of slums and building structures need to be taken into account and energy flow analysed in the different instances.

## 2.4 Urban metabolism

This section explores the concept of urban metabolism, through its definitions and applications, where the urban systems are seen as interactive and characterised by openness, constantly exchanging materials and energy with their environment. The Urban metabolism approach can be employed in order to understand materials and energy flows, natural resource consumption and wastes production in urban systems, while simultaneously improving their liveability so they can fit better within the capacities of local, regional and global ecosystems in a social equity and welfare framework (Newman, 1999).

While the conceptual use of urban metabolism is increasing, there is limited application of such a study in the urban informal settlement. This may result from lack of data, thus, indicating the necessity into conducting more research into how cities and urban informal settlements or slums are linked in relation to with their energy and material use. It may be of benefit to develop a method through which energy and material metabolic rate in urban informal settlements can be analysed in the African context. Seeing that urban metabolism analysis is still developing, however, information and results obtained from these analyses are key to shaping cities and their environs. This will be beneficial to cities for promoting a flow management practice (e.g. of flows: energy, water, nutrients, materials, waste, food etc.) by city planners and decision makers.

For sustainable city growth and development, urban metabolism fits into these bigger agenda, which has prompted a call for an extended urban metabolism study to include sustainability indicators.

### 2.4.1 *Concepts and definitions*

The concept of urban metabolism (UM) has been employed in recent years, as a method of improving our way of understanding on how the social, environmental and economic factors shape urban processes and phenomena. The theory, which is now widely used by different disciplines, (e.g. in urban ecology, industrial ecology, ecological economy, political ecology, to name a few) considers activities which are present within cities. These can either be observed based on their economic, social or physical factor (Kennedy et al., 2007).

Several researchers, among them Barles (2010); Kennedy et al. (2011); Mostafavi et al. (2014); Weisz & Steinberger (2010), have voiced the challenges on providing an understanding which can define urban metabolism in the urban context. The challenge also includes the extent to which the concept can draw on definitions from other fields, such as biology.

Although the definition of UM by Kennedy et al. (2007) is the most cited one, it only reflects the concept from an industrial ecology context. Currie & Musango (2016), thus, elaborated definition of UM by referring to it as:

*'the collection of complex sociotechnical and socioecological processes by which flows of energy, materials, information and people shape the city, service the populace needs, and impact the surrounding hinterland'.* (Currie, 2015; Currie & Musango, 2016)

A recent study by Lederer & Kral (2015) presented an historical case of urban metabolism application, where the work of Theodore Weyl on Metabolism of Berlin (around 1890) was introduced as the first pioneer study of urban metabolism studies (Lederer & Kral, 2015). Several decades later, Abel Wolman (1965) conducted a pivotal study and published an article highlighting the various system-wide impacts of consuming materials and generating waste within an urban environment (Decker et al., 2000). Wolman used data obtained at national level on food, water and fuel consumption. The data included the rates at which sewage waste is produced and air pollutant to determine the rates of flow per capita (both inflow and outflow) for a hypothetical American city of a million population. His work explains how cities metabolic requirements are all of the commodities and materials required for sustaining the city dwellers at work, home and for other activities (e.g. leisure and entertainment) (Wolman, 1965). A number of scholars (Warren-Rhodes & Koenig, 2001; Kennedy et al., 2007) took the lead from the work of Wolman to suggest that urban metabolism discipline evolves by responding to the increase in water and air pollution caused by a city. On the one hand, Warren-Rhodes & Koenig (2001) describe urban metabolism as a quantitative measure of "a city's load on its natural resources". On the other hand, Kennedy et al. (2011) find that the concept of urban metabolism involves 'big picture' quantification of inputs, outputs, energy storage, materials, nutrients, water and wastes of urban areas.

The urban metabolism notion is based loosely around the analogy of organisms' metabolism, which can be made between cities and ecosystem. This is because cities have the same characteristics to organisms as consumers of resources from their environment and excrete wastes. Similarly, "Cities can be seen to transform raw materials, water and fuel into built environment, human biomass and waste" (Decker et al., 2000; Kennedy et al., 2011).

Further attempts at explaining urban metabolism have led to authors relying on the history of *metabolism* in terms of biology and ecology. In biology 'metabolism' means the chemical processes through which organisms break down substances and, in turn, build new molecules for release, storage or utilization of energy (Smith & Smith, 2006).

Awareness has grown extensively on the application of urban metabolism in assessing questions on energy and material consumption of cities. One of the major reasons for which urban metabolism was developed was to address the concerns on how non-renewable energy resources depleted with little or none left for re-use. Increasing urbanization and land-use changes are displacing biodiversity and their respective ecosystem services leading to the emergence of green infrastructure as one possible strategy for mitigating urban displacement.

### 2.4.2 *Urban Metabolism (UM) Framework*

The concept of urban metabolism has become a way through which better understanding of energy and material flows within urban society can be analysed. One of the purposes of understanding urban metabolism is to provide its applicability in assessing urban sustainability. The adoption of this concept has brought about an understanding of what the city is, and how both the material and the immaterial flow through different economies and infrastructure, thereby mediating the production and reproduction of the city, as both a socio-economic and biophysical entity.

Urban metabolism has inspired a new way of thinking about the functions of cities as well as how they can become more sustainable. The concept has become significant and well known across different disciplines connecting urban studies with diverse fields of studies such as development, engineering, economics and human geography.

Urban metabolism analysis is a means through which the total energy, materials, water and waste fluxes entering and leaving an urban region can be quantified. Similar to human metabolism, the analysis of cities can be done based on the rates of their metabolic flow, which arises from the uptake, transformation and material storage, energy and waste products' discharge (Warren-Rhodes & Koenig, 2001). Since Wolman's application of urban metabolism, the concept has been applied to a smaller number of cities including Sydney, Hong Kong, Taipei and Vienna (Huang, 1998; Newcombe et al., 1978; Newman, 1999; Hendriks et al., 2000; Warren-Rhodes & Koenig, 2001).

One of the most comprehensive and early urban metabolism study involving real cities was in the 1970s. The study, which analysed the urban metabolisms of Brussels and Belgium, carried out by ecologists Duvigneaud & Denaeyer-De Smet (1977), involved quantifying urban biomass and organic discharges from dogs and cats (*see figure 2-2*) (Kennedy et al., 2007). The input and output flows of the city were presented in an attractive way with attention paid to key point. The study on Brussel metabolism was distinctive because it was inclusive of their natural energy balances, thereby extending beyond a quantification of their human activity induced by their energy flows (Kennedy et al., 2011). Other examples include studies on Tokyo (Hanya & Ambe, 1976) and Hong Kong (Newcombe et al., 1978).

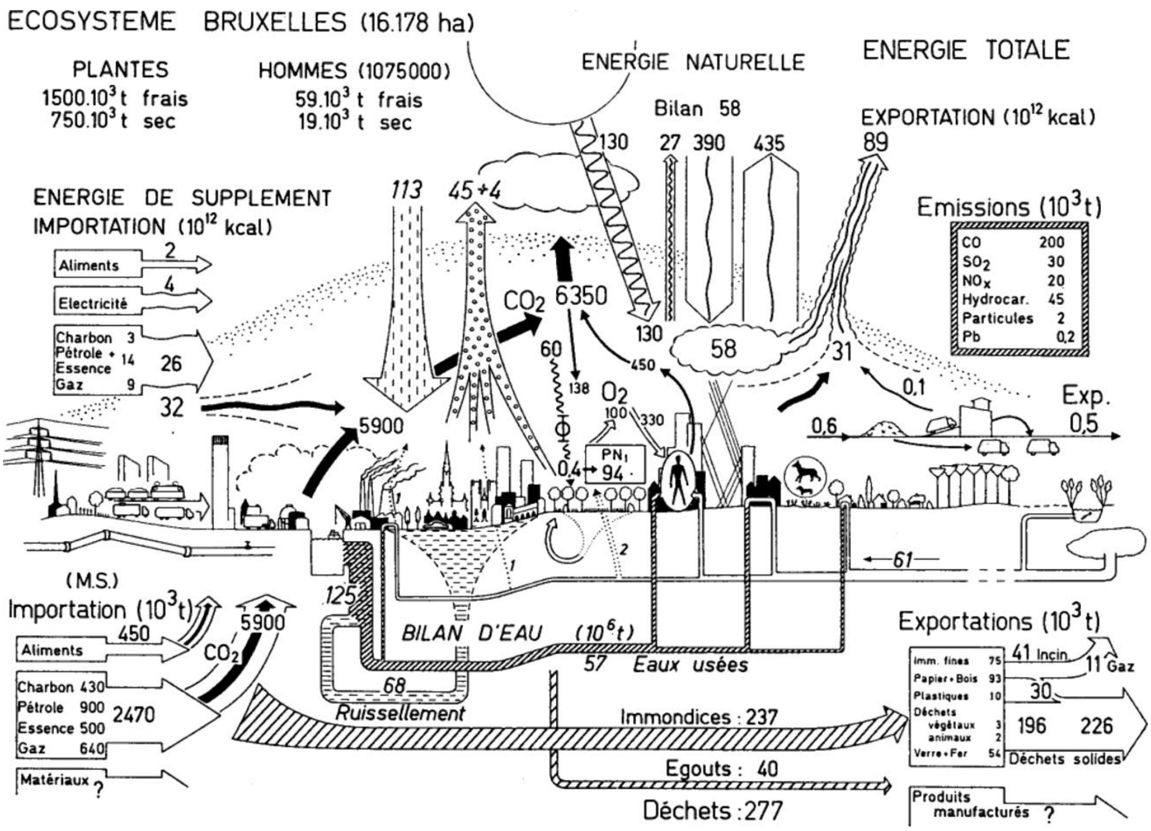



Figure 2-2: An analysis of metabolic patterns carried out by Duvigneaud and Denaeyer-De Smet on Brussels in 1977 (Kennedy et al., 2007:47).

Urban metabolism analysis of urban systems can provide significant information and/or data on recycling of material, energy efficiency, waste management and infrastructural transitioning. The urban metabolism framework can be combined with indicators and measures of economic and social wellbeing for a well-informed understanding of the social, environmental as well as economic human settlements impacts.

Further, the analysis of metabolism provides appropriate parameters for assessment of strategies and technologies required for reducing inputs and closing metabolic loops. Thus, urban metabolism is established as a suitable approach for assessment of cities sustainability (Codoban & Kennedy, 2008).

The conclusion from the past studies reviewed here is that the analysis of cities metabolisms has continued to increase over the years (Kennedy et al., 2007). It has been widely accepted that the linear metabolic pattern of cities in which resources are transformed into waste products results into unbalanced life support system of the world (Girardet, 2010). There is, however, a necessity to prioritise urban sustainability by *"…re-designing urban metabolism by 'closing the loop' in order to make if truly compatible with the processes occurring in the living world…"* (Girardet, 2010). In order to achieve sustainability, cities must reduce their rates of consuming all resources and decrease their waste outputs (Gaya, 2010). This can be achieved by changing to a circular metabolism rather than employing a linear metabolism (*see Figure 2-3*):

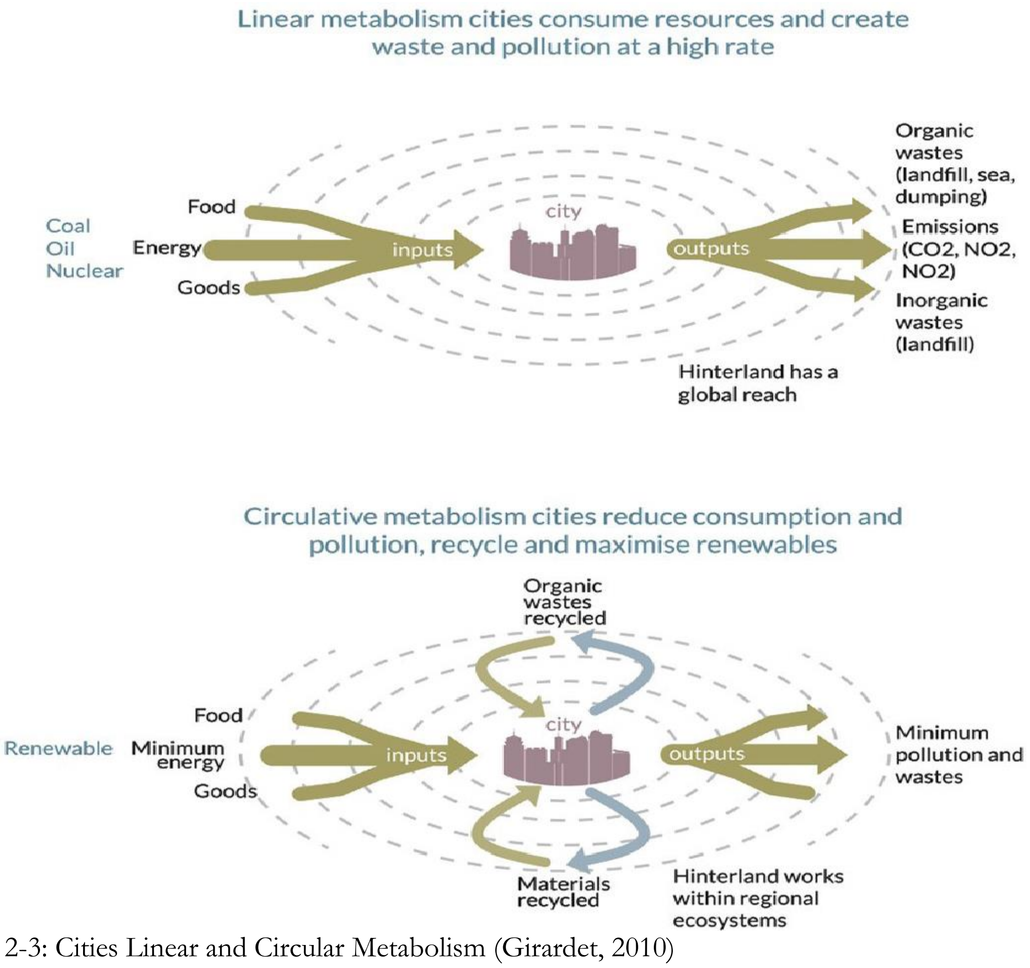



Figure 2-3: Cities Linear and Circular Metabolism (Girardet, 2010)

### 2.4.3 *Methodological tools and approach of Urban Metabolism analysis*

The modelling of cities can be carried out as if they were superorganisms consisting of different types of processes. As well, urban metabolism research can contribute to proffering solutions on urban environmental challenges and problems by revealing details of the metabolic throughput of the system. The processes of urban metabolism analysis can be done using a different set of methodological urban metabolism tools.

The set of detailed tools and methodological steps used in analyses of material flow or urban metabolism are developed in the work of Baccini & Brunner (1991), and other studies (see for example Hendriks et al., 2000; Warren-Rhodes & Koenig, 2001). The surge in these tools provides a useful overview on the patterns of cities consumption, by examining their required and used resources as well as those generated within the urban areas. The main assessment and accounting methods for urban metabolism are typically based on the analysis of energy flows and material flows, by tracking the input, output , transformation and storage processes (Hendriks et al., 2000; Zhang, 2013).

The required data for assessment of urban metabolism is driven by the methodology that is proposed for use in investigating a specific case study/metabolic flows. To carry out this assessment, the urban system of interest needs to be defined and done over a period time (GCRO, 2012).

There are different methodologies for urban metabolism approach used in accounting for and analysing urban metabolic processes (Barles, 2010; Dinarès, 2014). A number of studies were reviewed to provide detailed analysis on the different methodological approaches to urban metabolism, namely Daniels, 2002; Daniels & Moore, 2002; Hammer et al. 2003; Loiseau et al., 2012; Huang et al., 2012; Zhang, 2013). Examples of this approach include:

- Ecological footprint analysis (Holden, 2004; Mun & Galindo, 2005);
- eMergy (energy flow) analysis (Huang Shu-Li & Hsu Wan-Lin, 2003; Liu et al., 2011);
- Material flow analysis (MFA) (Brunner & Rechberger, 2004; Niza et al., 2009; Zhang, 2013);
- Life cycle analysis (LCA) (Chester et al., 2012)
- Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) (D'Alisa et al., 2012);
- Input –Output analysis (Liang et al., 2012).

These are all part of the main tools for carrying out physical accounting on the environment, based on variable in-depth study on energy and material flow analysis (Eurostat, 2001; Loiseau et al., 2012).

However, only few studies has accounted for a complete energy and material flows, with most providing documentation of few specific substances, such as water or carbon emissions, nitrogen or flow from proxies (Zhang, 2013). Understanding the importance of cities metabolic patterns can be done by comparing results between cities. This kind of comparison is limited given that different methods are used in undertaking the analysis of cities metabolism.

Studies by (Kennedy et al., 2011), (Mostafavi et al., 2014) and (Zhang, 2013) each offered a comprehensive history into urban metabolism where two primary approaches to urban metabolism analysis were identified, namely applying mass fluxes or energy balances. Barles (2010) provides an overview on substance flows, which is a specific analysis of mass flux.

The following sections explore these main approaches for analysing the energy and material flows of an urban metabolism (through which we can obtain an understanding of a city's metabolic profile) and some of their criticisms.

#### 2.4.3.1 *Material Flow Analysis (MFA) (or Mass fluxes)*

In the earlier studies on Urban Metabolism, researchers often adopted the accounting flow method of material flows analysis. The results from such studies can be seen applied in the design and management of several cities (see for example (Fischer-kowalski, 1998; Fisher-Kowalski and Hüttler, 1999) . In contrast with Odum's emphasis on energy, MFA provided information on flow and stocks of resources in terms of their mass (Kennedy et al., 2011). As such, the purpose of material flow analysis (MFA) is to track and quantify how materials flow in a defined case and over a time period (Hammer, 2003). According to Daniels & Moore (2002), MFA provides a methodological framework, which offers great scope for the general application, integration, synchronization and development of environmental accounting and system analysis.

In addition, MFA can be applied in order to establish a balance in the system energy and material resources. MFA is mostly applied at national scale given the easy accessibility of relevant data and the presence of methodological framework developed by Eurostat (2001). In addition, MFA is an important tool for assessing the dematerialization of a society or economy, thereby enhancing its social and economic growth, its wellbeing and its transition towards sustainability (Bringezu, 1997). One drawback of MFA is that it does not differentiate the type of resources, which demands that more information be provided on resource types used (Loiseau et al., 2012).

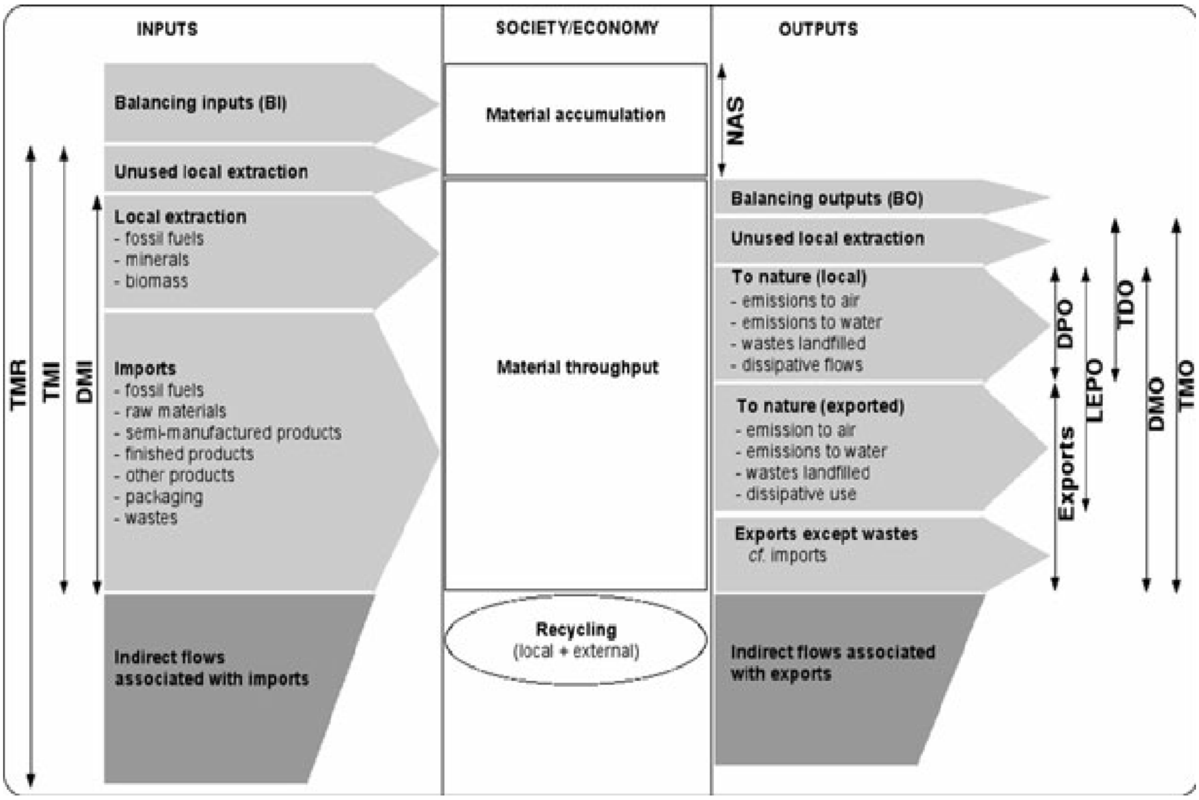



Figure 2-4: Materials flow diagram (Barles, 2009:900)

Figure 2-4 describes the main indicators and flows in a material balance system. The balance system includes the following: (i) a system or economy, limited by its administrative or political boundaries, consisting of the whole society (artefacts and population), but excluding the natural environment where their primary materials are extracted; (ii) the balance of water is also excluded except in balancing outputs cases.

#### 2.4.3.2 *Energy Balance*

Odum first carried out metabolism described in terms of energy in 1983, when he applied his method to a case study on Paris. The clarification on the fundamentals of emergy theory has been provided by Odum (1996). The approach based on thermodynamics was suggested as one of urban metabolism models consisting of emergy (solar energy equivalents) and embodied energy flows. Another energy balance method is that of *exergy*, "representing the quantity of useful work that energy can carry out in a system" (Zhang, 2013).

Although Odum's method has not become conventional, it was applied by Huang and Hsu in their study of Taipei's urban construction, Taiwan (Huang, 1998; Huang Shu-Li & Hsu Wan-Lin, 2003). Zhang et al. (2009) also applied emergy-based indicator system in evaluating Beijing's metabolic factors between 1990 – 2004 period.

The advantage of using exergy and emergy accounting measures lies in their ability to provide researchers with a way to combine material or energy flows consisting of different units of measurement. Examples of such are money flow, information, volumes or masses of physical materials and energy fuels content, which are then applied for an integrative analysis. This allows for comparison of relative significance, such as 'weight' or impact of different flows. In addition, researchers account for energy and material flows through the conversion of all the flows into a unified objective function (based on emergy or exergy). These integrated flows are then used in analysing socioeconomic systems. Analysing an urban ecosystem as a set of energetic flows that go in and out of the urban system provides a functional conceptual link between the urban and its natural environment.

According to Huang & Chen (2009), this allows for renewable resource sources inclusion, as well as for both direct and indirect flows. It also offered a synthesis using emergy of Taipei with respect to socioeconomic indicators. Figure 2-5 provides a typical energy flow diagram of an urban ecological system, where each of the arrows relates to a certain quantity.

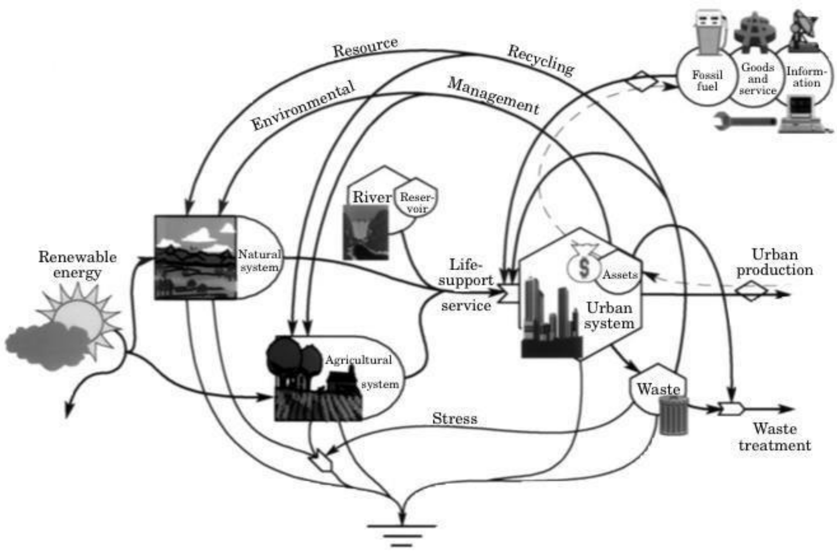



Figure 2-5: Urban ecosystem energy hierarchies (Huang, 1998:43)

The most significant drawbacks to energy and material flow analysis are the difficulties presented in judging a system's sustainability given that evaluation can only be done according to different spatial units by horizontal comparison and at different times by vertical comparison. The failure to provide sustainability degree (low or high) as well as assess sustainability changes (decreasing or increasing) is, however, a very significant limitation of energy flow and material flow analysis when compared to other accounting methods. The ecological footprint, for example, provides an evaluation on the ecological sustainability of a system. Table 2-5 below provides a descriptive analysis of different accounting methods that can be employed in urban metabolism.

Table 2-5: Comparing the different urban metabolism accounting methods (Zhang 2013:467)

| Methods | Benefits | Limitations / Challenges |
|---|---|---|
| **Materials Flow Analysis (MFA)** | To measure the input and output flow of a city's materials is one effective way of supporting resources and environmental management. Therefore, by tracking cities material and resource flows, it can assist in improving environmental pressures. | The addition of different materials weight directly increases resources substitution, thus, ignoring the differences in quality among materials. The analysis also ignores the significant role of energy flow, which is a very crucial omission, as these flows drive all material flows throughout the urban metabolic process. This approach is unable to judge the degree of sustainability and the changes in sustainability. One other limitation is the difficulty in indirect flows identification and quantification, which many times are estimated poorly (Barles, 2010) |
| **Energy flow analysis (Emergy)** | Through this accounting method, the energy that underlines all materials creation and flows is accounted for along with the materials. The differences in material quality and energy are also taken into account. | For the analysis, it is important to determine first all the appropriate energy transformation rates for all the flows. In addition, the accounting method for wastes has not been unified. |
| **Ecological footprint analysis** | This is an analytical method through which the socioeconomic development demands can be combined with the ecological environment's supply capacity and through which an ecological deficit or surplus can be determined by the researcher. Through the analysis, unsustainable ecological situation can be revealed and a reflection provided on the complementary relationship between natural capital and socioeconomic development. | Using a single land function neglects other potentially significant functions, and the functional land diversity (i.e. its ability to provide multiple services). In addition, the criteria for selecting the area for ecological supply are yet to be unified. The method relies on an incomplete resource description provided by the natural system, thereby underestimating the extent of human impacts. |
| **Life cycle assessment (LCA)** | The analysis gives an accounting of resources, products and services for their overall impacts on the environments. LCA is mainly applicable for analysing the estimates of indirect flows that are connected with non- | Carrying out LCAs can be time and resource intensive. There is also the problem of how far upstream the analysis can be taken given that there has been a continuous discussion on the appropriate application of the various methods of life cycle assessment to urban systems. Providing an appropriate system boundary definition is also a challenging task |

| | | |
|---|---|---|
| | renewable and renewable raw materials and resources with a low-level process. | |
| **System dynamics analysis** | The analysis is a method for understanding the dynamic behaviour of complex systems. It is an interdisciplinary methodology for understanding how complex systems change over time. Essentially, the methodology strives to mimic the "feedback" loops through which all agents in a given system interact, whilst taking into account changing variables over time and how these affect other variables. The system dynamic modelling finds a way to address long-term dynamic policy issues. | The main limitation to this methodology is in the rules of decision-making used when determining the dynamic hypothesis, usually not obtained from the data directly, rather through subjective perception. For example, stakeholders' and the modellers' perceptions on the under study system. |

### 2.4.4 *Strength and limitation of Urban Metabolism frameworks*

Urban metabolism has become one of the methods for creating a link between the analysis on the flow of energy and materials with resource consumption and production. The study by Newman et al. (1996), demonstrated how urban metabolism studies could become a significant part of state of environmental reporting (SOE). Significant objectives of SOE reporting are to provide an analysis and describe important trends and conditions in the environment as well as provide guidelines in the process of policy-making and the decisions (Maclaren, 1996).

The urban metabolism analysis provides important information and data about the urban systems on their energy efficiency, recycling of materials, adoption of a dynamic method of waste management and infrastructural transitioning and planning (GCRO, 2012). One of the strengths of the urban metabolism framework is its ability to provide parameters that can meet the criteria for a good sustainability indicator (which can be seen as outlined by Maclaren (1996). The framework is being validated scientifically (according to energy and mass conservation principles) and is relevant to urban planners and dwellers.

Furthermore, Hendriks et al. (2000) highlighted the usefulness of urban metabolism and material flow analysis as tools for early recognition priority setting, communication and effective policy-making. As an early recognition tool, rather than rely on environmental stress signals, the urban metabolism analysis highlights potential future challenges by demonstrating the regional changes in stocks and flows. Urban metabolism also has the ability to enhance the success of policy-making by ensuring decision makers put into consideration the overall system in policy-making as well as setting appropriately all the priorities.

One main gap in the application of urban metabolism in the assessment of cities sustainability is data availability and its accuracy. Often times, information at city level is not in formats that would enable utilisation of the existing standardised urban metabolism approaches. (Decker et al., 2000) detailed how the data for their study were made available as well as gaps thereof. Such gaps highlight the need for a more cross-cutting research and integrative data analysis (Decker et al., 2000).

A further limitation of urban metabolism is the tendency to focus majorly on the biophysical environment without little highlights on the economic and social related problems. Its usefulness is, however, of more relevance to decision and policy makers if social and economic issues are taken into consideration. Newman (1999) proposed an extended metabolism model that includes measures of living, such as indicators of work (human activity), money (income), health, household, education and community activities. Although cities can be seen as complex systems requiring integrated approaches to understand their various interacting systems within the larger urban systems (Valentine & Heiken, 2000). This quality is crucial in identifying the limitations and improving sustainability of urban systems.

Within the context of urban energy metabolism, considerable challenges have been faced in the process of highlighting the components available for energy systems (Zhang et al., 2010). According to Weisz & Steinberger (2010), some of the specific limitations relevant in understanding the metabolic patterns of urban informal settlements include those presented in Table 2-6 below.

Table 2-6: Limitations of Urban Metabolism approach

| | |
|---|---|
| No available data | There is recognition of the significance of cities in providing the total quantity of socio-economic energy and material consumption. Synchronized datasets generated yearly by the office of statistics are, however, mainly exclusively on a national level. Attempts to use literature in generalizing patterns and trends are, therefore, shown in the use of specific urban resources struggles with incomplete or incommensurable data. |
| Cities openness | Cities are involved in specific production, transformation and consumption rather than conduct their own resource extraction. This makes them depend on a hinterland for resource provision as well as goods and services. This hinterland has a global dimension. It is these exact openness of cities with respect to their materials and energy flows that brings about difficulty when specifying what the specific urban flows are (Weisz & Steinberger, 2010) |
| No common definition | For practical reasons, cities and urban areas are used interchangeably because both denote phenomena that are related, although not equal. There has been no existence of a common international definition of the terms. |
| Urban scale relevance | With respect to all the energy systems, these components are specific to urban scale and are different from other scales (such as rural or national). This is because many of the technical and physical factors in cities are in principle attributed to urban and national scales whereas their relevant significance can vary. |

Through the study of urban energy metabolism, key links in cities energy metabolism can be monitored. There is also the possibility of defining the function and status of components of urban metabolism. This is practically and theoretically relevant to achieving sound development and can guide policy development for effective energy management and infrastructure planning. The transition towards sustainable energy in urban informal settlements is a possible solution to energy poverty. To achieve this, it is essential to understand the nature of energy flows in an urban environment, particularly, knowledge and information on ways of energy production and consumption across various sectors in an urban setting.

### 2.4.5 *Application of Urban Metabolism Studies*

The study on urban metabolism provides information and knowledge that is key to informing as well as supporting appropriate decisions. Kennedy et al. (2011) provided four different applications, which were also tested for findings of urban metabolism studies. They highlighted the ability of urban metabolism studies to propose sustainability indicators of recycling of materials, energy efficiency, infrastructure, and waste management of urban systems. They also found that such studies are suitable tools for quantifying and accounting for urban greenhouse gas emission (GHG), other carbon equivalents and natural aspects attributed to a productive city.

Although most researchers have primarily employed the analysis of urban metabolism as a basis of an accounting framework, urban metabolism also provides a mathematical model to represent sub-processes, material flows and the economic output of cities. While these models are essential in determining the present flow of materials, they can also help in stimulating future changes to urban metabolism as a result of technical interventions or policies. These first three applications serve as informational tools that are essential to any decision-making process.

Urban metabolism studies also serve as tools for redesigning cities. This is done by redirecting the flow of their materials in such a way that these flows are informed by their social standards, which requires them to form a circular flow for their resources and be aware of the flows that enter their surrounding ecosystems (Kennedy et al., 2011).

Additionally, urban metabolism models provide a way of measuring the flexibility of cities; i.e. their resilience. Such models can be applied to the urban informal settlement contexts, which are agile and flexible systems with a high metabolic rate (Broto et al., 2011). According to Broto et al. (2011), urban metabolism presents the interface between urban resilience, urbanization and informality as a process (rather than concentrate on cities as 'objects'), where the urban metabolism concept is able to revive present practices and intellectual investigations on sustainable urbanization and urban sustainability.

## 2.5 Energy metabolism: understanding the concept and importance

According to (Musango, 2014), urbanization has become a key part to their socio-economic growth of emerging and developing countries in the world Musango (2014) . Whilst the level of urbanization is different for each continent and country, it is confirmed that cities have a relatively faster population growth than the rural areas, mainly resulting from migration (Musango, 2014). Recent estimates indicate that over half of the world's population presently live in urban areas (UN-DESA, 2013).

The assessment of long-term change in the energy flow pattern in cities is one of the most challenging tasks in the management of energy resources. Energy can be seen as the material basis for the development of cities' economies. According to the International Energy Agency, IEA (2008) two-thirds of the world's energy, as estimated in 2006, is consumed in cities. This accounts for more than 70 percent of GHG emission globally. This estimate will as well grow to almost three-quarters by 2030 (IEA, 2008), implying that the consumption of energy has become a critical challenge for cities and its regions. It is the case that cities are generally seen as less energy producers (Billen et al., 2009) in comparison with their large level of consumption in both primary energy and final energy. Thus, energy flows that often enter cities' boundaries are those of their energy products, which has an amount of hidden flows (GCRO, 2012).

To account for the significance of energy, Haberl (1997) pioneered the concept of 'energy metabolism'. Haberl (1997) suggests that metabolic research could establish a more comprehensive understanding of urban metabolism if it is inclusive of its energy metabolism. The concept of urban metabolism provides a methodological framework where relevant pathways for energy can be analysed at different levels, leading to the development of management systems, which, in turn, increases the efficiency of resource usage, wastes recycling and energy conservation (Holmes & Pincetl, 2012).

In an earlier section (*2.4.3 and 2.4.4*), the methods for assessing urban metabolism as well as their limitations (disadvantages) were discussed. Their limitations do not however mean the processes should not be investigated for better understanding of urban metabolism concept. By investigating the processes of urban energy metabolism, important links in the energy metabolism of cities can be tracked. Additionally, through metabolic flux quantification, a relationship analysis between metabolic components, structures and functions of urban energy metabolic systems makes it possible to define the function and status of each urban metabolism component. This has significant practical and theoretical relevance to achieving proper development and can serve as guidelines in policies development for effective energy management measures (GCRO, 2012).

### 2.5.1 *Energy metabolism in urban informal settlements*

The physical metabolism of a city can be provided through their energy flows quantification. Traditionally they are defined to consist of nutrients water, materials and wastes. The urban metabolism methodology of 'energy-material flow' has been used in studies over the years (Kennedy et al., 2011).Before speculating towards a sustainable energy path, it is necessary to first understand the metabolic pattern and/or nature of modern societies (GCRO, 2012), in order to obtain understanding on energy production and consumption at different hierarchical levels. Based on energetics principles, an effective energy flow analysis should first account for the differences between two different energy assessment categories, namely Energy Carriers (EC) and Primary Energy Source (PES) (Sorman & Giampietro, 2011). A preliminary distinction of these categories may be required in order to investigate primary energy resources consumed as well as energy transformed (Sorman & Giampietro, 2011).

Arguably, conventional understanding or definition of slums does not take into account energy as a key benchmark or indicator (Smit et al., 2017), yet the contribution of energy is seen as provided by (UNDP, 2016). As such, the lack of access to modern and clean form of energy has been provided as an essential characteristic condition for defining or measuring slums. However, only 43 percent of African population have access to electricity(IEA, 2015). Similarly, energy is seen as a dominant contributor to climate change, accounting for around 60 per cent of total global GHG emissions (UNDP, 2016).

Further, household (residential) energy consumption is becoming more recognised as a factor that plays an important role towards achieving sustainable development goals (Daioglou et al., 2012) as well as contributing to energy-related problems in the environment (e.g. scarcity of resources and climate change). Sufficient access to modern and clean energy, thus, forms the basis for socio-economic development and human well-being. As urbanization continues to increase, rapid rise in the energy consumption of urban areas is expected. Typical human activities occurring in an average urban resident or household usually relate more to modern energy intensive activities than to those of rural dwellers.

Energy used in urban informal settlements is generally low-grade fuels, which are normally less affordable (Karekezi & Majoro, 2002). This happens because informal settlement dwellers are mostly low-income earners, who mostly spend one-third of their income on energy (UN-Habitat, 2014a) The energy purchased is, however, incapable of meeting all energy requirements in informal settlement households (UN-Habitat, 2014a). The low-grade fuels, such as kerosene and biomass, are the most popular sources of air-pollution and health-related problems in such households.

Despite in-depth research and available literature that provides the relationship between urban cities and energy (see for example Ramos-Martín et al., 2009; Weisz & Steinberger, 2010; Kuznecova et al., 2014; Wang, 2014; Facchini et al., 2017), there is very little focus on urban informal settlements, with the aim of understanding them in comparison with other areas (Miranda et al., 2016; Kovacic et al., 2016; Kovacic & Giampietro, 2016; Smit et al., 2017). A few studies examine the energy and material flow pattern, and their implications in contributing towards a city sustainable development.

Studies are essential and provide the basis for energy flows assessment in urban informal settlement. As such, it is very essential to include other factors in the investigation of urban informal system metabolic patterns (which is their different settlement housing or building types), referred to in this study as multi-structured informal settlements. Smit et al. (2017) refers to them as a hybrid informal settlements.

To analyse energy flows, the input, consumption, output and exchange of energy can be taken into account. For practical utilisation, however, it is of importance to set ranges for the energy flow from the perspective of the energy services (such as heat, fuel, electricity).

## 2.6 Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM) approach

This section presents the concept of societal metabolism, the rationale behind the MuSIASEM approach, and its application in the analysis of the energy metabolism of urban informal settlements. The section also reviews the framework of MuSIASEM as well as how to conceptualise urban informal settlements in terms of their energy and material flows.

### 2.6.1 *Societal metabolism concept and the biophysical analysis*

The 'human society metabolism' is a concept used in characterising the processes involved in material and energy transformation in a society required for their continued survival. The energy metabolism analysis presented in this study is based on the framework of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) as theorised by Giampietro et al. (2011).

The notion that the activities done by human societies should be investigated by examining energy transformation resulting pattern has been proposed and implemented as reported in various studies (see for example Fischer-Kowalski & Haberl, 2007; Giampietro & Mayumi, 2000a; Giampietro & Mayumi, 2000b; Giampietro et al., 2011; Ramos-Martin & Giampietro, 2005; Ramos-Martin et al., 2007; Sorman & Giampietro, 2011). The term societal metabolism is a concept extracted from the works of Lotka (1922 ; 1956)`and Georgescu-Roegen (1971) which have been recommended to frame studies presenting narratives on the biophysical rather than on already predominant economic narratives.

Societal metabolism analysis was developed against the backdrop of energy flow analysis and thermodynamics of non-equilibrium. According to the approach of societal metabolism, it categorises cities as being of a dissipative structure, exhibiting a universal pattern (Weber et al., 1989; Kovacic & Giampietro, 2016).

Although societal metabolism approach is unable to capture both informal and formal drivers of informal settlement such as political, social, cultural and economic towards their urban development, it enables a more flexible definition, describing their syntactic relation as well as the semantics classifications used in representing the informal settlements. The process of metabolism on production involves both the biophysical methods of energy discharge and the way through which information across different levels or scales are handled for purposes of organisation.

Additionally, analysing both the biophysical energy process (scalable) and information (non-scalable) variables, enables establishing of linkages between quantification and theory. As such, an analysis of informal settlements metabolic pattern, based on characterisation of their expected characteristics and recognition rather than on the exact observable measurement, can provide a way of dealing with the increasingly changing conditions of informal settlements (Kovacic & Giampietro, 2016).

The analysis with MuSIASEM proposes a drastically different procedure for handling quantitative data that belongs to non-equivalent descriptive areas. The approach is rooted in the theory of complex systems, rather than simplifying the information space characteristic of societal metabolism. It also highlights the complex interrelations between the society's functional and structural elements across different hierarchical scales of the organisation (Giampietro & Bukkens, 2015).

As an analytical tool, the accounting system of MuSIASEM can be used in describing and presenting the characteristics of the actual pattern of metabolism in a social economic structure. Such an analysis provides integrated quantitative information in terms of the following:

- Demography; which comprises of total working population, technological capital, land use and availability of land (defined as fund elements which are those variables that remain the same; flows consisting of water, money, energy, and food (defined as flow elements).
- In the case of each flow, the consumption, of the end users, losses present, internal supply including amount imported and exported are all defined;
- Ratio of the flow per fund, which explains the rate in one hour of activity, and energy intensity of the flow across various hierarchy (including the entire system) are defined (Giampietro & Bukkens, 2015).

Comparisons are then made applying these ratios against specified benchmarks (standards) by defining various types of socio-economic organisations (Giampietro & Bukkens, 2015).

With the review of methods that relate to urban metabolism assessment, the MuSIASEM approach is deemed most relevant in capturing household and informal activities within informal settlements, which are then utilised to examine energy and other material flows.

The following section presents the theoretical and rational concept of an integrative approach of MuSIASEM, which was developed for analysing the metabolic patterns of *energy* in modern society.

### 2.6.2 *Understanding the rationale behind MuSIASEM approach*

The methodological approach of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) was introduced by Giampietro & Mayumi (1997, 2000a, 2000b) and studied more systematically by Giampietro (2003). The empirical analysis of this approach has been applied on several countries, such as Peru (Iorgulescu & Polimeni, 2009); Vietnam (Ramos-Martin & Giampietro, 2005), China (Ramos-Martin et al., 2007) and Ecuador (Falconí-Benítez, 2001). While other applications have been regional, for example; Catalonia (Ramos-Martín et al., 2009) (used in the study of Catalonia's energy metabolism, through analyses of the economy at different levels), Campania (D'Alisa et al., 2012) (in the study of the density of waste disposed in the region towards waste management).

The rationale behind MuSIASEM approach can be summarised as follows: (i) Analysing the energetics and material flows by employing exosomatic and endosomatic concepts based on Georgescu-Roegen's flow-fund scheme; (ii) Analysing the metabolic patterns and/or structures using the analogy of bio-economic of both the dissipative and hypercyclic ecosystem parts; (iii) the economic development, which consists of the dramatic changes in the total metabolic size, metabolic pace and the typology of structures of the energy dynamic budget, hence forcing human activity profile reallocation and usage of land over the different economy sectors (Giampietro et al., 2009).

In view of an integrated approach to sustainability, Georgescu-Roegen introduced the bio-economics and flow-fund approach. According to Ramos-Martín et al. (2009), the approach proposed distinguishing between the different quantitative representation categories used, that is, flow categories, which present the elements that disappear over a period of representation or, conversely, exit the process without having entered it (e.g. a new product or fossil energy). Flow elements categories comprise of energy and matter *in situ*, energy and matter dissipated as well as controlled energy and matter. For the direction of flows, two different types of factors usually control them, namely (i) internal factors such as the capability of analysing the flow available during the conversion process (e.g. technology and expertise); (ii) external factors such as stock availability or environmental input flow accessibility. The fund elements categories include people, capital and Ricardian land, referring to elements that remain "unchanged", over the period of their representations (they go in and out of the process). The fund elements present two characteristics, that is (i) they must be continually renewed; and, (ii) they are only used at a specific rate (Giampietro et al., 2009; Giampietro et al., 2013).

One of the theoretical pillars of MuSIASEM is that the societal technological development can be presented regarding their:

*acceleration of material and energy consumption together with the dramatic reallocation of age distribution classes, human activity profile on time use, and patterns in land usage across different sectors of the economy, which, result in saving of land and time in their agricultural and energy sector* (Mayumi, 1991).

Based on the analysis of MuSIASEM, qualitative changes in the forms of energy are not addressed by using the concept of thermodynamics such as enthalpy and exergy. Rather, MuSIASEM uses the time dimension of transformation of energy in the energy sector in relation to the different economic sectors. This centres on important qualitative factors (i.e. the flow and fund ratios, such as energy per labour hour, human labour hours in one year, typical labour hours that are productive), which thermodynamic analysis and other traditional biophysical analyses have not sufficiently considered. The MuSIASEM approach is an effort to integrate these qualitative changes into the metabolic patterns and intensity of flows, which can be used in the analysis of societal metabolism towards addressing sustainability issues.

### 2.6.3 *A flow-fund representation*

The concept behind a MuSIASEM analysis is borrowed from Georgescu-Roegen's bio-economic approach to the economic process, which specifically provides a discourse on the biophysical feasibility and constraints (Ramos-Martin et al., 2007).

The flow-fund representation lies at the core principle of MuSIASEM having proven extremely relevant in characterising the metabolic patterns of society and social systems (Giampietro et al., 2013). In the MuSIASEM framework, fund elements are transformative agents of the observed system that are expressed as functions needed by the society. Funds are used but not consumed; and they remain 'unchanged' all through the time of analysis. They represent *"what the system comprises of"* such as human beings, usage of managed land, technological capital, and rivers. To ensure sustainability, these fund elements need to be reproduced and maintained during the metabolic process all through the time of the analysis (Giampietro et al., 2013). Fund elements relate (up to a specific extent) to production factors (e.g. land, labour, and capital) in the economic narrative.

Flow elements are those attributed to change over the time of the analysis (they either appear or disappear during analysis). They are outputs produced or inputs that are used by the socio-economic process. The conversion of flow analysis describes to us *"what the system does"* in relation to its environment or context (at a large level) and with respect to its internal components (at the local scale). Examples of flow elements are food production and consumption, water (used for household consumption, drinking, irrigation, industrial processes), energy (electricity, fossil energy) and other essential materials (Giampietro et al., 2013).

In clear contrast to traditional input-output analysis (e.g. energy intensity for the economy, water footprint per crop produced, energy input per output unit), the MuSIASEM approach describes flows in relation to funds (e.g. input of energy per labour hour, GDP per annual capita, water consumed per land hectares in the production, energy consumed per annual capita). This characteristic is significant because it helps in accounting for the special nature and size of the system being analysed.

For any metabolic system (e.g. human beings, a society), the expected relations between specific flow and fund elements are described in both quantitative and qualitative terms. Therefore, the constraints and biophysical feasibility are analysed in terms of:

- Demographic changes
- Profiles of time allocated for human activity and land use in different sectors of the economy
- Process of energy and material transformation
- Socioeconomic factors within consumption and production.
- The impact flows and matter metabolised by the society has on the health and survival of the ecosystems as well as the capacity the ecosystems supply and sink embedded in the society (Ramos-Martin et al., 2007).

Basing metabolic patterns analysis on the model of flow-fund presents the possibility of integrating several pieces of quantitative information in a very coherent way by referring to their various dimensions of analysis, namely economic, biophysical, demographic, agronomic and ecological.

In order to bridge the ecological and socio-economic view, the MuSIASEM analysis simultaneously integrates two complementing but non-equivalent fund elements' definitions. The first definition is relevant for its socio-economic analysis (technology or capacity or power as well as its human activity). The second definition is essential for ecological analysis (land covers or land uses, energy funds) at all, scale and hierarchy considered (e.g. whole society, economy or community) (Giampietro et al., 2013). Here, the analysis provides an integrated description of the metabolic patterns of the society and its influence on the embedded ecosystems, by integrating non-equivalent systems of accounting (Giampietro et al., 2013).

### 2.6.4 *Understanding the metabolic pattern of urban informal settlement*

Urban informal settlements face serious challenges of governance around the world. Here, South Africa is not excluded because almost 43 percent of population in urban areas live in informal settlements (UN-Habitat, 2003). As such, urban informal settlements are fast-changing and dynamic systems (Smit et al., 2017), thus, the drastic increase in their population size and demography raises the issues of data scarcity or lack thereof on informal settlements. Scarcity of data poses a difficulty in carrying out surveys, while survey data and or information becomes quickly invalid (Kovacic & Giampietro, 2016).

As is the case for many developing countries (UN-Habitat, 2003), South African cities are faced with an increase in urban growth, which is one of the compelling forces for the increasing expansion of informal settlements at the periphery of urban regions. South African urban informal settlements are analogous to those in other African countries (Davies & Thurlow, 2010), characterised by informal housing structures, issues of land tenure and security, slow rate of slum improvement, inequality and poverty among others. The growth of many of these unplanned informal settlements bring about various environmental and land related issues.

The metabolic dimension of MuSIASEM can be applied to analyse the energy structure, pattern and consumption of urban informal households presenting different building structures or typology. Urban informal settlements' biophysical characteristics and societal metabolism can be examined at different levels, which include individual, household and whole settlement levels for various resources.

MuSIASEM can be used in generating biophysical indicators and benchmark values by providing the basis upon which a bio-economic analysis is able to compliment information coming from mainstream economic analysis. It can also enable an analysis of the different flows of a system such as water, energy, food and money, especially when the dynamics of population are taken into consideration. Land use changes and GHG at different scales of the economy (Giampietro et al., 2013).

Unlike most conventional approaches to urban metabolism, such as an economy-wide material flow analysis (Raupova et al., 2014; Kovanda, 2014) ecological footprint analysis (Wang et al., 2014) and input-output analyses (Huang & Bohne, 2012), the MuSIASEM approach can characterize informal settlements at different levels and scales in terms of funds and flows and across multiple dimensions (Smit et al., 2017). Fund elements include: (i) human activity measured in time; (ii) exosomatic devices in the form of technology and infrastructures; and (iii) Ricardian land measured in terms of land use. Here, flows are normally represented by the elements metabolized in the system, which include food, energy, water, waste, and money.

Essentially, the MuSIASEM approach is a multidisciplinary analytical tool for analysing human society development with respect to sustainability (Giampietro et al., 2001). The approach is capable of integrating variables relating to non-equivalent descriptive domains and equipped to incorporate data from specific hierarchical levels (Giampietro et al., 2001).

#### 2.6.4.1 *Analysis of informal settlement metabolic dimension*

Giampietro et al. (2009) describes the MuSIASEM framework and steps followed to examine the metabolic patterns of energy and materials. MuSIASEM enables the analysis of societal metabolic patterns at different scales, expressed as the whole settlement or community level (n), household level (n-1), and individual (n-2) (Giampietro & Mayumi, 2000a; Ramos-Martin et al., 2007; Giampietro et al., 2009; Ramos-Martín et al., 2009; Giampietro et al., 2013; Kovacic & Giampietro, 2016; Kovacic et al., 2016; Smit et al., 2017). Table 2-7 describes the levels of hierarchy of an urban informal settlement that is analysed in understanding their metabolic patterns and energy consumption.

Table 2-7: Description on the components analysed by MuSIASEM at different hierarchy of the urban informal settlements

| Level | Description |
|---|---|
| Level (n) | This consist of patterns involved in the flow of material and energy in the whole society, describing the population demography of the settlement with respect to the total available hours over the duration of a single year |
| Level (n-1) | The patterns examined involve their human activities, which is further divided into two sector of the economy.<br>• Paid work (PW): describes the total working hours of the working population in a whole year.<br>• Household activities (HA): it describes the number of hours spent on doing non-paid work (usually calculated from both the non-working and working population of the community) |
| Level (n-2) | At this level, both the household activities and types of paid work are further categorized into leisure and social activities, physiological overhead, unpaid work, formal work, and informal work. |

Further, the whole settlement or community (level n) can be divided into the number of people in the settlement multiplied by the number of hours in total available for the whole year. At the lower level (n-1), the human activity may be divided into the following:

i. Household (HH) activities; which refer to the amount of time (in hours) used to do work in a whole year by the working population; and
ii. Paid-Work (PW) sector: referring to the non-working population (Giampietro et al., 2009).

At the next level (n-2), both the household (HH) activities and the paid-work (PW) sector can further be divided into different categories as follows:

- Non-paid Work (NPW) (e.g. caring for elderly and children)
- Informal Work (e.g. gardening)
- Leisure and Social Activities (e.g. watching TV, sleeping, eating, socializing etc.)
- Formal Work (Giampietro et al., 2009; Giampietro et al., 2013).

This distinction is essential in understanding the activities in informal settlement as well as identifying the advantage point that may improve the productivity and development of the settlement (Smit et al., 2017).

According to Smit et al. (2017),both informal and unpaid work, which are present in an informal settlement, contribute to the society or economy. Nevertheless, these activities are productive for different reasons. An example is in Non-Paid Work (NPW) (e.g. caring for elderly or a neighbour's child), which might not necessarily add directly to the economy, but can indirectly be regarded as productive because:

- The recipient of this service is provided a means to be active economically.
- It contributes socially to the informal settlement economically.

Time spent during transportation (daily back and forth as well as waiting time in between transportation), should ideally decrease, through provision of a better public transport systems and networks. This time can be spent carrying out more productive activities either in Paid Work (PW) sector or doing other Human activity (HA), thereby improving their quality of life (Smit et al., 2017).

## 2.7 Summary

Given the imperative to understand slums, or informal settlements and how they connect with the broader urban systems, there is a need to first re-conceptualise these spaces beyond just their physical characteristics. Such re-conceptualisation should be based the fact such neighbourhoods are poor or deprived neighbourhoods with low quality housing but still intricately linked to socio-ecological systems (Smit et al., 2017).The understanding of informal settlements' material and energy flow in the context of urban sustainable development is still being researched. Thus, several pathways for urban energy metabolisms based on their slum dimension conceptualisation exist. Each of the pathways provides a range of perspectives, which describe urban informal settlements on the level of their energy flow (production, consumption and by-product waste management) patterns at different levels, ranging from broad to narrow.

Investigations into the urban informal settlements' energy flow, by analysing their metabolic patterns in terms of household energy throughput (for both their demand and consumption) are required. Although most informal settlements constitute different dwelling types or housing structures, this study analysed the buildings/structures in relation to energy demand and consumption. It can be argued that urban informal settlement require being analysed for their metabolic perspectives (Smit et al., 2017). As such, a multi-scale integrated assessment of societal and ecosystem metabolism (MuSIASEM) approach was deemed relevant in this study, as it provides rich data on all aspects of the informal settlements at different hierarchical levels or scales.

The MuSIASEM approach is also relevant to urban and developmental planning and policy. Further, it is significant in addressing the uncertainty levels that affect urban informal settlement analysis and, therefore, introduces a socio-technical solution. It can also be used to understand material standard of living of urban informal settlement dwellers, the dynamics of slum development and their interaction with the extensive socioeconomic backgrounds (Miranda et al., 2016; Kovacic & Giampietro, 2016; Kovacic et al., 2016; Smit et al., 2017)

Since the primary objective of the study is on the biophysical aspects of urban informal settlements, household energy flow and economic development, the MuSIASEM approach presented in this study only examines the system (urban informal settlement) structure of the human economy based on the following factors:

1) Exosomatic energy as a flow in terms of hours of consumption, energy fuel type used, energy access and energy appliances used;
2) Income generated and expended (in the form of expenditure) as a fund;
3) Household profile (to describe the population dynamics) and building structures (to understand the effect and their influence on both energy access, energy fuel type used, and energy consumption).

The study contributes to the understanding of the societal metabolisms of urban informal settlements, using Kayamandi informal settlement as its case study. The use of Time, Energy and Money was investigated by applying the MuSIASEM approach.

# Chapter 3 Research design and methodology

## 3.1 Introduction

This chapter describes the methods (tools) used in order to address the research problem and achieve the objectives of the study. The chapter outlines the development of tools, and analyses them scientifically, thereby establishing their validity and reliability for application in the study. The research design and methodology includes describing the research techniques, instruments, data collection and analysis methods used with regard to each of the research objectives as well as the justifications for the choices made.

## 3.2 Research design

Research can be categorised into three basic types, namely mixed methods, qualitative, and quantitative research (Kothari, 2004; Cohen, 2007; Creswell & Garrett, 2008). Qualitative research is based on nature i.e. the research method studies and aims to understand the daily life of several groups of people or societies in their natural environment. Qualitative research mainly involves taking a natural and interpretive approach to a subject, by attempting to make sense and understand the phenomena with regard to how the people provide meaning to them (Denzin & Lincoln, 2000).

Conversely, quantitative research uses the positivist, the experimental and the traditional approach to investigations into a known problem (Antwi & Hamza, 2015). In addition, statistics can be generated from survey research data obtained by using questionnaires and interviews (which can either be structured or semi-structured) through quantitative research (Hittleman & Simon, 1997). This research approach allows researchers to use sample subjects, measuring their variables and analysing these variables in order to provide the relationship them using statistical effects such as relative frequencies, correlations, and/or mean differences.

According to Blaxter (2010), four types of approaches to research design are useful when conducting social sciences research. These approaches include case studies, action research, surveys and conducting experiments. The choice of research method(s) and research design appropriate in studies that involve social interaction and behaviour as the agents are quite dynamic in nature (Onwuegbuzie & Leech, 2005), therefore, employing a mixed methods provides a more pragmatic approach to the research. Mixed methods comprise both qualitative and quantitative data, which was deemed suitable for the subject under investigation in this study. Although each of these methods has its limitations, they can be complementary. Arguments have revealed similarities between qualitative and quantitative methodologies and the combination of both methods in order to promote triangulation[5] (Brewer et al. 1999; Onwuegbuzie & Leech 2005) .

The research strategy employed in this study comprised of stages in the research process, and how each of the research objectives were analysed based on different tools and instruments, as shown in Figure 3.1.

[5] Being able to use mixed method approach provides an advantage of research triangulation. Triangulation is one common feature of mixed methods studies.

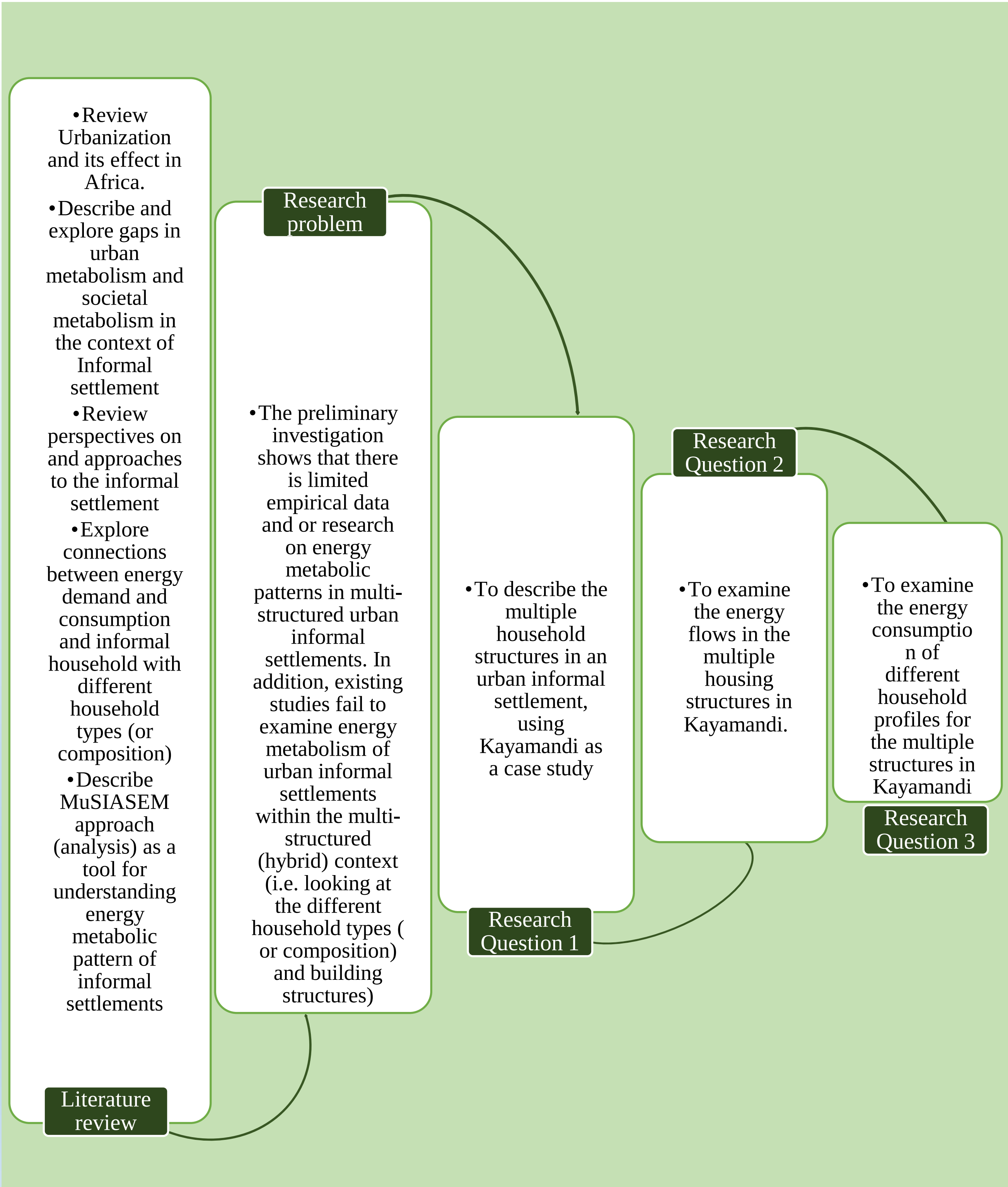



Figure 3-1: Research Strategy

## 3.3 Research methodology

The rationale for adopting a mixed methods approach was justified based on the following observations:

1. The objective of the research was to analyse the energy flow and consumption for different household types (or composition), and
2. The analysis was examining the energy flow or consumption based on the multiple or hybrid building structures in an urban informal settlement.

Based on the current and existing review, it was revealed that there were no studies that have analysed household energy flow in an urban informal settlement by accounting for their energy demand and overall consumption based on their different building or housing structures and household types (composition). Here, gaps presented in the literature (see chapter 2) in terms of research that connects either household type (or composition), and different building or housing structures with energy flow and consumption in urban informal settlements.

The need for better understanding and analysis of urban informal settlement energy flow emerged from the study itself (that is not just based on literature review, but also from both quantitative and qualitative analysis of data as well as their validation). The following observations were made from the extensive review of literature:

- Initial literature reviewed showed gaps in terms of research that relates informality with energy metabolism, when different household types (or composition) and/or building structures is considered.
- Based on the reviewed literature on urban metabolism and energy metabolism in urban informal settlement contexts, the identified gaps in literature pointed to the need for expressing perspectives and study on urban informal This was followed by a quantitative analysis of data and responses obtained from the qualitative research. This research process, thus, shows mixed method as most appropriate for the purpose of the study because all the processes improve the possibility of describing the topic in details in order to provide information on the energy metabolic patterns of a hybrid informal settlement.

The quantitative analysis was used to validate the qualitative data analysis, by providing statistical representations and analysis of the energy flow and total energy consumption. The quantitative aspects of the study focused mainly on the research deductive nature (Quinlan et al., 2011; Hayes et al., 2013). The mixed method approach is considered appropriate, which, according to Creswell et al. (2003), enhances a comprehensive understanding of the problem, thereby delivering various insights through different methods.

## 3.4 Research methods, data requirements and analysis

The different techniques and instruments for collecting and analysing the data are specific to each of the research questions. The following section, therefore, describes the relevant research methods, data requirements and criteria as well as research processes employed in carrying out the data analysis with respect to each of the research objectives.

### 3.4.1 ***Research objective 1:*** *To describe the multiple household structures in an urban informal settlement (Kayamandi as a case study).*

The first objective was achieved through the following research processes:

#### 3.4.1.1 *Selection of a hybrid urban informal settlement case study*

According to Yin (2003), *the distinctive need for case studies stem from the desire to understand a complex social phenomenon*. This is because *a case study method provides a platform to an investigator of retaining the meaningful and holistic characteristics of real-life events*, such as human activities or actions in a community. One of case study research objectives is to understand human beings in a social context by describing their activities and actions either as a cluster of people, community or as clusters of events. In general, a case study is a preferred method depending on when, why and how questions are being asked, and when the emphasis is on a phenomenon speaking to a real life context (Yin, 2009).

One significant application of case study research is in situations where contextual circumstances of the event under study are critical, as well as in situations where the researcher cannot control the turn of events as they unfold. According to Lewis & Ritchie (2003), the primary characteristics of a case study is that it provides a *multiplicity of perspectives which are rooted in a specific context*. Furthermore, a case study helps to explain the procedure and results of a phenomenon through overall observation, reform and analysis of the case under investigation (Tellis, 1997).

After the initial literature review for this study, and having discovered gaps that speaks on energy flow and metabolic patterns in urban informal settlements, in the light of the nature of the research problem and research objectives, case study design was deemed appropriate. Case study design provides a systematic method for data collection, analysing the obtained information and reporting the results, thereby providing an in-depth understanding into a particular situation or problem. Specifically, case study design provides answers from a diversity of participant perspectives; and employs several techniques for collecting data.

##### 3.4.1.1.1 *Overview of the case study*

In this study, the case study selected was an informal settlement called Kayamandi, which is found Stellenbosch Municipality. According to history, Stellenbosch is among the oldest towns in South Africa. The residents now live within three sections of the town, namely Stellenbosch centre (comprising of the university campuses, and various high income "white" neighbourhoods), Cloetesville and Kayamandi (Rock, 2011).

Kayamandi can be regarded as the second oldest township in South Africa. When it was established, it consisted of only 80 housekeepers and farmworkers (Nicks, 2012). However, the township has grown significantly more informal after apartheid became an official policy. Such drastic changes in population are often associated with lack of basic services (e.g. energy access, water, proper waste management etc.) and poor living conditions. The changes require curtailing if the urban area (Stellenbosch municipality) in which they are present is to advance towards a sustainable urban development.

For purposes of this study, the desired sample of data required from the case study was to capture the urban informal settlement household types or composition, their different building or housing structures, income, expenditure, energy access and consumption pattern. This was achieved by presenting the households human activities, household composition, household income and expenditure, energy fuel mix (or type), and how these factors contribute to the overall energy demand and consumption of an urban informal settlement. In addition, Stellenbosch Municipality was selected given its accessibility for the project and convenience for field visits. The availability of appropriate reference data for verification of the research objectives was an important factor in selecting the case study.

The next stages in the research process were questionnaire design and finalization as well as their validation, sampling design and data collection strategy, which will be explained as part of the research tools and techniques employed to achieve research objective 2.

#### 3.4.1.2 *Identify household typology in the hybrid urban informal settlement*

There are factors that determine the changes in total energy demand in a particular household, the first of which is the change in their household composition. By using a lower scale analysis, it is possible to differentiate types of households by viewing their household composition (with different household type representing different household composition patterns). However, the energy demand and consumption of a household (with a particular number of household members) is, not linearly linked to the population of the community or household but rather to the type of building or housing structures and household composition.

According to the case study in this research, five main settlement types (depicting the different housing or building structures in a hybrid urban informal settlement were identified, each of which has its own characteristics. According to Smit et al. (2017), these categories were described under hybrid / multi-structured settlements (the description is presented in the results in section 4).

#### 3.4.1.3 *Observation and Photography*

Observation is the most frequently used method particularly in social research studies, or studies on human behaviour (Thomas, 2010). To a certain extent, we observe things around us, but this kind of observation is not scientific observation. Observation turns into a scientific technique and a data collection tool when it aimed at achieving a formulated research objective, when it is analytically planned as well as recorded, subjected to control, and checks on reliability and validity (Thomas, 2010).

One key advantage of observation is in eliminating bias (whether individual or personal bias), if it is carried out precisely (Kothari, 2004). In addition, information gathered through observation relates to current happenings, and as such, there is no complication from previous behaviours or future attitudes or intentions (Kothari, 2004).

In order to identify and select households to participate in the survey, the building types and structures present in Kayamandi informal settlement were identified. To achieve this, I first tested the framework in reality through direct observation of activities of the community in real life. The analysis units were field notes and pictures taken of the different types of housing structures present. After paying a visit to Kayamandi informal settlement, accompanied by a community resident from Enkanini research centre (who was one of the field researchers), the building structures present in Kayamandi informal settlement were identified. The identified housing structures or dwelling types[6] are as follows:

- RDP homes (stand-alone)
- RDP houses with backyard shacks

[6] The photographs and description of the identified housing structure was presented as part of the results analysis in section 4 to achieve objective 1 of this research study.

- Municipal flat
- Hostels
- Freestanding shacks
- Backyard shacks

#### 3.4.1.4 *Sampling design*

The sampling design for this study depended on the population, number of households and building structures as well as the method of analysis. As explained earlier under the objectives and limitation of the study (see section 1.4 and 1.7 respectively) the main objective was to analyse the energy metabolism in a hybrid / multi-structured informal settlement. From the exploratory findings and literature reviewed, however, it was more appropriate to focus the study on the different building structures present in Kayamandi informal settlement.

Rather than attempting to study the entire population of Kayamandi, a selected sample was used. This was done to save time allocated for the research as well as the finances. Collection of data from the different household types and the different building or housing structures for the whole population, and the analysis and their interpretation would have been impossible to accomplish within the period available to carry this study.

In this study, a non-probability sampling was adopted. Non-probability sampling allows for sampling plans that are dependable, thus offering key leads to information that are potentially useful on the population (Cavana et al., 2001). The sampling method involved a non-inclusive sample in every one of the population elements, i.e. each household surveyed during the pilot phase of data collection was excluded from the final phase of the survey process.

In order to get the actual sample size required for this study, the different types of housing structures were first identified. This was done in collaboration with the community members, and combined with direct observation. The responses and observations were recorded as either audio recordings or field notes, and were referred to for paraphrasing or direct quotation in the data analysis where appropriate. Once the housing structures types were identified, a decision was made to include five households from each housing structure typologies for the test phase. Thereafter, each area of the community (settlement) comprising of the above factors was identified and household participants selected using random selection/sampling.

In the final data collection phase, 20 households were included for each of the five housing structure typologies identified. Table 3-1 presents the number of participant selected based on the different housing structure typologies (for both the test and final phase). The sample used in this study was a representative sample selected from the different household structures in urban informal settlement. The type of non-probability sampling used in this study was purposive or judgemental in combination with snowballing sampling procedure, which allows a primary contact to be made with a small group of people relevant to the research and through them establish contacts with others.

Table 3-1: Shows the number of participants (households) selected for each of the housing structure typologies

| Building types | Number of participant selected (Pilot phase) | Number of participant selected (Final phase) |
|---|---|---|
| RDP houses (with backyard shacks) | 4 | 25 |
| Backyard shacks | 5 | 25 |
| RDP homes (stand-alone) | 2 | 8 |
| Freestanding shacks | 6 | 31 |
| Municipal flats | 2 | 4 |
| Hostels | 1 | 7 |

The initial participant selection was to comprise 20 participants for each of the different building structures present in Kayamandi (which makes a total of 120 participant and questionnaires to be administered). Owing to fact that the percentage of the housing structures present in Kayamandi informal settlement varied i.e. more shacks and RDP homes were identified over Hostels, and Municipal flats, the structure of participants selection changed as shown in table 3-1. This was discovered during discussions with the field researchers from Enkanini Research Centre, and was validated through personal survey around Kayamandi with field researcher.

#### 3.4.1.5 *Data Collection*

According to Sekaran (2000), each participant in the research is specifically set up by the researcher, and may include individuals, groups or respondent's panel whose opinions are sought on certain problems. Conducting an interview, use of questionnaires and participants' observation are the three key data collection methods employed in a research survey.

Part of the data collection tools employed in this study, were self-administered questionnaires and semi-structured interviews. These were combined in order to achieve research objective one (with data collected on housing structures type, household profile) as well as research objective two (data collected on energy, time and human activity for the urban informal settlements). The primary data was collected from the household residents of Kayamandi informal settlement.

Upon identification of the research methods, research strategy, process, and sampling design as proposed by Leedy & Ormrod (2005) and Cavana et al. (2001), data collection was planned for both the quantitative and qualitative aspect of the study. The entire data collection was carried out between September and October 2016. The data collection procedure covers the pilot study, and both the quantitative and qualitative aspects of the study. Other data collection tools also used in this research study were the literature reviews, questionnaires, direct observation and participant observation, which were all used in achieving the objectives of the study

### 3.4.2 ***Research objective 2:*** *To examine the energy flows in the multiple housing structures in Kayamandi.*

The purpose of this objective is to investigate the energy flow patterns in Kayamandi's different housing structures, and the effect on their energy consumption. The aim is to extend the current scope of understanding and perspective on how energy demand and consumption in an urban informal settlement is measured. In addition, the effects of household profiles on the energy fuel types consumed in the various households are examined. Such effects can also influence the overall energy consumption in these households. This is done with the aim of understanding the different energy fuel types available and used in informal households and the amount spent on each of these fuel types. The data collection tools used to obtain this information included direct observation, self-completion questionnaires and semi-structured interviews.

#### 3.4.2.1 *Population and sample size*

All plots in Kayamandi have different zoned division. From each zone, a cluster sample of plots was drawn to respond to the questionnaire. The identification of the participants under each cluster was done through the snowballing technique (Marshall, 1998).Any household member present at the time of the face-to-face interview could contribute (and sign the consent form for ethical reasons). In total, 120 questionnaires were administered. The sample represented households in this community with different building structures.

#### 3.4.2.2 *Testing for questionnaire validity*

The instrument validity can be regarded as the extent to which *the instrument actually reflects the research abstracts being examined* (Burns & Grove, 1987:294). The questionnaire method was the most appropriate approach through which the primary data in this study was collected. After designing the questionnaire, the validity was tested. Each question was studied by discussing with the learning supervisor, where each response was weighed on concerning participant's ability in providing appropriate responses to the proposed investigation in the research. In addition, the questions were also presented to the Enkanini Research Centre Association, who assisted in the data collection for fine-tuning (an example is on the questions regarding the type of household appliances that are can be found in the informal settlement households).

Although the questionnaire was deemed suitable for the proposed research objective and purpose, it was piloted beforehand in order to improve its reliability. In this case, 20 questionnaires were piloted, and after reviewing the responses of the participants from the survey, some of the questions, which were not clear to either the co-researcher and/or the participant during the pilot survey, were revisited for proper clarification. An example was on questions requesting for household consumption in hours for their electrical household appliances, as well as those seeking percentages of each fuel type consumed per week for the different household activities (such as cooking, lighting, water heating, space heating and electrical appliances).

Further, participants struggled with the physical difference between the different types of lighting bulbs (Incandescent and Florescent bulb), thereby requiring provision of pictures in order to provide the clarification for the participants.

##### 3.4.2.2.1 *Interviews*

Interviews are techniques of collecting information through verbal questioning using a couple of pre-planned core questions (Thomas, 2010). A semi-structured interview was carried out during the exploratory part of the research. The face-to-face interview was conducted by asking some pre-planned and semi-structured questions relating to the building typology or housing structures present in Kayamandi, access to electricity, available and presently used energy fuel types, energy activities present in a typical household in Kayamandi, as well as the costs and sources of the different energy fuel types.

The semi-structured interview was carried out by visiting Enkanini Research Centre; a research support centre on activities of informal settlement, which is located in Enkanini informal settlement (shares boarder with Kayamandi). The content of this interview allowed for deeper exploration and probing, where responses obtained provided validation of the designed questionnaire content.

#### 3.4.2.3 *Design of Questionnaire*

Challenges were encountered when designing of the questionnaire. The challenges included structure, format and the content. In this study, a structured questionnaire design was employed. Each of the questionnaires required approximately 45 minutes to 1 hour for completion (the time was reduced after completing the pilot stage and feedback response received from the co-research and the participant). The use of a self-administered questionnaire rather than conduct an online survey or postal or email questionnaire was to motivate people to participate in the study (Smit, 2015).

One advantage of using a questionnaire in surveys is that it can capture a larger audience as compared to interviews. Questionnaires, however, have the disadvantage of not being able to modify itself to the persons or group under study as with other data collection tools. According to Malhotra (2004), the advantages of using a questionnaire in data collection include the ease of administration, reliability of the gathered information or data, a comparatively simple and straightforward process of data coding, analysis and interpretation.

In the questionnaire, each question was designed as a close-ended question. This is done in order to obtain different thoughts and opinions of each of the participants. A copy of the research tools used for this study to achieve research objective 2 is shown in Appendix B.

##### 3.4.2.3.1 *Question framing*

The major objective for conducting the survey was to obtain direct information and detailed data report from each of the participants in different housing structures in Kayamandi. The questions were framed to be somewhat redundant in order to detect missing information and inconsistency of data. For example, respondents were asked types of fuel used for different household activities (e.g. cooking, lighting, water and space heating, electric goods), how much is spent per week/month on each fuel type, proportion of each fuel type used for each household activities. This provided the possibility of accounting for fuels (e.g. candles) that were sometimes not reported as part of the type of energy fuel used for lighting service due to their little contribution to the energy mix of the household. The questions were close-ended divided into four different parts as follows:

**I.** Part one consisted questions on Household Type and building structures. These are identified as

- Age
- Sex
- Household composition and number of people per household.
- Preferred language
- Building structure type (example is freestanding shack)
- Location in Kayamandi (example is Snake valley, Zone O)
- Number of backyard shacks
- Gender of interviewee

**II.** Part 2 consisted of questions on Time and Human Activity. These are identified as

- Paid work (PW) activities
- Non-paid work (NPW) activities.

**III.** Part 3 consisted of questions on Money. These are identified as:

- Income, and income source
- Total household income per week and month
- Household expenditure per week and month
- Grants type (if received)
- Household management of cash shortfalls
- Household management of cash surplus

**IV.** Part 4 consisted of questions on Energy. These are identified as:

- Access to electricity and how electricity it is supplied, such as direct connection or indirect connection (through neighbours)
- Cost of electricity
- Energy type of fuel, used for activities such as lighting, cooking, space heating, electric goods and any other activities that require energy use.
- Cost of energy fuel type used per week for the activities listed,
- Cost per unit fuel type
- Source of energy fuel type used,

- Percentage and/or proportions of energy fuel type (all used for different household activities)
- Energy appliances used for different household services and activities.

#### 3.4.2.4 *First draft and pre-testing of questionnaire*

In order to improve the reliability of the data collection tool, a pilot (test phase) was first carried out prior to implementation of the finalised questionnaire. The pre-testing of the questionnaire highlighted the need to define certain concepts, as well as adapt the questionnaires to the informal settlement in South Africa context. The underlying aim of piloting the questionnaire was to improve its content validity, which led to a restructuring, and improvement of the questionnaire. After piloting, the questionnaire was improved upon.

The first draft of questionnaire provided 20 questions separately for five pre-identified building structures, which constitute the different sections and zones in Kayamandi. The set of five questionnaires, each per different housing structures, were used in conducting the pilot test. In addition, each of the five questionnaires per housing structure was employed in different sections and zones in Kayamandi. Figure 3-2 presents a map of Kayamandi informal settlement, highlighting some major part of the community.


Figure 3-2: Kayamandi map

Source: (Google Maps, 2017)

Table 3-2 present an overview of the overall number of the sampled households from the population included in the survey and the response rates from the participants

Table 3-2: Indicates the number of participants for pilot test of the survey and their response rates.

| | Contacted to participate to complete the questionnaire participant | Participation rate | Average time used for completion | Invalid response | Valid response | Valid response rate (%) |
|---|---|---|---|---|---|---|
| Participant | 20 | 100% | 1 hour | 0 | 20 | 100 |

The survey was conducted in person by a field researcher who read the questions to each of the household participants, filling in the responses on the questionnaires on behalf of the participants. Participants also signed consent forms before the questionnaires were administered as part of ethical considerations.

Through direct observation, responses received, and the time required to complete each data collection process during the pilot test, the draft questionnaire was improved and modified. The time required for each data collection process was also modified.

After completion of the pilot test phase of the survey and implementation of all necessary modification, final draft of the questionnaire was produced. The questionnaire (see Appendix B) was designed to extract data relevant to each of the three research questions. The closed-ended questionnaire was considered to makeup the quantitative part of the data analysis through descriptive statistics, such as bar graphs, pie charts, and frequency tables as well as constitute the qualitative data, which required a computer-assisted qualitative data analysis using Excel presented as direct quotations. The questionnaire was distributed and used together with a semi-structured interview (face-to-face) with the occupants of the target households.

Owing to the language structure of Kayamandi community, the questionnaire required translation in order to accommodate the widely spoken language of Xhosa for the data collection process. An expert from the Stellenbosch University Language Centre translated the questionnaire, (which was done without loss of content of the questions of the original questionnaire). Finally, 100 of these questionnaires were administered by a field researcher who read the questions and at the same time transcribed the responses into the questionnaire on behalf of the participant. The response rate and total sampled households from the population are presented in Table 3-3.

Table 3-3: Indicates number of participants for final phase of the survey and their response rates.

| | Contacted to participate to complete the questionnaire participant | Finalised questionnaire participant | Participation rate | Invalid response | Valid response | Valid response rate |
|---|---|---|---|---|---|---|
| Participant | 100 | 100 | 100% | 4 | 96 | 96.67 % |

One of the challenges faced during the data collection process was time and ability of the participants to interpret properly the research questions, as well as reluctance in answering some of the questions, especially those on the use of money and source of income.

Another challenge in data collection tools was in obtaining appropriate answers and information from the respondents even without knowledge on the actual information required or lack of proper translation, which leads to marginal error. An example is on the human activity: hours of doing non-paid work (NPW) such as sleeping were varying with some respondent providing 1 – 2 hours, which can be seen as incorrect as this was meant to be hours with respect to the entire day (24 hours). Another example was on the quantity of energy fuel type used per week for the different household activities. The respondents seemed to have no knowledge on how to calculate the actual units of electricity used per week (what they are aware of is the amount spent on electricity per week).

This happened with other energy fuel type such as paraffin, where there were differences between the actual quantity used per week for each of the different appliances (such as paraffin heater, paraffin lamps and paraffin stove) and the overall quantity used per week provided by the household. In order to overcome these challenges, only the provided actual quantity used per week was taken into account for their consumption analysis on all their paraffin appliances.

#### 3.4.2.5 *Data capturing and Data analysis*

Data capturing and refining was done on Microsoft office Excel 2016. The case study analysis, which involves both the quantitative and qualitative data processes, was both deductive and inductive and were related to questions and concepts that came from the questionnaire data obtained through the survey process. The data analysis was both Inductive and deductive because of the mixed method research employed for the study, which required the results presentation and explanation based on the case study phenomenon in order to achieve each research objective from the data collected.

The data collected required processing and analysis. The processing phase involved; classification, editing and tabulation of the collected data, which were ready to be analysed. The analysis phase involved interpretation of research findings using statistical analysis to determine their validity upon which the conclusions can be based. In other words, analysis of data denotes the way of describing a phenomenon through both quantitative statistical representation and qualitative explanation by studying the data and information available. Data analysis supports the approach of achieving the findings and results from which the conclusions of the research are to be facilitated.

###### 3.4.2.5.1 *Data processing*

After data collection, each of the questionnaires required proper arrangement from all the received completed questionnaires. Some of the questionnaires were found useful and others not for the purpose of the study. This step required editing, classification and tabulation of all the received questionnaires.

###### 3.4.2.5.2 *Editing*

Data editing process involves examining the collected raw data for error detection and omissions, and then make necessary corrections. It also involves thorough scrutiny of the completed questionnaires. The aim of editing was for careful inspection of all collected questionnaires to ensure completeness, error-freeness and readability.

###### 3.4.2.5.3 *Classification*

The aim of classification was to divide the questions in the questionnaire into different groups. For example, in this study, the sections of the questionnaire, which were populated on a Microsoft Excel Spreadsheet, were grouped under the use of Time, Money and Energy forming the basis of the framework applied to achieve research objective 3.

##### 3.4.2.5.4 *Coding*

This refers to allocating figures or any other symbols to answers provided in the completed questionnaire, in order to group responses into limited categories (Henczel, 2001). It is important to note that during the coding process, each of the categories must be appropriate to the research problem under consideration (Smit, 2015). Coding was done in this study by allocating numbers to each of the RDP houses and their corresponding backyard shacks for proper analysis on this particular building structure (RDP house with backyard shacks). This assisted in maintaining anonymity of participants whilst allowing the researcher to study RDP homes with backyard shacks as a coherent category.

##### 3.4.2.5.5 *Tabulation*

The process of tabulating the data collected was to summarize the data and display them in an appropriate manner in order to facilitate further analysis.

#### 3.4.2.6 *Method of data analysis*

This step has a crucial impact on the whole research process leading to the testing and validation of the research data and information. The method of data analysis used to achieve this objective included quantitative arithmetic measurement and frequency distribution.

**a.** Frequency distribution

The data collected provided information as well as answers to some of the problems raised in the study. Descriptive statistics can be used for data analysis. The initial step is analyse using frequency distribution, in order to summarize the data for displaying the number of observations and grouping them into specific categories or classes for each of the distribution. In this study, data and graphical analysis tool were used (Cavana et al., 2001; Creswell & Garrett, 2008).

**b.** Arithmetic measurement: This is done to present the factor of evaluation as an arithmetic mean and average (Cohen, 2007; Creswell & Garrett, 2008).

### 3.4.3 ***Research Objective 3****: To examine the energy consumption in the different housing profiles for the multiple structures.*

The main objective of applying MuSIASEM to the case study presented was anchored in its potential to analyse the energy and resource flow in assessing the sustainability of the socioeconomic systems. Based on the typology of urban informal settlements in South Africa, a particular settlement was identified (Kayamandi) and the societal metabolic dimension applied by using MuSIASEM (Miranda et al., 2016; Kovacic & Giampietro, 2016; Kovacic et al., 2016; Smit et al., 2017).

This objective was achieved through:

i. The use of the MuSIASEM approach in understanding energy metabolism in an informal settlement and addressing the issues of energy flow in this settlement;
ii. Analysing the MuSIASEM approach, its importance in studies of urban metabolism and energy metabolic pattern of a system, and comparing it to other approaches; and
iii. Identifying gaps in previous studies as well as how to mitigate and close such gaps.

#### 3.4.3.1 *Multi-Scale Integrated Analysis and Societal Ecosystem Metabolism (MuSIASEM) approach*

This section discusses the development consolidation of an integrated accounting method by applying MuSIASEM approach to characterize energy and their interrelation with a complex system (society) [in the case study, the society is an urban informal settlement] as well as its interaction with its environment. The energy metabolic pattern was studied based on the different housing or building structures present in the case, Kayamandi.

The analysis on the patterns of metabolism was applied in this study in order to describe ways in which the urban informal settlement changed over time and to describe the settlement typologies as well as characterise their energy metabolic patterns. MuSIASEM is used in characterising the societal metabolism in terms of the following:

i. Fund elements: which are measured using extensive variables to describe the system characteristics, such as exosomatic devices and population (e.g. building structure, household appliances);
ii. Flow elements: which are measured using extensive variables to describe the quantities produced as well as consumed during the representation time. Examples are money, materials, food, energy, and waste;
iii. Rate of metabolism of the functional compartment used in characterising the functionality of the system. They are measured by using intensive variables, namely the flow/fund element. Examples are energy consumed per unit fund.

Understanding the metabolic rate provides the possibility of contextualising the observed flows instead of characterising informal settlement as energy (in form of electricity) consumers (whereas this definition is subject to lack of data, error of measurement, high uncertainty level associated with informal settlements due to their dynamic characteristics). The flow-fund model describes the informal settlement in terms of their metabolic patterns (i.e. based on estimates of the system capacity consumption, such as appliances, energy fuel type used for the appliances and the pattern of use of the appliance (Kovacic & Giampietro, 2016).

The flow-fund model provides the characteristics of the different typologies of informal settlement, according to:

i. The level of system openness: the level of self-sufficiency in flow production such as reliance on the monetary flows generated outside the community or economic activities present within the settlement.
ii. The degree of system complexity
iii. Social activities diversification, which are usually expressed by the hierarchical level of the system and/or organisation. Examples are microenterprise, governance structures, emergence of organisations in the community or dependence on external service providers.

In addition, the approach for analysis is key in understanding the different categories of uncertainty that affect the analysis of energy metabolism in urban informal settlement and the introduction of socio-technical solutions. It can also be used to understand the resource and material standard of living of informal settlement occupants, slum dynamics development as well as how each of the spaces interacts with the bigger socio-economic context (Miranda et al., 2016; Kovacic et al., 2016; Smit et al., 2017). The MuSIASEM approach, which recognises all the characterises of an urban informal settlement by providing rich data at different hierarchical levels, providing deeper understanding into the reality of urban informal settlement energy and material and their residents, highlighting areas requiring policy intervention, is relevant for both urban and developmental planning and policy.

In summary, the approach was used in understanding the societal metabolism of Kayamandi informal settlement by investigating the use of Time, Money and Energy.

#### 3.4.3.2 *Energy flow pattern analysis using MuSIASEM approach*

To analyse the energy metabolic patterns of a hybrid multi-structured urban informal settlement required identifying and representing the expected characteristics for their metabolic networks, rather than on the precise measurement of observable characteristics of their special instances

(Kovacic & Giampietro, 2016). In order to understand the characteristics of energy and material flow of urban informal settlement, analysing the settlement societal metabolism based on their building structures, household composition, energy fuel type (including energy classification present in their different household), as well as other instances was required.

In view of this, energy metabolic pattern was examined for the different building structures present in the hybrid urban informal settlement focusing on their metabolic pattern. This was done to allow system characterisation based on the function that it expresses, rather than focusing on the set of characteristic measurement normally considered relevant when observing a specific instance (Kovacic & Giampietro, 2016).

The metabolic pattern analysis of energy was done by describing the informal settlement energy flow and total energy consumption. The societal metabolism was characterised by using MuSIASEM in terms of fund elements and flow elements. The first step in the analysis is in the identification and selection of the flow and fund elements, and developing the relevant taxonomy for the fund elements. The selected set of flows metabolised by informal settlement (e.g. energy and money) was linked with the selected set of funds (e.g. building structures in various categories, human activity hours accounted for in different categories). An important part in this analysis is in assessing the level of system openness by defining the extent to which the flows and funds crosses the boundary between system and their context.

In this study, the fund element included were the building structures measured at different categories and human activity (HA). Assessing the human activity is linked to their structure and population size, and the socioeconomic activities carried out by informal settlement dwellers. In addition, assessing the time allocation profile is relevant for the socioeconomic dimension of the analysis.

Thus, MuSIASEM analysis provides two separate descriptions of the organisational structure of the informal settlement, namely human time allocation and energy consumption. It is important to note that MuSIASEM accounts for the system closure. The accounting categories, both for building structure and human activity, must be mutually exclusive (no overlap) and thorough (each of the categories must be fully accounted for). The accounting is essential to understand the informal settlement internal activities as well as its immediate surroundings (e.g. cities or urban areas). In fact, understanding the spatial analysis of flows provides the possibility of studying how functional elements within informal settlements interact and how slum relates with its context.

With regard to the flow elements, the two categories included are the monetary and energy flow (value added and expenditure).

#### 3.4.3.3 *How MuSIASEM works*

The first step in the analysis of the metabolic pattern of urban informal settlements is the identification of fund and flow elements. The flow elements metabolized by slums (such as energy, food, water and money) is then connected with the selected set of funds element (example we have human activity work hours counted in different categories, household types (or composition) and/or building structures counted in different categories). A key aspect of the analysis is the assessment level of the system openness, which defines the extent to which both funds and flow elements cross the boundary between the system and its context.

Figure 3-3 presents a Dendrogram on the different hierarchical levels based on MuSIASEM as described by (Giampietro et al., 2009). According to Smit et al. (2017)), the MuSIASEM approach characterises the informal settlement according to its different levels of analysis in terms of their flow and funds elements across several dimensions or pattern. Figure 3-3 also illustrates the heterogeneity of the functions within the informal settlements while describing the time allocated in hours per year for the different household activities.

Analysis on human activities is done based on the time allocated measured in hours/year. The analysis may be carried out at different scales, expressed as individual (n – 2), household (n – 1) and the informal community or settlement (n).

Categorizing and distinguishing the different activities is an essential factor that can help to understand the informal settlement activities as well as aid in identifying the key aspects that may assist in the productivity and development of such a settlement.

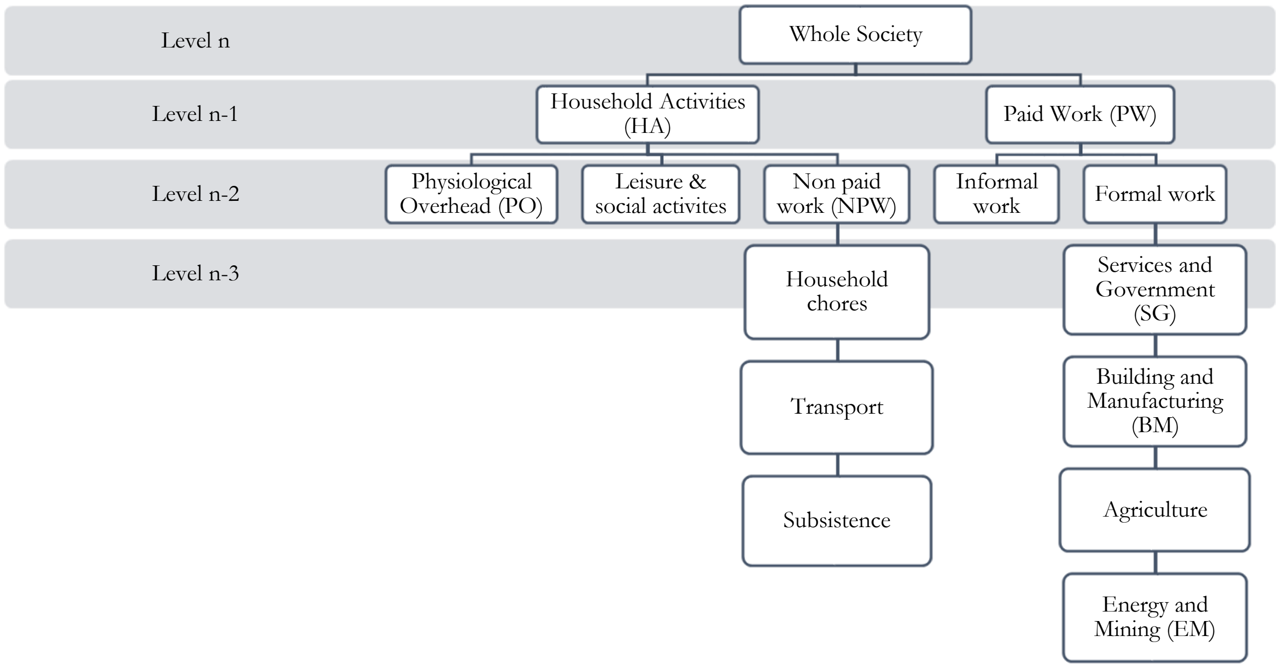



Figure 3-3: Human Activity Dendrogram[7] (Smit et al. 2017)

### 3.5 Summary

Chapter 3 provides a practical approach to the research methods and processes used in the study, which was influenced by the research method employed and various instruments and tools used to collect and analyse the necessary data required to achieve the research objectives.

In chapter 4, a presentation of the results of the study as they pertain to each of the research question is discussed.

[7] A Dendrogram is a tree diagram mostly used in illustrating clusters arrangement produced by hierarchical clustering

# Chapter 4 Results and discussion

In this chapter, the progression of results obtained from the data analysed are presented based on each of the research objectives. As specified in chapter 3, several data collection tools were employed for proper data triangulation. The data analysis and interpretation were both quantitative and qualitative in nature.

Nevertheless, for logical results organisation and presentation, a linear design was employed, which related to the individual research objectives and the research tools employed to collect data that was specific to that objective. Although the results which relate to the individual tools form just a segment of the whole, each research objective was investigated by interpreting not just the segment (that is based on the individual tool applied in collection of data) but also of the whole in order to gain the general (or complete) insights and perspectives.

The chapter focuses on energy flows analysis, by considering the consumption of different household based on the different housing or building structures. The relationship amongst housing structures and household types and energy consumed, overall energy use, and energy fuel type (energy mix) used is explained. The results are presented as the characterisation of the informal settlement under study in relation to their energy and money flows[8], metabolic pattern and/or rates and the system openness, their funds such as exosomatic devices, and human activity as well as land use.

Section 4 presents the results of how the quantitative representations reflect the qualitative understanding that characterises the debate on urban informal settlement. The analysis of the data obtained was done using the MuSIASEM framework[9] (as discussed in chapter 2). Here, the data presented were divided into three different parts based on three parameters, namely Time, Energy and Money.

[8] Description and analysis on the households' money flow is presented in Appendix E

[9] A conference paper was submitted for SAIIE28 on the MuSIASEM framework development. It also provided a summary of literature reviewed on urban and energy metabolism in informal settlement as viewed by different studies, and the significance of understanding the informal settlement towards an inclusive urban policy planning and implementation as well as energy transition for sustainable development in cities and there surrounding informal settlements. (Makinde et al., 2017)

## 4.1 Understanding the different household typologies in the urban informal settlement

As discussed in chapter 3, Kayamandi is an appropriate case study. It can be classified as a Hybrid, Multi-structured type of settlement (Category E: Formal/Informal, Legal/Illegal, Planned/Unplanned, and Legitimate/Illegitimate). Kayamandi initially comprised of hostel structures and later included RDP homes (Smit et al., 2017). Owing to overcrowding and the lack of influx control, however, the settlement devolved from its former Category A (Legal, Formal, Planned) settlement, to include different types of settlements and building structures (Chenwi, 2012).

Understanding the societal metabolism of urban informal settlements and their biophysical characteristics requires an integrated assessment of their energy patterns and flow. This is done while estimating the energy demand of urban informal settlement, given that many of these households do not possess a legal tenure, and therefore, not entitled to provision of public services (Durand-Lasserve & Royston, 2002; Payne, 2001). Kovacic et al. (2016) describe the methodological uncertainty that arises from estimating how the demand in energy increases with the growth in population. Demand in energy in urban informal settlements is, however, not directly correlating to the population size.

It is essential to understand that there are different important energy functions that contribute to energy usage in an urban informal household. Such functions include lighting, cooking, heating-water and space, cooling and electrical appliances (Schipper et al., 1996; Pachauri, 2004; Musango, 2014). There is, however, limited research on energy consumption in urban informal settlements in developing countries (e.g. Shrestha et al., 2008; Kovacic & Giampietro, 2016; Kovacic et al., 2016; Smit et al., 2017). As such, the proliferation of urban informal settlements in and around urban cities is projected to increase as a result of urbanization, which implies that energy demand will also increase. It is also the case that generally, urbanization determines energy fuel type and quantity consumed in developing countries (Dzioubinski & Chipman, 1999; DeFries & Pandey, 2010).. Urban informal settlements may, however, portray different patterns of energy consumption.

There is a need to understand the pattern in energy use in relation to their socio-economic characteristics in order to devise strategies for transitioning towards sustainable energy consumption and behaviour in urban areas. This requires different approaches based on

MuSIASEM approach, which presents the urban informal settlement at their different levels including the whole settlement level, household levels and for different resources.

## 4.2 Building typology in an urban informal settlement

Informal settlements present a big challenge to address in order to transition towards sustainable development and future. A number of developments and planning initiatives aimed at upgrading such settlements in order to promote socioeconomic development have been implemented. Here, Kayamandi is not been left behind but the initiatives have heard no or limited success. This point to a missing link in policy planning and implementation.

As described in Section 3, identifying the different housing structures in Kayamandi required direct observation of the real-life human activities in the settlement, through field notes and pictures to capture the different types of housing structure identified. Table 4-1 describes the identified housing types present in Kayamandi informal settlement.

Table 4-1: The different housing structures identified in Kayamandi

| | |
|---|---|
|  Figure 4-1: Picture showing an example of RDP homes in Kayamandi informal settlement. | RDP homes: These consist of government provided homes or individually owned homes. For the purpose of this study, this is the RDP homes without backyard shacks. |

Figure 4-2: Picture showing an example of RDP houses with backyard shacks in Kayamandi informal settlement.

RDP homes with backyard shacks: these consist of government provided homes with rented shacks of at least one shack at the backyard of the building. Backyard shacks are normally informal erected on residential property (usually found at the back of the buildings) in formal legal townships. Nevertheless, this type of building structures is found in a similar way but in informal settlements.

Figure 4-3: Picture showing an example of freestanding shacks in Kayamandi informal settlement.

Freestanding Shacks: these are classified clusters of informal structures which are usually located on a tract of land within formal townships; in buffer zones between townships; on tribal land usually close to urban centres; on undeveloped farm land; and or on vacant land which were formerly White, Coloured or Asian dominated areas. In informal settlements like Kayamandi, a large number of household occupying different freestanding shacks (each of which are of different household types and constitute different kinds of human activities) are found) (Urban Foundation, 1991; Smit et al., 2017).

Figure 4-4. Picture showing an example of municipal flats in Kayamandi informal settlement.

Municipal Flats: they are a form of social or public housing system built by the municipalities.

Hostels: Slums emerged from hostel types of accommodation, which included barracks and compound, were built as mainly single-sex type of accommodation to house and control (most times) male workers who were employed at the municipality or industrial employers' and railways. Due to overcrowding, and very intense use majority of these buildings have rapidly deteriorated (Smit et al., 2017). Most of which, now house families in informal settlements.

Figure 4-5: Picture showing an example of hostels in Kayamandi informal settlement

### 4.2.1 *Household characteristics: Building Structures*

Before analysing the household composition, it is important to examine the different building structures or typology discovered in the informal settlement. There are different ranges of dwelling types in informal settlement in South Africa. Dwellings range from formal structures (e.g. RDP homes, Municipal Flats) to traditional and informal housing (e.g. freestanding shacks, shacks in backyard, hostels).

The survey consisted of respondents from household within the settlement, described in figure 4-6 is the percentage of respondents (participants) from the different identified housing or building structures. These represent the number of the surveyed households of the different building structures in a hybrid / multi-structured urban informal settlement. (*See table 4-2*)

Table 4-2: Households building structures or dwelling type

| Housing type | Number of respondents (i.e. households included in the sampled population) |
|---|---|
| Free-standing Shacks | 31 |
| Hostels | 7 |
| Municipal Flats | 5 |
| RDP (with backyard shacks) | 24 |
| Backyard Shacks | 25 |
| RDP Houses | 8 |

Of the 120 household respondents, about 37% reside in formal housings (Municipal flats, hostels and RDP housing), whereas about 63% of the sampled population reside in informal housing (shacks in backyard and the freestanding shacks).

Out of the respondents residing in formal housing, about 24.2 % (RDP with backyards shacks) of this group have one or more informal housing (backyard shacks) connected to them. Figure 4-6 provides a diagrammatic view of the different housing structures present in Kayamandi informal settlement and the percentage of the sampled population.

From the sampled population housing, consisting of a large percentage of RDP or formal housing structures having one or more shacks present at the back of these structures (with some having as high as 8 backyard shacks). This indicates the extent of continuous growth and dense population of urban inform settlement. Given to this situation, most residents have to either live in freestanding shacks and/or shacks at the back of an RDP home. Owing to continuous urbanization, this phenomenon will remain, with more people having only the option of this informal housing as their dwelling types. Here, many are prone to the issue of land tenure and security, which eventually pose a challenge of policy planning and implementation to urban planners, municipalities and/or government.

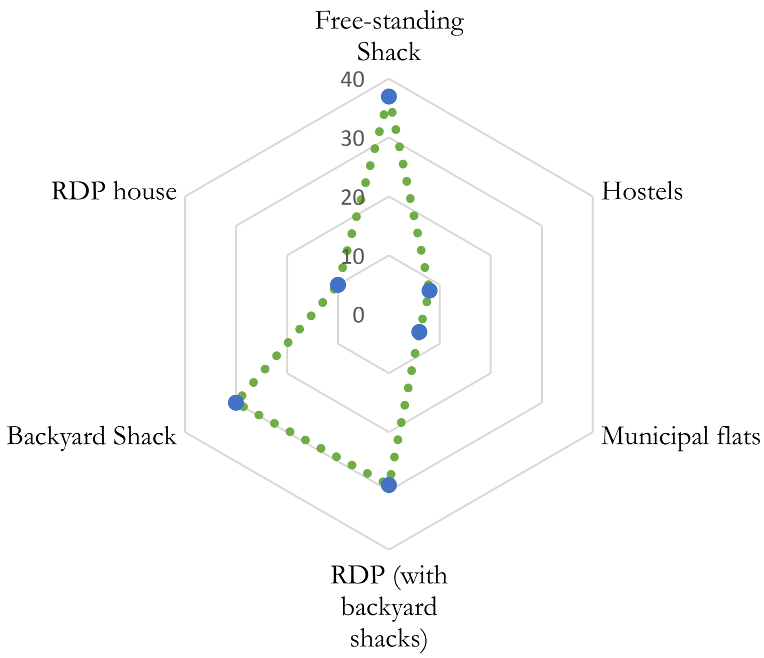



Figure 4-6: Kayamandi Housing/ Building Structure Type.

## 4.3 Household profile (type or composition) in an urban informal settlement

In order to explain the different trends that determine the energy consumption in urban informal settlement households, it is essential to analyse the system using a bottom up approach (i.e. at a lower level of analysis). This is done by identifying the different typologies needed to explain the differences. The first factor that determines changes in the total energy demand in urban informal settlement is the household composition. Applying a lower scale analysis, it can be used in distinguishing among the different types of informal settlement households by examining their composition.

Limited research exists at urban informal level with respect to the energy consumption although a few studies have been conducted in the recent past on how to conceptualise slums (Smit et al., 2017). Households' energy consumption profile, thus, raises awareness to relevant questions on the connections energy has with the economy, security, environmental protection and society. As such, the patterns of energy consumption within households may differ dramatically in ways that reflect and intensify economic and social inequalities affecting informal settlements.

Based on the questions from the survey obtained on the household profile, the characteristics of the surveyed households with respect to their composition (or type), and population dynamics is presented in the next section.

### 4.3.1 *Household (HH) characteristics: Population dynamics and gender*

The section highlights the household composition of an urban informal settlement, by presenting some key results on the population dynamics of the settlement. At household (HH) level (n-1), the metabolic pattern of the settlement is closely related to the household composition. The households (HH) level data mainly consist of age, gender, population and/or demographics of the household. The data analysed from the sampled population consisted 47% of the respondents' male while 53% were female (*see figure 4-7*) with most of them aged between 25-30 years.

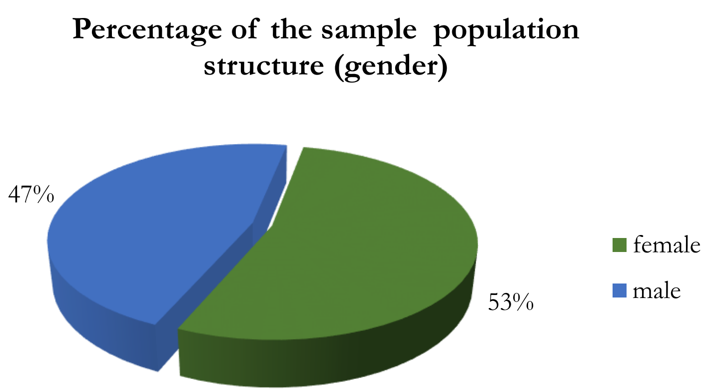



Figure 4-7: Gender category of the surveyed households

The population of Kayamandi primarily comprised of young adults, with the proportion of ages close ranged. The highest proportion from the sampled data is 15.5% of the population are between age of 25 and 30, the closest falls between the ages of 15 and 20, as well as 30 and 35 (both at 12.2%). A high proportion of children are between the ages of 5 and 10 (see Appendix C; Table 6-1). One can argue that the demographic structure changes in the urban informal settlement of the population signal a movement across the system change trajectory (see Figure 4-8). Further analysis can be used in determining the demographic structure of the settlement.

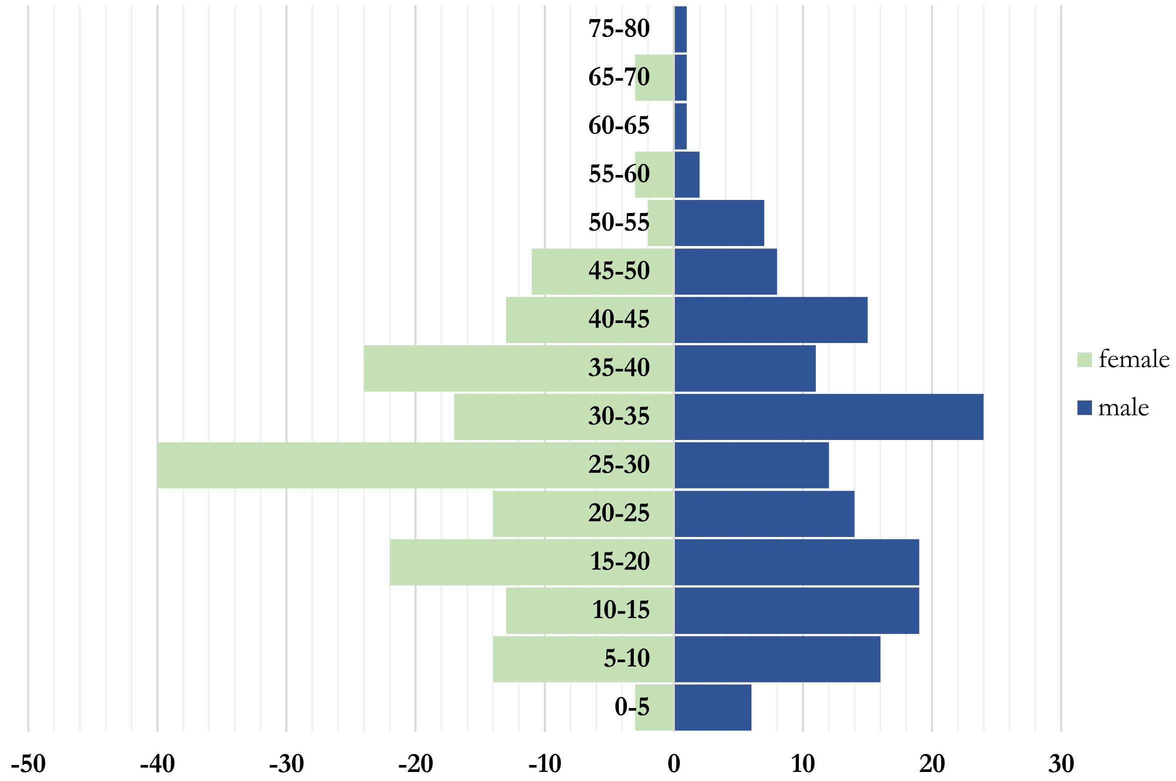



Figure 4-8: Population composition of an urban informal settlement

According to  Kovacic et al. (2016), one of the factors that affect fuel consumption in urban informal households relates to their population dynamics. Kovacic et al. (2016) finds that the impact of household composition at the level (n-1) has a major effect on the type of energy fuel used and the quantity used. It is the case that Enkanini informal settlement population has nearly doubled over a period of 3 years (between the years 2012 - 2015), the settlement's energy and fuel consumption did not change. Rather, the consumption was determined by the instances and numbers of certain household (HH) types, and the fuel type used combination[10].

In order to explain this phenomenon (on how household composition affects the total energy demand), the data at household level (n-1) was analysed further to characterise the household composition (type). Figure 4-8 shows the population dynamics from the surveyed data (of the sampled population) of Kayamandi informal settlement for the year 2016. Households may be composed of: (i) 1 Adult; (ii) 1 Adult, 1 Senior, 1 Child; (iii) 2 Senior 1 Adult; (iv) 2 Adults; (v) 2 Adults 1 Child and so on.

[10] Detailed description is presented in the results analysed in the next section 4.2 on monetary and energy flow in an urban informal settlement.

The total population sample data (from the surveyed households) representing the different age group and gender, which describes the general overview of population structure that characterises an informal settlement can be seen in Appendix C; Table 6-1.

Although the household data on population might not actually present the composition of each household, analysing the data shows the different household composition of the sampled population in a typical urban informal household (this can be seen in Appendix C; Table 6-2).

One noteworthy observation is that the building structures do not necessarily determine the household composition. For example, a household comprising of seven residents having a household composition of 5 Adult; 1 Senior; 1 Child (age range from 12 years – 58 years) live in a RDP housing structure, whereas a household consisting of 3 Adults; 1 senior; 1 Child, living in a backyard shack.

Different household types have different patterns of composition. For example, a household composed of only one Adult will present very different characteristics in terms of their energy consumption, time use and expenditures when compared to a household that comprises of two adults with children (Giampietro et al., 2010). Similarly, a household comprising of five single adults and children will consume more fuel (overall). Thus, energy demand is not linearly correlated to the number of household members, but rather to the household type or composition.

Notably, as the household composition changes, the overall energy demand also changes. To describe the drivers of change in the energy consumption of household, three factors are required, namely (i) classification of the household type or composition (HH), (ii) the estimated pattern of consumption for each type of household, (iii) the distribution profiles of different types of household.

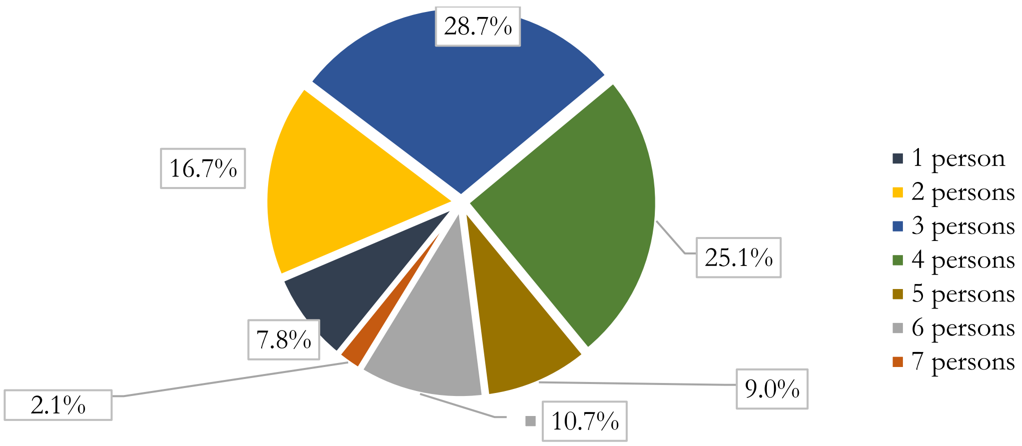



Figure 4-9: Percentage of Household composition.

### 4.4 Understanding household energy flow patterns in a multi-structured urban informal settlement

In this section, the results of the different quantitative representations on household patterns of energy demand and consumption that characterise an urban informal settlement are presented.

#### 4.4.1 *Energy access and consumption pattern*

To characterise the societal metabolism of an urban informal settlement that is based on the flows of energy metabolised by the system in order to replicate its functions in the case of the metabolised energy flows, an increasing complexity of the flow is given by:

i. Increase in the quality of the metabolised flows, such as switching from consuming candles to electricity.

ii. Increase in the different type of flows, as illustrated in the diversity of consumer goods purchased (which are revealed from the household expenditures (Appendix E: II)

iii. Changes that occur in the set of funds element, for example; as the number of children increases, important metabolic patterns of the settlement can be expected (such as changes in the household composition), and also, a tap water installed inside the house dramatically increases the quantity of household water consumption.

Another factor that characterises the patterns of consumption of energy in urban informal households is the fuel type or energy mix used by the households, that is, the expected energy flow pattern of the types.

Energy flow is estimated by analysing the type of energy carriers (EC) (or source) used in a particular household rather than just estimating the total energy throughput measures in Joules.

The distinction between the various energy carriers (EC) provides the possibility of assessing the qualitative differences in the standard of living of informal settlement households, which involves moving beyond per capita accounting of energy consumption. The survey data from Kayamandi informal settlement shows how energy demands vary depending on the number of people in the household.

In terms of energy flow, Kayamandi informal settlement is a net energy consumer with a municipal-supplied electricity access. Illegal electricity connection from neighbour's main electrical box is, however, an ongoing challenge faced in South Africa. As such, illegal connections are a major cause of shacks' fires. People also lose their lives through electrocution seeing that such connections are done unprofessionally. In order to deal with such issues, Musango (2014) highlights the need to understand better the extent of these illegal connections. There are, however, limited studies documenting the extent of illegal electricity connection, thus, identifying culprits is carried out in an ad-hoc manner (Musango, 2014) .

From the 120 households surveyed, responses showed different categories of connection types in relation to the sampled households' access to electricity supply, which was found to be either through:

i. Direct connection (to the grid) users;
ii. Indirect connection (through neighbour) users;
iii. Solar users.

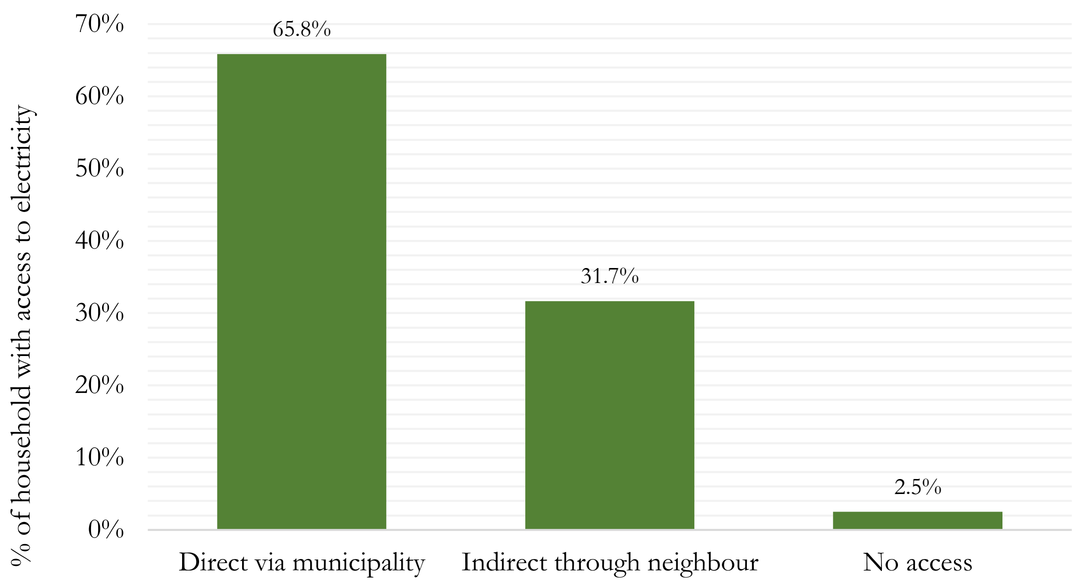



Figure 4-10: Community energy access (or connection) for households in Kayamandi informal settlement.

From figure 4-10, the percentage of sampled data on household access to electricity (electric grid) shows that:

i. 65.8% are officially (directly) connected to the Municipal electricity grid;
ii. 31.7% were connected unofficially, i.e., indirectly to their neighbours;
iii. 2.5% remained with no form of connection (or access) to the electricity grid; such households presented with limited options to choose from in order to get a similar or almost similar type of services provided by electricity. The households represent 1 out of 30 households from the sampled population (which is 4 households from the 120 sampled households). The 4 households opted for a solar electric system.

Based on the categories, the following observations can be made regarding household energy access:

**a.** Indirect users

According to the surveyed households from the sampled population, the responses with indirect connections through their neighbours stood at 31.7%, which is a very high percentage, and worrying to municipality and government. These indirect connections from neighbours are not metered with the household users of these services paying the neighbours monthly. One interesting discovery is that these households end up paying equal amount for electricity received irrespective of whether the service was able to serve the intended purpose for them monthly (thereby making the service expensive). One of the reasons as to why there are illegal connections is the lack of or poor access to clean and modern energy services by the urban informal settlement households.

It is the case that majority of these households of indirect electricity users are restricted from the number and/or type of appliances which can be used on the line, whilst, the connection stability reduces along the line because of distance, as well as the number of household connected to the line. Other drawbacks of the illegal connections are:

- At times households of this type of connection need to pay for more electricity before end of the month,
- Load shedding,
- During winter, power sometimes trips.

The illegal connections phenomenon presents a difficulty in which households on this connection are only provided with little or low output voltage to power their electric appliances, prompting these households to consume only the electricity supplied through these connections majorly for just lighting their 60 Watts or 100 Watts bulb.

**b.** Solar users

For those with no access to electricity connection (figure 4-10), the 2.5% opted for solar electric system as their main source of energy. This service is provided by iSHACK project, situated in Enkanini informal settlement (this settlement shares border with Kayamandi, both located in Stellenbosch Municipality). The solar electric system users were found in different dwelling types, as housing structures is not a factor for not having access to electricity, but the reason for majority of these users are either :

- Due to households being new to the community; and/or
- Household composition. For example, with a household consisting of one Single working adult requiring less human activity hours for non-paid work (NPW) due to the number of hours spent doing paid work (PW) e.g. a security guard, who mostly works 12 hours per day, with many running a 6 days shift. Such a household requires less energy consumption, prompting options of solar electric system. Other factors that need consideration for this type of household composition is the number of appliances present in this particular household[11].

With households with no electricity connection the solar users (only 3 households were using solar system out of the sampled population). These services are provided by a private facility called iSHACK project in Enkanini informal settlement to households at 130 Rand per month rent. One interesting observation from the household energy use was that, some households with electricity access (connection) were using solar water heater (with 11 households found to be using solar for heating, mostly water used for bathing).

It should be noted here that the households without any connection to the electricity grid do not consider themselves as having any access to electricity, given the limitations posed by the solar electric system and the few services/uses it can offer.

Informal settlements are characterised by a low energy throughput. It then follows that the growth in overall household electricity consumption in informal settlements is entirely attributed to the following:

---

[11] A detailed explanation on how energy consumption can be based on household appliances is provided further in this section 4.

i. Access to electricity (provided by the government);
ii. Income level of households.

The growth in overall population of Kayamandi, however, does not seem to lead to a higher energy throughput, but instead affects the rate of energy demand of the settlement.

An increase in energy throughput requires increasing capacity of fund elements (such as household composition or structure) to consume the energy. As seen in the case of electricity, this increase in capacity of consumption depends on the exosomatic devices (such as electrical appliances used in the households) availability. The households with no income source or the poor households are, thus, seen not just as low-level income households and low energy throughput households, characterised by the limited capacity of the households to increase their energy throughput.

According to the view on societal metabolism, energy consumed by households is not determined by the household energy carrier or income only as suggested by concept of energy poverty by (Sagar, 2005). It crucially depends also on the following:

- characteristics of the household composition (single adult household as compared to a family household);
- the settlement (such as proximity and connection to the electricity grid, status of legal tenure, system used in collecting revenue from utility user, social services, available infrastructure; and
- an understanding of the energy flow patterns gained through multiple levels of analysis (Kovacic & Giampietro, 2016).

Here, the issue of the settlement evolving (becoming or emerging) can be investigated. As observed with the overall metabolic pattern changes in the settlement, which can occur as a result of emerging new household composition or types, or due to changes in their technical coefficients, the demand in energy is determined by the household composition or types. In this case, an increase in the society complexities such as change in their distribution patterns, for instance, over types or new types will change completely the behaviour of the energy demand system.

Metabolic pattern analyses that are based on types or composition, instances, benchmarks and their distribution profile (for the fund and flow elements), enhance the possibility of handling the challenges arising from such complexities. Similarly, the overall energy demand depends on household composition that constitute the community, and on the number of each household type instances.

### 4.4.2 *Energy access: Analysis based on their building structure*

The analysis of energy access based on the housing structures or dwelling types shows most households with direct electricity connection (37%) are those of RDP with backyards shacks; 13% for RDP without backyard shacks; 34% for freestanding shacks; 9% for hostels and 7% for municipal flats (Figure 4-11).

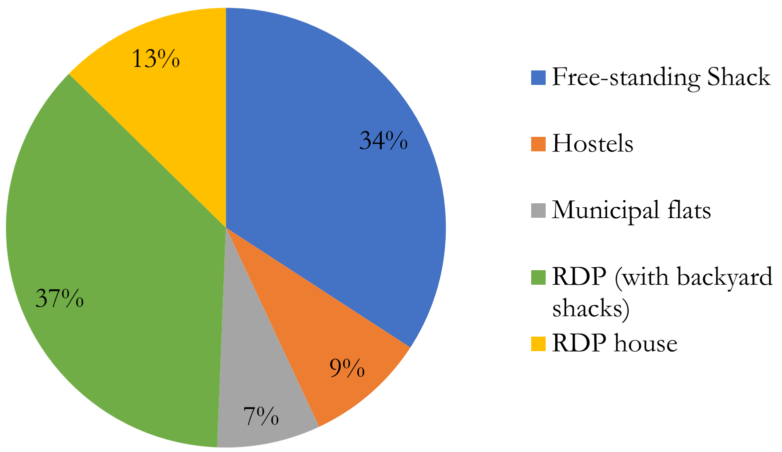



Figure 4-11: Direct electricity users based on building structure

The results also shows that for indirect electricity connection through neighbour's supply, is not just an issue present in only one particular housing structure in the community, but cuts across different dwelling types. However, the proportion of indirect connection users largely exists among backyard shacks (informal dwelling types), which are usually located behind a formal RDP building structure. Among households' having indirect connection, 79% are backyard shacks, while 18% are freestanding shacks, with only 3% hostels (Figure 4-12). Informal dwellings having a higher proportion of households on indirect connection is, however, not surprising as these structures have no permanent tenure and many are likely to be illegal structures unrecognised in urban development planning.

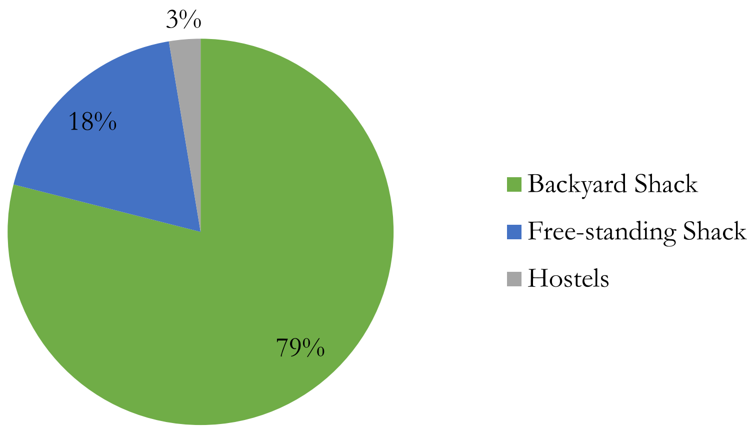



Figure 4-12: Indirect electricity users based on building structure

A further analysis of urban informal settlement energy access based on their different housing structures can be carried out using a larger sampled population, in order to get comprehensive information and/or data from larger proportions of households and housing structures. As such, municipalities and government require an understanding of the urban informal settlements' basic needs and their demographic structure, seeing that over time, with continuous growth, if these households are not included in plans and policies, they end up being indirect electricity connection users.

### 4.4.3 *Household fuel types*

It is important to understand the pattern of energy use in informal households' when analysing the different household fuel types. The change in the energy fuel types used in each household is another factor that explains the changes in household energy demand for an informal settlement.

This part of survey question investigated the energy fuel source present in informal settlement households. The question was a multi-response question, i.e. households had the options of choosing more than one fuel type.

In the case of this study, the analysis comprised each housing structure (i.e. understanding the changes in energy demand and consumption in a hybrid/multi-structured informal settlement household).

Households frequently rely on different types of fuel for various household activities, which can also be seen in the case of Kayamandi informal settlement as revealed from responses to the questions asked from the survey carried out. The survey questions disintegrated the fuel options (Table 4-3 highlights the different fuel options, and the overall classification as per the different household activities).

Table 4-3: Overall energy fuel type and classification for the various household activities

| Energy fuel type (source) | Cooking | Lighting | Space heating | Water heating | Electric goods and appliances |
|---|---|---|---|---|---|
| Paraffin | 21.0% | 11.4% | 72.9% | 21.0% | |
| Wood | | | 0.9% | | |
| Gas | 25.3% | | 0.9% | 8.8% | |
| Candles | | 27.4% | | | |
| Coal | | | | | |
| Solar | | 2.5% | | 6.1% | 2.5% |
| Biogas | | | | | |
| Batteries | | | | | |
| Car Batteries | | | | | |
| Generator (Petrol/Diesel) | | 0.5% | | | |
| Eskom (direct and indirect grid electricity) | 53.8% | 58.2% | 25.2% | 64.1% | 97.5% |
| The overall consumption amount to the total (%) | 100% | 100% | 100% | 100% | 100% |

Majority of the household combine different energy fuel types for various activities (as described in table 4-3 on the overall fuel classification obtained from the sampled population). It is the case that certain fuel types present in low-income households as well as in those with very much higher income. An example is in the use of paraffin, which is considered as a low-income household fuel, but the findings of this study show that it is a predominately-used fuel for different household activities second to the use electricity. The difference between higher income households is that this is not their main primary energy source. According to Truran (2007), majority of households that consume paraffin for their household activities simply do so because the fuel type fills a specific niche in their household energy mix better than other options.

A number of factors determine the use of the different energy fuel types in majority of urban informal settlement households, namely affordability, lack of access to alternatives (e.g. electricity), availability, and low running costs.

At this point, we can estimate that the extent to which energy consumption increases at the level of Kayamandi informal settlement as a whole society (level n) is a result of the differences in household composition and the energy fuel types (or mix) used. The overall energy consumption can differ due to changes in the instances of the different households' composition (or type).

### 4.4.4 *Household monthly fuel cost*

Ensuring there is energy security at household level requires that households be provided with access to modern and clean energy at a price that is affordable, which brings the need to understand the energy cost that households incur. Increasing energy fuels expenditure indicates how vulnerable households are to changes in costs of these energy fuels. Household fuel was, thus, recorded as a single amount. Table 4-4 presents the overall household expenses as a percentage of the overall expenditure at 8.0%.

Table 4-4: Household monthly energy expenditure

| **Average energy expenditure per month in urban informal settlement** | |
|---|---|
| Expenditure on electricity (Rand / month) | **262.31** |
| Expenditure on all energy fuel used in households (Rand / month) | **431.82** |
| Energy as a percentage of total household expenditure | **8.0%** |

Based on the data collected, household fuel costs were grouped into eight levels as shown in figure 4-13. Majority of the respondents from the sampled population spent between 200 and 400 Rand per month on all their energy fuel needs. Average energy fuel cost for the sampled population was 200 Rand per month. Although a large proportion of households with no income is incurring energy fuel costs, they have no means of paying for the cost of energy fuel consumed (in this case, the household rely majorly on money from friends or family).

The largest proportion of household respondents whose fuel cost is between 201–400 Rand per month are in the income category of 4001–6000 Rand per month. In addition, some households are spending beyond their household income on energy fuel, which might put them in a situation of vulnerability in case of price change on energy fuel. It is important to note that energy fuel cost in this study might not be able to provide, in detail, the extent of financial burden fuel cost places on households based on the energy fuel type used. Further investigation into their expenditure based on each particular energy services (e.g. cooking, lighting, water and space heating, and electrical appliances) with respect to the total household expenditure will be required.

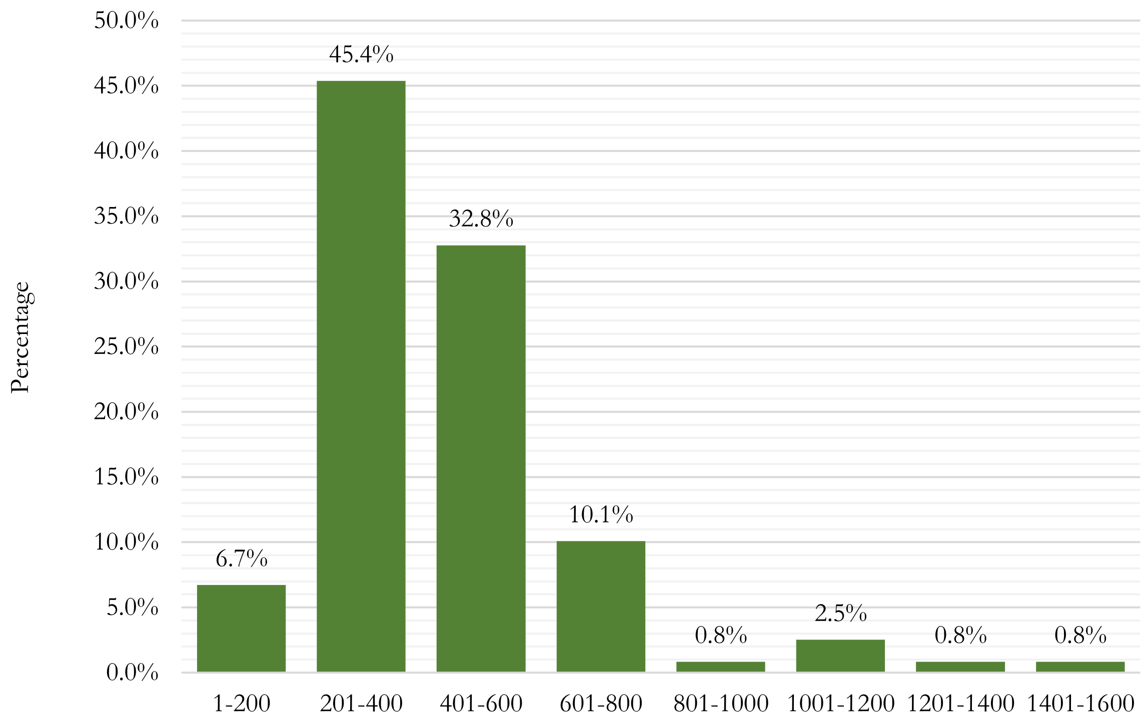



Figure 4-13: Household monthly fuel cost

From the household energy cost groups, as presented in figure 4-13, 45.4% incur between 201-400 Rands on their energy fuel consumption monthly, which is the highest cost from the sampled population. A detailed analysis into household energy fuel cost with respect to the household income per month (*see Appendix E; Table 6-4*) raises questions on how it influences household energy choices, which may also require further investigation.

## 4.5 Energy consumption by household activities

In Kayamandi, several energy fuels types are used for different household activities as observed from the sampled population data. Electricity (described in Table 4-3) is the most used universal energy for various household activities such as lighting, cooking, water heating, space heating and electric goods (and/or appliances). Figure 4-14 shows the graphical representation of the different energy fuel types per household activity. In this section, each of the household activities is discussed with respect to the pattern of energy fuel types consumed.

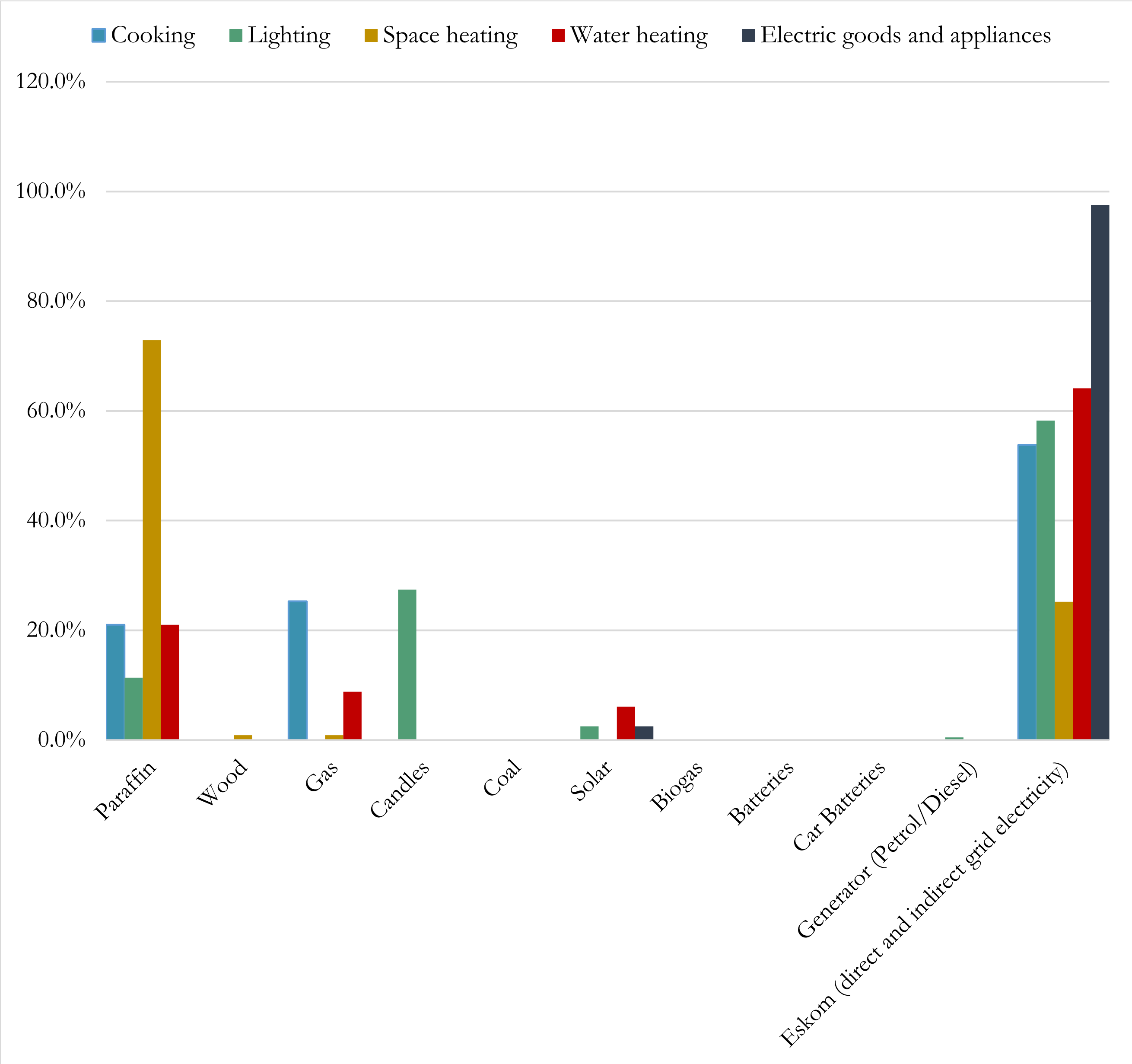



Figure 4-14: Energy Fuel Source for Household Activity

From the figure above, the sampled population (97.5%) mostly use electricity for their electrical appliances, with only 2.5% (this percentage represent households with no connection to the electricity grid) using solar energy to power their household appliances (e.g. solar fridge, solar light bulbs. etc.). It should, however, be noted that the solar electric system users do not consider themselves as having access to electricity, given that the system only allows them access to limited appliance usage.

Affordability is one of the driving factors used by households to choose their energy fuel types for the different household activities. Poor household respondents often have to choose more risky and dangerous fuel types, despite having connection to the electricity grid. It can, however, be noted that across all monthly income levels, households earning below 1000 Rand monthly spend an average of 168 Rands monthly on their energy fuel. This indicates that although low-income households might struggle with meeting their daily needs, majority count energy a significant part of their 'must meet need' in the household.

### 4.5.1 *Energy fuel type for cooking activity*

The energy fuels used in informal households for cooking has become a major cause for many health related issues. Examples of such health issues include those caused by inhaling carbon monoxide. Access to clean-fuel for cooking is, however, a big challenge in informal households due to cost and lack of access to a more clean and efficient energy fuel type (with challenges from electricity supply, different sections of the community experience load shedding at one or more points in time during the month).

In Kayamandi, it was established that different households used different energy fuel types for cooking, e.g. electricity for cooking and boiling water (using an electric kettle), some household uses paraffin while still others use gas.

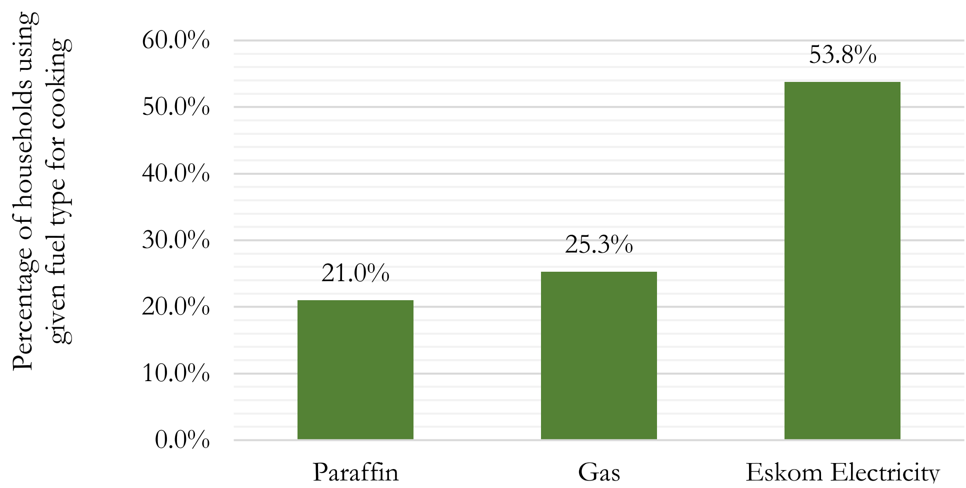



Figure 4-15: Main source of household energy fuel type for cooking

From the surveyed households (*presented in Figure 4-15*), a large proportion of the households were found to be using different energy fuel types for cooking. Cooking represents one of the most energy-intensive household activities, with households having to cook more than once per day for a long time (ranging for several minutes to hours).

Across the sampled population, a larger percentage, of slightly over half (53.8%) of the households use electricity as the main energy fuel type for cooking. Others use either slightly over one-fifth of paraffin or slightly over one-fourth of gas, at 21.0% and 25.3% respectively.

For non-electrified households, natural gas was their main energy fuel type for cooking purposes. For electrified households, however, different trends are evident in each household's consumption of the diverse fuel types for cooking. For example, it was observed that each household had a different proportion for each fuel type in the overall quantity of fuel used. ; with some households combining both paraffin and gas for cooking at different ratios (6:4, 4:6, 3:7 or 7:3) and others combine gas and electricity. This indicates that most households in informal settlements rely on more than one fuel type for cooking. Similarly, from the sampled population, households with relatively low-income levels often consume a mix of the different energy fuel types but these represent a small proportion from the sampled population.

An interesting aspect from the survey results, which is also theoretically ambiguous, is that the use of electricity for cooking is not based on the household population group, income level, or education. This implies that an improvement in the household income and level of education, will not necessarily lead to a displacement of other renewable energy sources e.g. solar energy.

Based on the household comments obtained from the questionnaire, the following views were identified for not utilising solar or for those with the solar electric system still requesting for connection to the electricity grid:

- The solar system does not cater for most household thermal energy needs
- Solar is weather dependent
- Access to household appliances is limited
- Maintenance; this issue is mainly dependent on the service provider.

Most household respondents are okay with the price for installation and maintenance, only if the service is able to cover all their household appliances e.g. refrigerator, lighting bulbs, television, microwave etc.

### 4.5.2 *Energy used for lighting*

The majority of informal household uses electricity as their energy source for lighting purposes, with the sampled population data *(see in figure 4-16)* showing about 52.8%. A worrying proportion of the responding households, however, still uses candles for lighting (27.4%) even though the largest percentage of the sampled population have electricity. The median consumption of candles was about 18 Rand per month in the households that used candles.

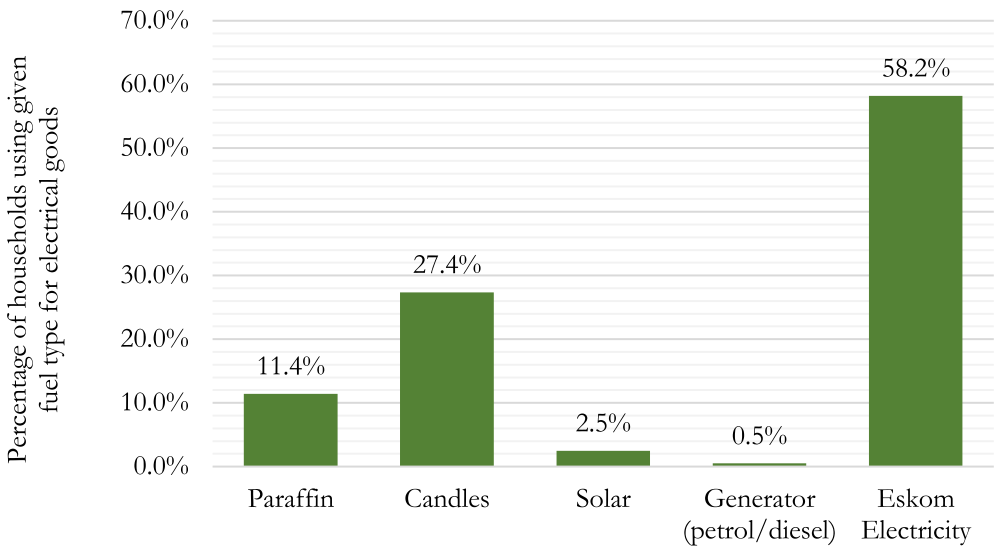



Figure 4-16: Main source of household energy fuel type for lighting.

The figure 4-16 translates to the following observations:

- Over a quarter still rely on candles;
- Half of the sampled households use electricity;
- One-tenth rely on paraffin, using paraffin lamps in their homes for lighting;
- The only proportion relying on solar are those without connection to the electricity grid;
- One person indicated the use of generator (petrol/diesel). It is, however, not clear if this household uses the appliance for other activities such as informal business.

It is also unclear what factors have led to the limited use of renewable energy by Kayamandi informal settlement households, particularly the use of solar for lighting. Although majority of household respondents prefer electricity for their household services as it seems to be the better of the other fuel types to meet the household energy needs and not affected by other factors as seen in the case of solar (e.g. weather, limited use for household appliances). In order to understand various views and opinions of informal settlement residents on their choices of certain fuel types, especially renewable energy, further investigation will be required.

### 4.5.3 *Energy used for water heating*

The main solar energy use in the urban contexts is for water heating purposes mostly for washing and bathing. The energy fuel type used for water heating, however, varies per household, with majority of the households indicating electricity as their source for water heating; others are paraffin (21.0%), Gas (8.8%) and Solar (6.1%). The percentage of solar electric system users is the lowest. This is attributable to the fact that most households in Kayamandi are electrified (either directly or indirectly) thereby decreasing the requirement of solar as a fuel type for water heating in the urban informal households.

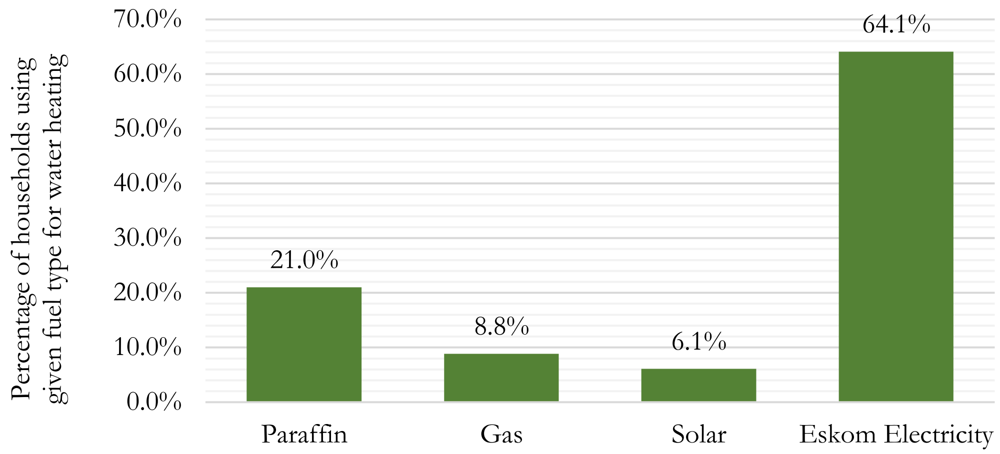



Figure 4-17: Main source of household energy fuel type for water heating

### 4.5.4 *Energy used for space heating*

The main energy fuel type used for space heating was predominately paraffin, even in the case of electrified households. Over 72.9% from the sampled population used paraffin as a source of energy for space heating. This characteristic can mainly be attributed to cost, as electric heaters tend to consume more energy (in terms of electricity). Figure 4-18 presents the data on household energy consumption and the energy fuel types used for space heating. Other household fuel types for space heating were electricity (25.2%), coal (0.9%) and gas (0.9%).

From the results presented, only a small proportion of urban informal households rely on liquefied gas, coal or wood for heating up their homes during winter. This too is relatable to cost in the case of liquefied gas as compared to that of paraffin, as well as the quantity of this fuel required for heating homes (where in the winter, most homes run these appliances for more than 1 hour per day).

The type of appliances used in space heating was highly correlated to the energy fuel type used. Some of the interesting features include:

- In terms of appliances, the paraffin users had a paraffin stove to provide for space heating. Majority of the households consume a lot of this fuel with the effect on availability and cost in the community; (i.e. the continuous use and increase in demand due to the need of the people affect the cost of paraffin, causing it skyrocket especially during winter.)
- Those who burn coal and wood mainly use an open brazier called ''Imbawula'''; only one person indicated the use of this appliance for space heating.
- The households using electricity have in their homes electric heaters; with those using gas as energy fuel type using a gas heater for their space heating.

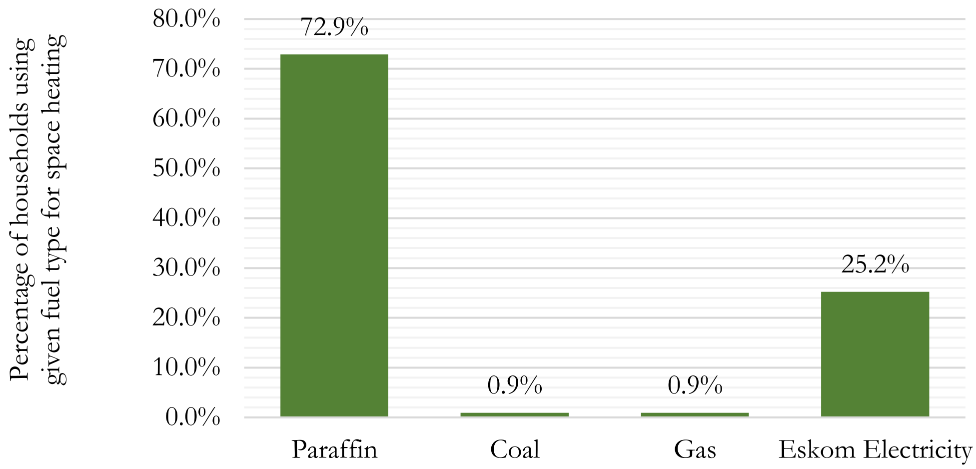



Figure 4-18: Main source of household energy fuel type for space heating

### 4.5.1 *Exosomatic devices*

From Figure 4-19, majority of Kayamandi households rely and consume electricity for their household appliance. With only 2.5% with no connection to the electricity grid relying on solar electric system.


Figure 4-19: Main source of household energy fuel for electrical goods

At the household level, the household appliances were considered. While majority of the households used electricity, many relied less on electricity for cooking, lighting and space heating as much as they use it on household appliances such as refrigerator, television, DVD, radio, microwave, iron, hair dryer etc.

A potential increase in energy consumption should as well be coupled with an increase in the number of households who own electrical appliances. As such, an increase in energy consumption requires an increase in power capacity.

## 4.6 Energy consumption by building typology in a multi-structure/hybrid urban informal settlement

An analysis of household consumption based on the different flow provides insight into the different energy used for different household activities in urban informal settlement. The previous section provided a generalised estimate on household energy fuel type and classification for different energy services. Based on research objective 2, at the household level, a further analysis can consider the housing structures in Kayamandi informal settlement and how they metabolise their resources (in terms of their energy fuel types or energy mix used) for different household activities. Connection to the electricity grid is not determined by the housing structure, as seen in the case of freestanding shacks, where the legality of the settlement and the land tenure might have played a role in connecting freestanding shacks to electricity. Understanding how energy fuel types and energy mix are used in the different housing structures will further provide insights into the overall consumption at household level (n-1) and the community level (n).

#### 4.6.1 *Energy metabolic pattern: RDP homes without backyard shacks*

Majority of RDP homes either consist of one or more backyard shack. Although having access to electricity, many still rely on different energy mix for the various energy services. An average household living in this building structure spends 202 Rand monthly on electricity.

Table 4-5 presents the responses on energy consumption from the above building structures respondents. Electricity remains the predominately-used energy fuel in this housing structures, where having connection to the electricity grid is not determined by the housing structure. One interesting thing about this housing structure is that, although they have electricity connections, the households consume different energy mix for the household energy services. The consumption of paraffin in households is not an effect of the housing structures, but of other factors such as affordability and availability. Paraffin is the dominantly used fuel for space heating (70.0%) with 10.0% from the sampled households not having space-heating appliances in their homes.

Electricity is majorly used, whether alone or combined with other fuel types, for energy services. Owing to energy fuel cost and low-income, many are still using other energy fuel types for the various energy services (with their choices based on affordability, thereby moving beyond just accessibility). Whereas these energy fuels are, non-sustainable as they are sources of GHG emission and are dangerous (being sources of health related diseases, fire, death etc.).

Table 4-5: Energy consumption pattern: RDP homes (without backyard shack)


Source: Own data (See Appendix F)

### 4.6.2 *Energy metabolic pattern: RDP homes with backyard shacks*

This housing structure type usually has the presence of one or more backyard shacks on its premises (with this housing structure having an average of three (3) backyard shacks). The presence of the backyard shacks presents a different consumption pattern in terms of their flow (both energy and money). For example, an RDP homeowner with at least one backyard shack resident collects rent for the space occupied by this shack monthly as well as money for utilities (e.g. water and electricity).

The presence of the shacks facilitates the continuous growth in the population of urban informal settlement because of urbanization. Many of these residents migrate from other provinces and municipalities in search of:

- Employment
- Improved living standards; this might be very different based on how some of the residents live in a poor state. Majority of urban informal settlement dwellers, derive other opportunities from the community and the surrounding urban areas
- Education
- Access to basic government services.

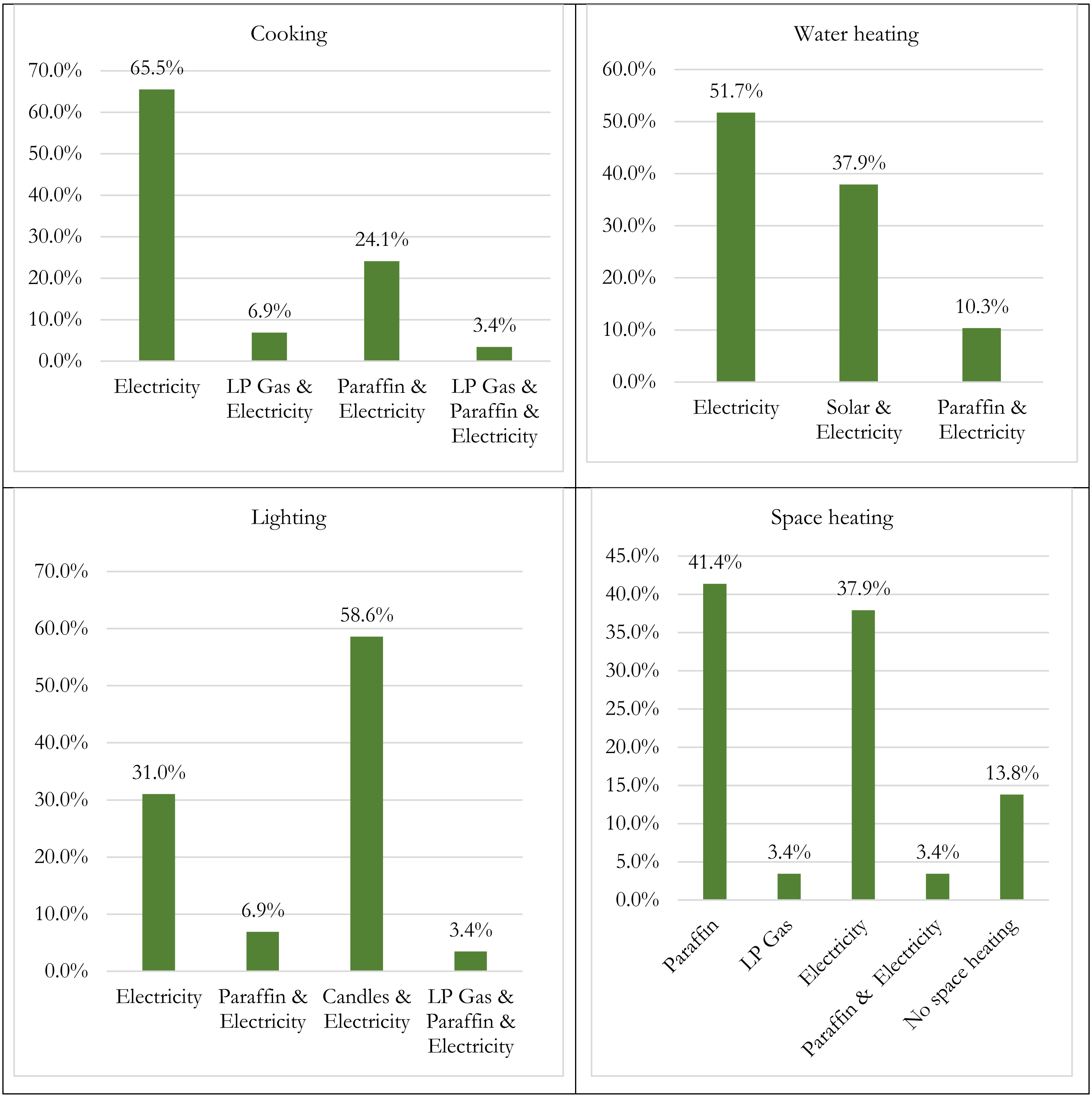
The average household composition for these housing structures is 3 Adults 1 Child. In terms of their energy flow, majority of the household still rely on different energy mix for cooking, lighting, space and water heating as well as for their electrical appliances. An average households living in this building structure spends 436 Rand monthly on electricity. This is rather expensive and can be attributed to the presence of unmetered indirect connections, as this situation does not reveal the actual amount spent monthly on electricity in households in this building structure. Such n arrangement presents a challenge when seeking to understand electricity use in this building structure. The consumption patterns in such building structures can be understood by analysing each structures and household profile.

Table 4-6 presents a capture of household energy consumption in an RDP homes with one or more shacks at the back of the houses

One important feature of households having these structures is that majority are fitted with a rooftop solar panel (as water heating geyser), as seen from their responses for water heating (table 4-6) where 37.9% combine both solar and electricity for water heating. This might present a small shift towards the use of renewable energy for household energy services. Some households with these appliances opt out of making use of them, which might be the reason for the low response as majority of the households' still use electricity for water heating (51.7%). Others combine paraffin and electricity (10.3%), the latter response might be due to unavailability of the solar water heating system.

With regard to the above situation, Kovacic et al. (2016) argue that deploying solar panels only reduces the issue of electricity access to technical problems and the urban informal settlement understanding to only about its physical characteristics, thereby failing to challenge the political and social order by which poverty and marginalisation are created in such settlements. This may explain why households with access to electricity combine or use alternative energy fuel types for their household energy services.

Table 4-6: Energy consumption pattern: RDP homes (with backyard shack)




Source: Own data (See Appendix F)

### 4.6.3 *Energy metabolic pattern: Backyard shacks*

The larger percentage of indirect electricity connection users are from the informal dwellings. This indicates how population and growth in the informal settlement, having led to the proliferation of shacks, is a factor that has led to the high rate of illegal or indirect electricity users in urban informal settlements. Majority of the households' residents of backyard shacks are mainly indirect connection electricity users, as this type of housing structures fall under the informal dwelling type category, which are not included in the architectural and demographic plan of the settlements. This makes the household residents of these housing structures more dependent on dangerous and risky energy fuel types e.g. candles and paraffin.

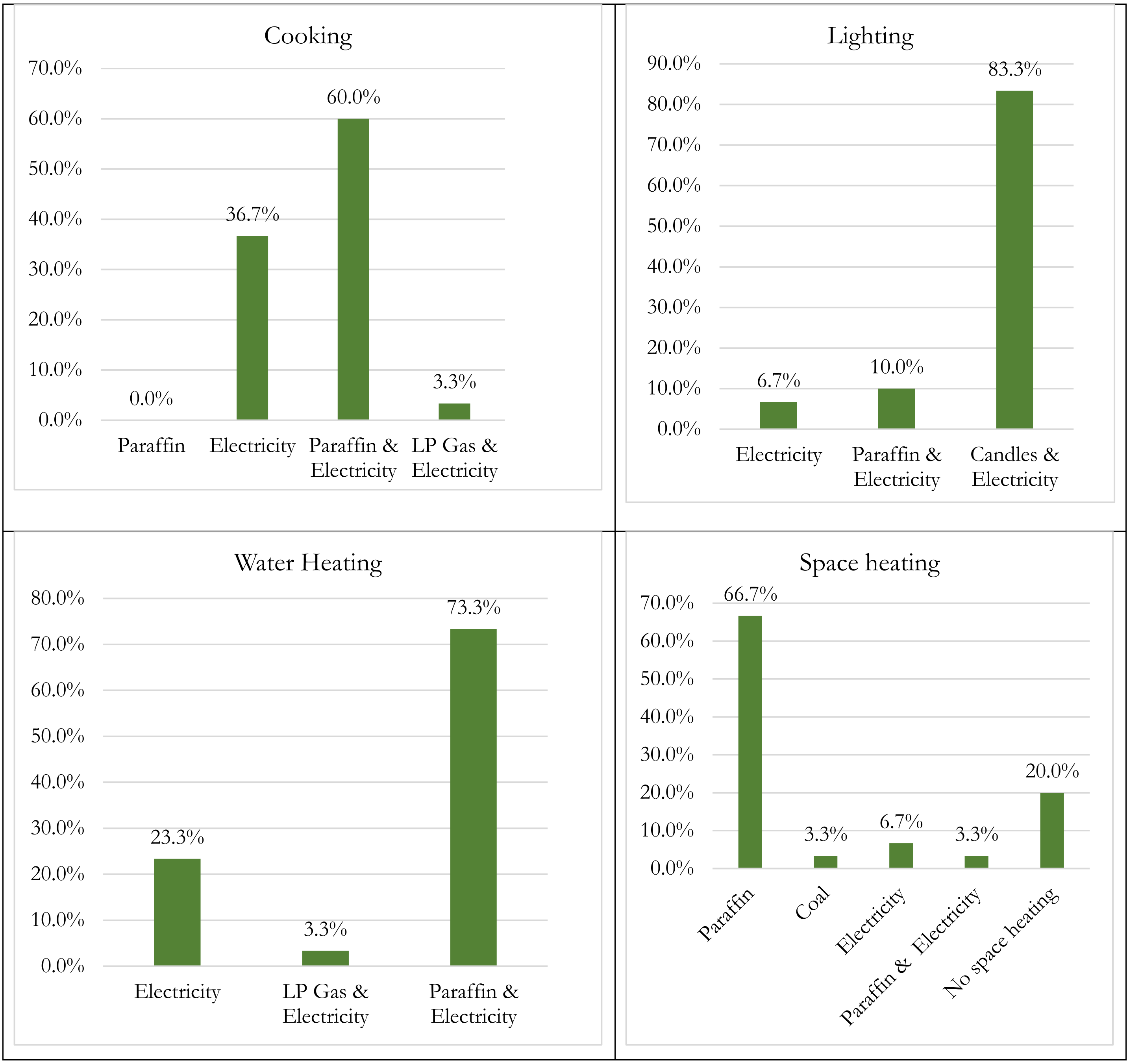
On average, the households' residents spend 170 Rand monthly for electricity, which is rather very expensive when compared to those households with direct electricity connection, even though the average household composition for this structure comprises of 2 Adults 1 Child.

The high electricity cost might be attributed to those using electricity to cook (table 4-7, shows that 36.7% from the households of the sampled population cook with electricity, with 60.0% cooking with both electricity and paraffin and 3.3% cooking with gas and electricity).

Other factors that might be the cause of high electricity cost will be in the use of appliances. The households use electricity for their appliances. Examples of households' appliances from the households of the sampled population included electric stoves, paraffin stoves, washing machines, televisions, home theatres, DVDs, DSTV cables, fridges, iron, hair dryers, microwaves and cell phones.

Table 4-7 presents the households energy profile and consumption patterns for their different energy services.

Table 4-7: Energy consumption pattern: Backyard shacks




Source: Own data (See Appendix F)

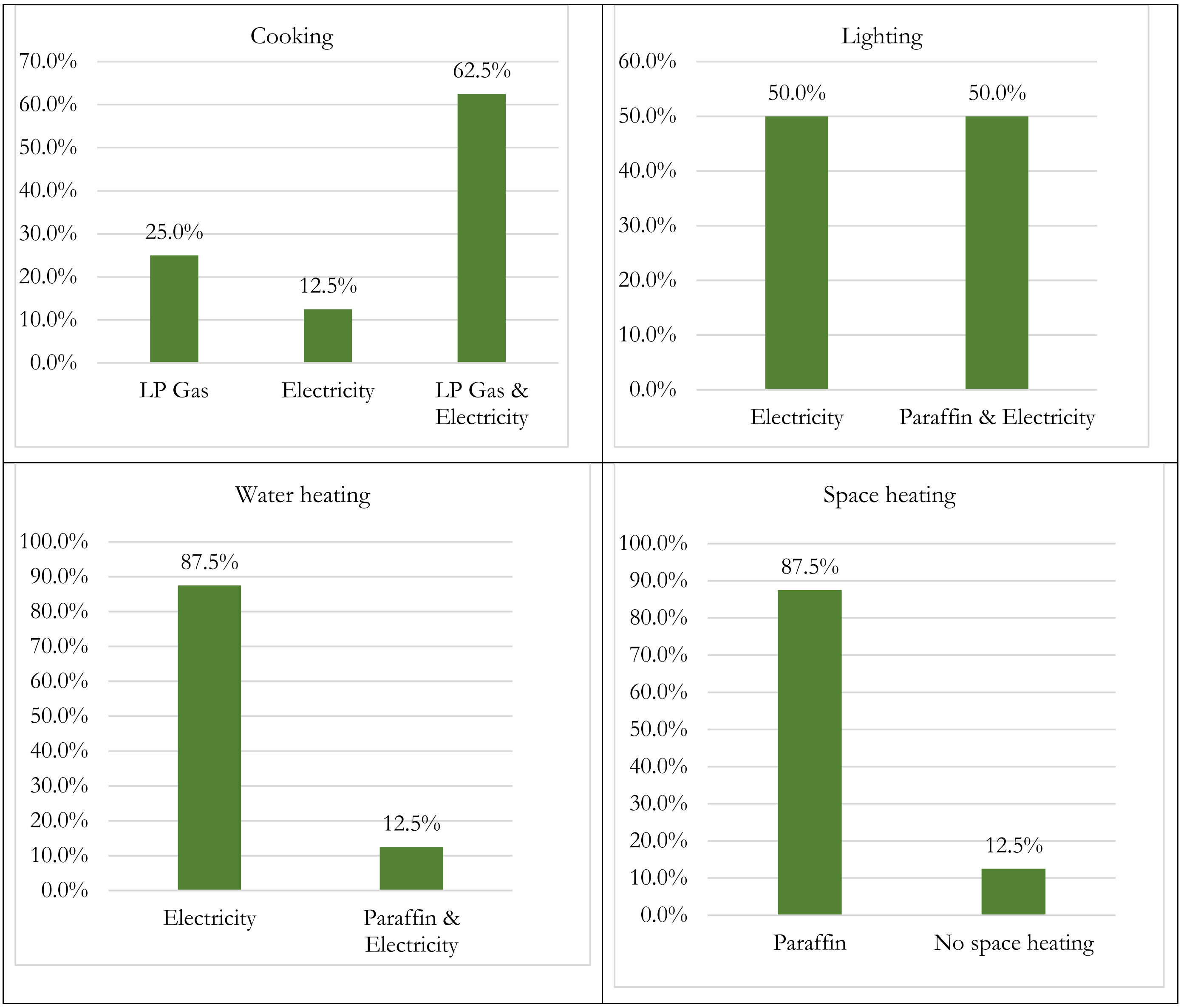
### 4.6.4 *Energy metabolic pattern: Hostels*

For hostels, majority of the households are direct electricity users via the municipality, while only one household respondent from the sampled population indicated indirect electricity connections. The responses from the sampled population provided insights into this type of structure, energy consumption profile. On average, the households' resident spends 238 Rand monthly for electricity, whereas the average household composition for this structure comprises of 2 Adults

Additionally, majority of household respondents from the sampled population indicated gas and electricity for cooking. 50% of households use electricity for lighting, although part of that percentage still combines it with paraffin. Here, paraffin remains the predominately consumed fuel for space heating (87.5%).

Table 4-8, presents the households energy profile and consumption patterns for the different energy services.

Table 4-8: Energy consumption pattern: Hostels




Source: Own data (See Appendix F)

### 4.6.5 *Energy metabolic pattern: Municipal flats*

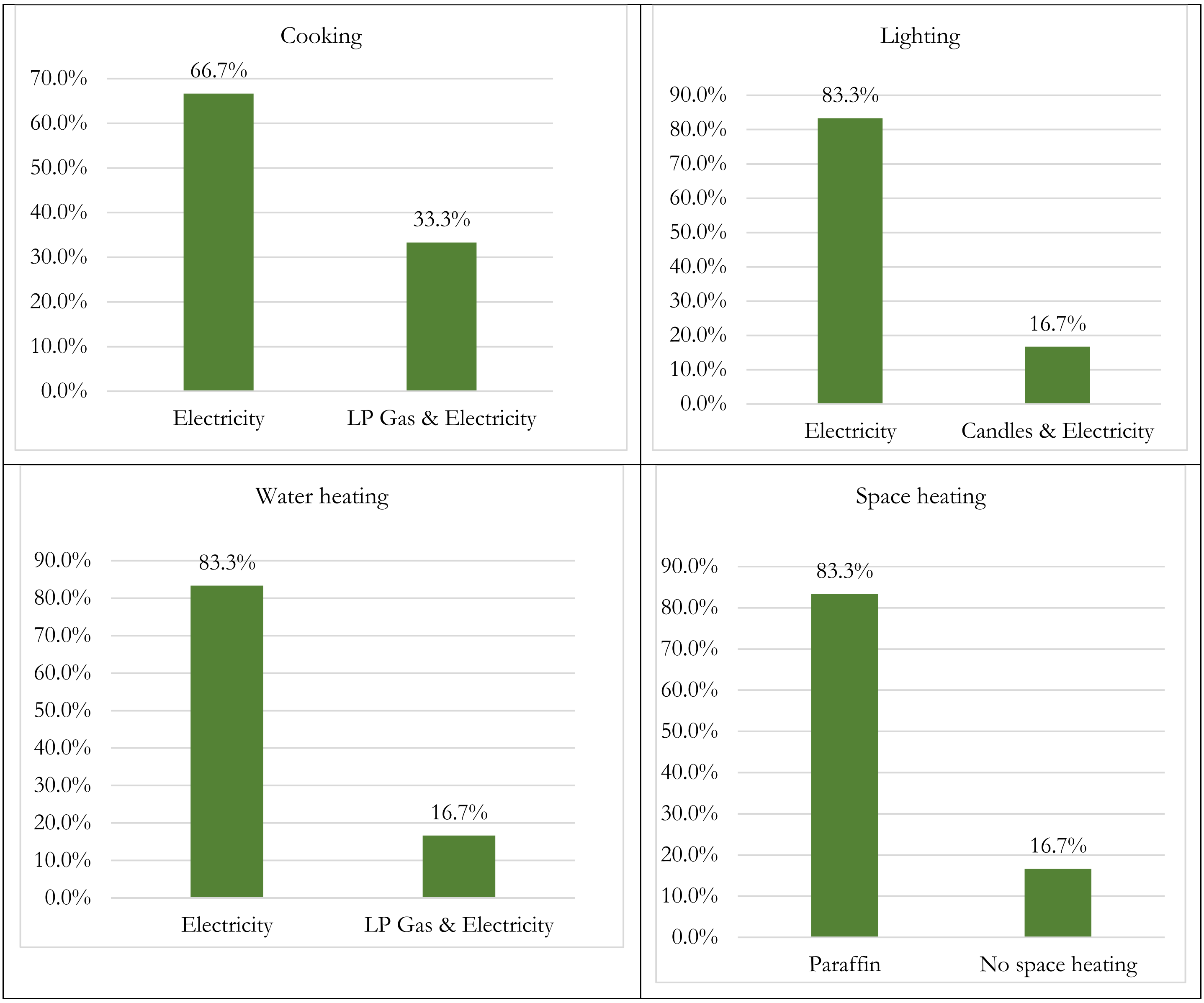
For municipal flats, the households are direct electricity users via the municipality, giving the residents better energy access. However, the respondents from the sampled population provided insights into this type of structure's energy consumption profile. The average electricity cost is 225 Rand monthly, which can be attributed to the majority of household appliances present in the households while the average household composition for this structure comprises of 1 Adult 1 Child.

The provision of electricity to the housing structures did not stop the use of other energy fuel types. As seen in the case of the energy fuel types used for space heating where 83.3% indicated paraffin as the energy source for space heating, with the remaining 16.7% indicating no appliance used for space heating. This indicates that electricity is still not the reliable source of energy for the households to heating their homes, and is mainly attributable to:

- Increased rate of consumption, e.g. an electric heater, which consumes between 1800 - 2000 watts of electricity on average;
- Cost of electric heater, or
- Other unknown factors

While electricity is still the commonly used energy fuel type for cooking (66.7%), other household respondents indicated a combination of both electricity and gas (33.3%), as shown in Table 4-9. The table presents the households' energy profile and consumption patterns for the different energy services. Average municipal flats households consist of the following appliances: 60 watts bulb (4), either or both gas stove and electric stove, electric kettle, television, home theatre system, AC radio, fridge, iron, microwave and cell phones.

Table 4-9: Energy consumption pattern: Municipal flats




### 4.6.6 *Energy metabolic pattern: Freestanding shacks*

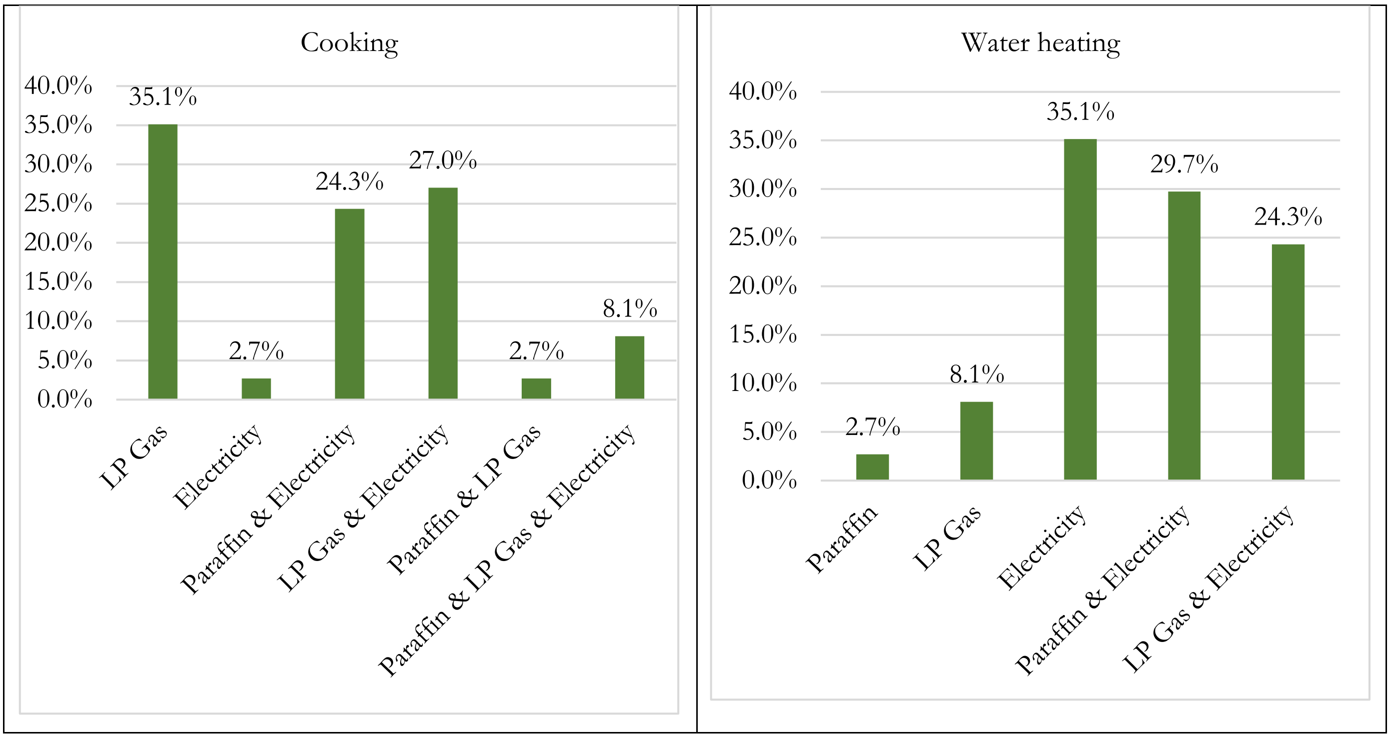
Majority of households with these housing structure are connected to electricity via the municipality (62.2% of the households' respondent from the sampled population), while the others are either indirect connection users (18.9%) or solar electric system users (2.5%). Between the direct and indirect electricity users, however, there is a slight difference in the cost of electricity, with direct and indirect users spending on average 251 and 241 Rand per month respectively. The average household composition in this housing structure comprises of 3 Adults, which has an effect on the overall energy consumption of the households.

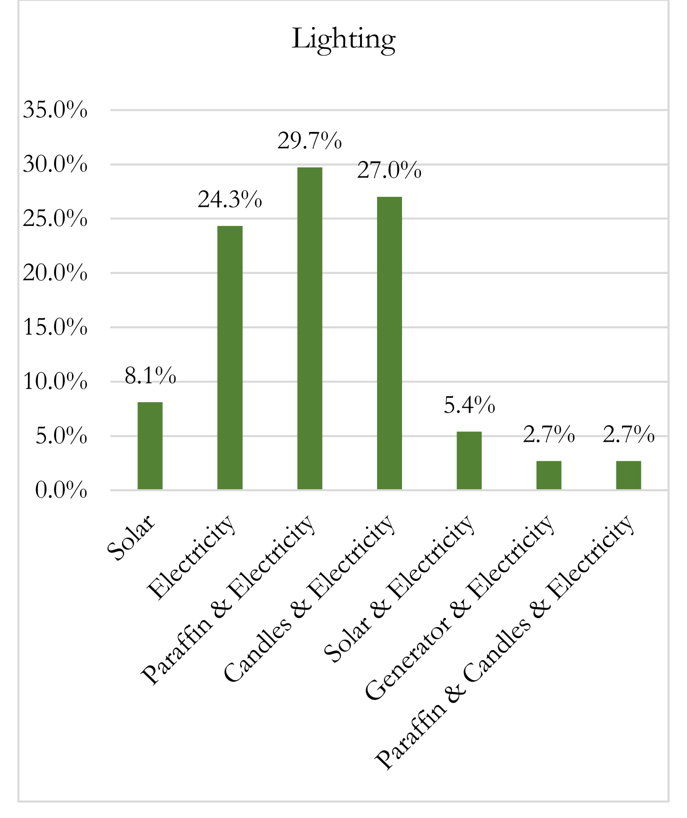
Households in these housing structures use different types of energy fuel for cooking, with gas accounting for the highest proportion (35.1%), while others combine both gas and electricity together (27.0%). An interesting finding was the use of paraffin for cooking, which is mostly combined with electricity (24.3%) or gas (2.7%). Other trends discovered are shown in table 4-10.

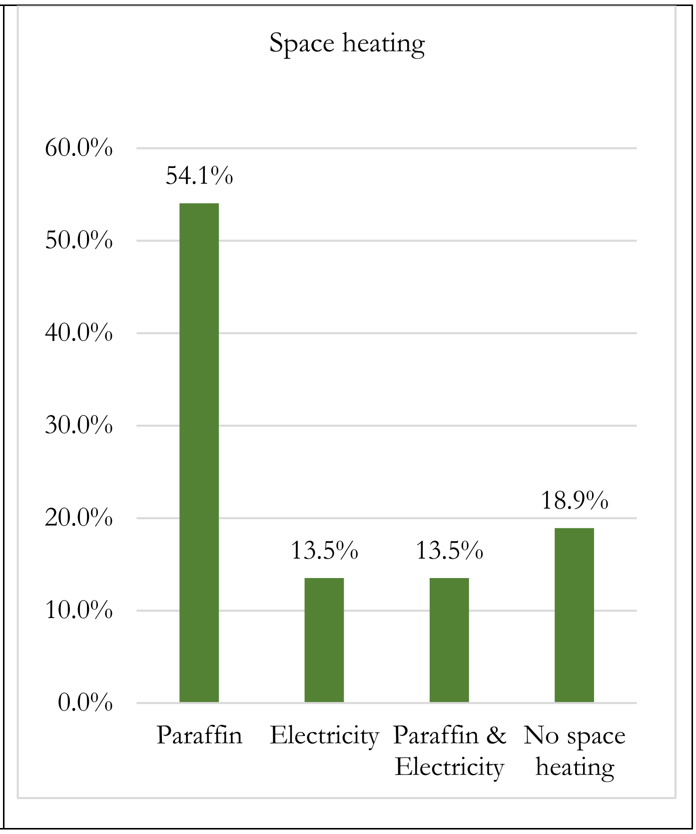
One other important trend is in the use of paraffin for space heating, with highest proportion of household respondent of 54.1%, and those with no space heating appliances standing at 18.9%. Electricity only accounted for 13.5%.

For lighting, households' respondent indicated different combination of fuels for lighting their homes. Table 4-10 presents the households energy profile and consumption patterns for the different energy services.

Table 4-10: Energy consumption pattern: Freestanding shacks






Source: Own data (See Appendix F)

### 4.7 Multiple hierarchical level of metabolic patterns

Applying societal metabolism approach to analyse the demand and consumption of informal settlement provides the possibility of establishing sets of quantitative benchmarks by using identified projected states in their metabolic pattern. Specifically, the differences in their flow types and quantities are ascribed to the differences in funds. Analysing from the point of societal metabolism shows that energy consumption is not only based on the general needs of the households, but is attributed to several factors at various levels of hierarchy; either at the whole society level, household level, or various sectors of the society level.

The overall energy demand is dependent on the household composition and different number of instances for each of the household types. It is also the case that the overall energy throughput depends on the existence of governance arrangement and infrastructures already established at the community or settlement level.

Kovacic et al. (2016), suggest that although different informal settlement possess various and different characteristics from each other, it is possible to observe trends that favour electricity consumption over other energy fuel types (e.g. paraffin and gas). As seen in the Kayamandi case study, for their space heating, paraffin remains the most used energy fuel type. However, energy demand estimates are obtainable by analysing the informal settlements characteristics based on their building structures and expected indicators.

When analysing urban informal settlements by considering them as whole systems or at just one level of analysis, the richness and complexities of information required to describe their energy evolution is lacking. With regard to estimating energy demand in informal settlement households, it is necessary to take into consideration the different cost of energy fuel types. For example, the price of paraffin does vary between 10 and 11 Rand (depending on whether it is bought in Spaza shops in the settlement or in town), In winter, however, the prices skyrocket (as it remains the main source of energy for space heating). In addition, the differences in the quality of service need to be taken into account; an example is the solar electric system and/or those with solar rooftop panels, which depends on weather, with limited capacity and electricity supplied from the grid, the more stable source of energy with very high capacity.

## 4.8 Comparative synthesis of the energy metabolic pattern of a multi-structured informal settlement

With respect to the Research Objective 3, which is to determine the overall energy consumption of the different household profiles for the multiple structures in the case study, it is important to analyse and understand the different metabolic patterns related to the multi-structured urban informal settlement as this provides insights into the following:

i. The consumption pattern differences based on their household composition;
ii. The changes in energy profiles when the household composition are analysed based on the housing structures.

This section, therefore, provides the results on the different metabolic patterns and consumption rates based on the following:

- Total energy consumption for the different household composition and their building structures (typology) present in an urban informal settlement.

As stated earlier in the previous section 4.6, analysis was provided on the consumption pattern for the different housing structures by analysing it in terms of percentages of the overall population sample of the community. Here, the analysis is provided at household level (n-1) based on individual total household consumption.

Understanding the different patterns of consumption for the different household types and housing structures provides a way of understanding the flow pattern in an informal settlement and how each household manage their consumption (input) based on the demands of each occupant (i.e. their input).

### 4.8.1 *Energy consumption by building structures*

This section provides the analysis on the energy consumption difference between the different building structures in Kayamandi informal settlement. Table 4-11 presents the median energy consumption for the different building structures present in an urban informal settlement (from the sampled population).

Table 4-11: Consumption analysis of different building typology[12]

| Building structures | Electricity consumption per month (kw/hr) | Gas usage per month (kg) | Paraffin usage per month (litres) |
|---|---|---|---|
| Free Standing Shack | 243.7 | 5 | 8 |
| Municipal Flats | 310.3 | 0 | 12 |
| Hostels | 255.3 | 5 | 12 |
| Backyard shacks | 411.8 | 0 | 8 |
| RDP (with backyard shacks) | 607.9 | 0 | 12 |
| RDP (without backyard shacks) | 286.8 | 5 | 10 |

The households with the lowest consumption rate for their electricity, are those found in a freestanding shacks (at 243.7 kw/hr), while those with the highest consumption rate (at 607.9 kw/hr) are those living in an RDP house (with a backyard shack) (at least 1 shack is on the RDP premises).

It can be argued that this very high electricity consumption rate is due to the presence of shacks connected indirectly to the households, where shack dwellers pay directly to the households with the connection meter for their electricity. This change in connection will affect how electricity is consumed by both building structures sharing one meter.

In addition, it was observed that on their monthly gas consumption, the household usage varies across the different household profiles. This variance can mostly be attributed to the difference

[12] Data calculated was based on the overall household's median per each building structures.

household needs monthly (i.e. usage based on their household activities and hours of use). Most households consume 5kgs of gas monthly across the different building structure (50% of the building), while the other 50% shows households in building structures who have no option of gas as part of the energy fuel types used in their households.

From households living in building structures (such as municipal flats, backyard shacks and RDP with backyard shacks) who opt out of using gas have the highest rate of consumption on paraffin averaging 12 litres per month.

This shows that although households across the different building structures consume electricity monthly, they also use other energy fuel types for their different household activities. In this regard, 'energy fuel cost' plays a major role in how informal settlement households use and manage their energy consumption. As discussed in the previous section 4.5 on results obtained based on energy consumption by their household activities, the main uses of gas in households are for cooking, with very low percentage opting for its use for heating their home space. While paraffin is also opted for cooking, majority of the households use it as their space heating option.

### 4.8.2 *Energy consumption by household type or composition*

This section provides the analysis on the energy consumption difference between the different:

i. household composition
ii. household composition of the different building structures in Kayamandi informal settlement

#### 4.8.2.1 *Freestanding shacks*

The results show that different household profiles exhibit different consumption patterns in freestanding shacks (see Table 4-12):

Table 4-12: Describes the energy consumption pattern for HH types in freestanding shacks

| Building structure | HH Type | Median monthly usage (Kw/hr) | Median monthly usage (kg) | Median monthly usage (litres) |
|---|---|---|---|---|
| Freestanding shacks | 1 Adult | 149.2 | 5.0 | 0.0 |
| | 1 Adult; 1 Child | 0.1 | 5.0 | 0.0 |
| | 1 Adult; 1 Senior | 166.5 | 5.0 | 0.0 |
| | 1 Adult; 1 Senior; 3 Child | 440.9 | 9.0 | 12.0 |
| | 1 Adults; 2 Senior | 450.4 | 0.0 | 8.0 |
| | 2 Adults | 246.7 | 5.0 | 14.0 |
| | 2 Adults; 1 Child | 248.6 | 5.0 | 12.0 |
| | 2 Adults; 1 Senior | 213.9 | 2.5 | 18.0 |
| | 2 Adults; 1 Senior; 1 Child | 330.1 | 3.0 | 12.0 |
| | 2 Adults; 2 Senior | 332.8 | 9.0 | 40.0 |
| | 2 Adults; 3 Senior; 1 Child | 115.1 | 3.0 | 8.0 |
| | 3 Adults | 382.6 | 5.0 | 5.0 |
| | 3 Adults; 1 Child | 482.0 | 0.0 | 8.0 |
| | 3 Adults; 1 Senior | 405.4 | 0.0 | 20.0 |
| | 3 Adults; 1 Senior; 1 Child | 500.9 | 2.5 | 10.0 |

A comparison of the households with the lowest and highest profiles presents the following observations: (i) 1 Adults household in a freestanding shack has the energy consumption pattern; (ii.) While a 3 Senior; 1 Senior; 1 Child household has the energy consumption pattern as seen in the table above. From these two comparisons, it is observable that their energy consumption difference is mainly relative to electricity with a high consumption difference of 351.7 kw/hr monthly.

This indicates that the changes evident in the energy consumption result from the household composition as there is an increase in consumption as the household profile changes. However, this argument might not hold in all instances where the household consumes less with an increasing HH composition. This argument is only based on one instance (where this household type only appeared once among freestanding shacks dwellers) but it provides more insight into how household energy consumption can be based on several factors affecting their choice of energy fuel and consumption pattern. This is one benefit of MuSIASEM approach as it provides detailed information into energy metabolic patterns by analysing different trends at various scale of analysis. Support for this argument is seen in the example of households with 2 Adults; 3 Senior; 1 Child with a consumption pattern which indicates that impact on household consumption in a freestanding shack is not only based on their household composition but also the types of household appliances present in the households. Here, households having appliances with high power rating, (in watts) consume more electricity when used, given the number of hours of use monthly.

One notable observation from the household type (HH) is from households using an energy mix of both electricity and gas as their fuel source. The households are among those with few household residents. For example, a 1 Adult 1 Senior household with electricity and gas consumption both have 166.5 kw/hr and 5 kg per month respectively. In the case of household with very high electricity consumption, although gas and paraffin are still consumed for different household activities, then, the types and number of household appliances requires consideration when comparing their consumption pattern with households of more single adults living together.

#### 4.8.2.2 *RDP with backyard shacks*

A RDP building typology presents a different consumption pattern from that of a freestanding shack despite both having a direct connection to the electricity, although the freestanding shacks are informal building structures.

In reference to table 4-13, the following observations can be made on the total energy consumption (electricity, gas and paraffin) across the different household types in an RDP with backyard shacks building structure:

- 92.9% of the household type of households living in RDP with backyard structure used both paraffin and electricity as their energy fuel choice;

- 7.1% (this percentage reflects only 1 household type; 3 Adults; 3 Senior across the sampled population) are using both gas and electricity.

Table 4-13: Describes the energy consumption pattern for HH types in RDP with backyard shacks

| Building structure | HH Type | Electricity consumption monthly (kw/hr) | Gas consumption monthly (kg) | Paraffin consumption monthly (litres) |
|---|---|---|---|---|
| RDP (with backyard shacks | 1 Adult; 1 Child | 413.352 | 0 | 20 |
| | 1 Adult; 1 Senior | 428.382 | 0 | 4 |
| | 1 Adults; 2 Senior; 1 Child | 330.784 | 0 | 16 |
| | 2 Adults | 618.564 | 0 | 4 |
| | 2 Adults; 1 Child | 450.866 | 0 | 12 |
| | 2 Adults; 1 Senior; 1 Child | 674.072 | 0 | 8 |
| | 2 Adults; 1 Senior; 2 Child | 672.504 | 0 | 8 |
| | 2 Adults; 1 Senior; 3 Child | 657.968 | 0 | 16 |
| | 2 Adults; 2 Senior; 2 Child | 777.576 | 0 | 16 |
| | 3 Adults | 797.232 | 0 | 10 |
| | 3 Adults; 1 Senior | 446.428 | 0 | 12 |
| | 3 Adults; 1 Senior; 2 Child | 650.104 | 0 | 20 |
| | 3 Adults; 3 Senior | 593.2 | 5 | 0 |
| | 4 Adults | 969.54 | 0 | 16 |

Although all RDP (with backyard shacks) are formal housing with direct electricity connections, these households are seen to still rely on different energy mix for their household activities, which can be attributed to the quantity of energy required to meet all household energy needs. In addition, majority of these households prefer to combine with others to reduce their electricity cost at the end of the month. However, electricity is the only used fuel for running household appliances, water heating and lighting. It is also the case that energy fuel choice for activities such as cooking and space heating are dependent on the household energy fuel preference.

Similarly, the results presented from the different household profiles exhibit different consumption pattern in RDP (with backyard shacks). Comparing their different rates of consumptions presents the following:

- RDP with backyard shacks have generally high energy consumption rate (for their electricity), with the least seen in figure 4-28 as 330.8 kw/hr and the highest as 969.5 kw/hr monthly.

- Majority of the households across the different household profiles consume less to none on gas, with only one household type (3 Adults; 3 Senior) as the only household profile using gas (5kg) monthly, with an electricity consumption of 593.2 kw/hr.

- Paraffin usage monthly is that consumption of these energy fuel type varies across the different household profiles, with consumption not being a determinant of the different household profiles, but might be attributed to household choices and needs in these household profiles. An example can be drawn from household type of 1 Adult; 1 Child with an electricity consumption rate of 413.4 kw/hr monthly using 20 litres of paraffin per month, while household with 4 Adults having an electricity consumption rate of 969.5 kw/hr consuming 16 litres of paraffin per month.

The above general observations from the results show that household type mainly contribute to the rate of household consumption on their electricity, but with no impact on how the household use gas or paraffin. Looking at the overall consumption across the different energy fuel type for each household profile, however, one can make the argument that household type is one determining factor on the total energy consumption for households based on their household profiles in RDP with backyard shacks.

This might require further investigation by analysing the energy consumption pattern in an RDP housing by examining each shack present on their premises, as well as every other indirect connection to the buildings and how this affects the overall rate of electricity consumption for the household types.

#### 4.8.2.3 *Backyard shacks*

Backyard shacks building typology presents different consumption patterns, as they are informal housing structures, with indirect connection to the RDP house where they are located. Table 4-14 describes the different energy consumption patterns across the various household profiles in backyard shacks.

Table 4-14: Describes the energy consumption pattern for HH types in backyard shacks

| Building structure | HH Type | Electricity consumption monthly (kw/hr) | Gas consumption monthly (kg) | Paraffin consumption monthly (litres) |
|---|---|---|---|---|
| Backyard shacks | 1 Adult | 326.894 | 0 | 8 |
| | 1 Adult; 1 Child | 451.724 | 0 | 8 |
| | 1 Adult; 1 Senior | 414.71 | 0 | 8 |
| | 1 Adult; 1 Senior; 1 Child | 415.976 | 0 | 12 |
| | 1 Adult; 1 Senior; 2 Child | 378.022 | 0 | 6 |
| | 2 Adults | 413.452 | 0 | 12 |
| | 2 Adults; 1 Child | 421.63 | 0 | 8 |
| | 3 Adults; 1 Senior; 2 Child | 367.772 | 0 | 8 |
| | 3 Adults; 2 Child | 509.124 | 0 | 12 |
| | 4 Adults; 1 Child | 728.48 | 0 | 8 |

The following observations were made from the results on analysis of energy consumption by household profile in backyard shacks:

- By using the median of the different energy consumption across instances for the household profile, households in backyard shacks generally do not use gas as an option for their energy fuel.

- From their electricity consumption, the households rates differ from each other based on their household profile. An example is from households of 1 Adults rate of electricity consumption calculated as 326.9 kw/hr, while that of a 4 Adults; 1 Child households rate of electricity consumption is as high as 728.5 kw/hr, with a difference in consumption of a very high 401.6 kw/hr.

- In the case of paraffin, the same observation as seen in household types for RDP (with backyard shacks) also holds where paraffin use is generally as a result on household choices and energy needs and not subjected to the household profile and/or building structures. Households in backyard shacks generally use paraffin in heating their home space.

In general, apart from examining each backyard shacks household type, also investigating them as an indirect connection household can further provide insights into the overall energy consumption when analysing the informal settlement at the community level (n) using MuSIASEM. This will be useful information to decision makers planning for upgrade and implementation of infrastructure for the settlement.

#### 4.8.2.4 *RDP (without backyard shacks)*

This type of building typology presents a different consumption pattern across the different household profile. Table 4-15 describes the different energy consumption patterns across the various household profiles in RDP houses without the presence of any backyard shacks.

Table 4-15: Describes the energy consumption pattern for HH types in RDP (stand-alone)

| Building structure | HH Type | Electricity consumption monthly (kw/hr) | Gas consumption monthly (kg) | Paraffin consumption monthly (litres) |
|---|---|---|---|---|
| RDP (without backyard shacks) | 1 Adult | 252.5 | 2.5 | 10 |
| | 2 Adults | 899.2 | 0 | 0 |
| | 2 Adults; 1 Child | 5798.3 | 9 | 5 |
| | 2 Adults; 1 Senior | 171.5 | 5 | 8 |
| | 3 Adults | 244.1 | 5 | 12 |
| | 5 Adults; 1 Senior; 1 Child | 1123.7 | 5 | 12 |

The following observations were made from the results on analysis of energy consumption by household profile in RDP (without backyard shacks):

- Households generally have high-energy consumption across the different household profiles.

- The household with 2 Adult; 1 Child has a very high monthly energy consumption of 5798.3 kw/hr; 9 kg; 5 litres for electricity, gas and paraffin respectively, while a 2 Adult; 1 senior household has an energy consumption pattern of 171.5 kw/hr; 5 kg; 8 litres monthly. This might also be traceable to indirect connections, where although these building structures are stand-alone, they do not limit them from being a supply source to other households.

#### 4.8.2.5 *Municipal flats*

Households living in municipal flats generally have different types of household composition (as seen in Table 4-16). In order to analyse their energy consumption, the median of each household type was calculated.

Table 4-16: Describes the energy consumption pattern for the HH types in Municipal flats

| Building structure | HH Type | Electricity consumption monthly (kw/hr) | Gas consumption monthly (kg) | Paraffin consumption monthly (litres) |
|---|---|---|---|---|
| Municipal Flats | 1 Adult | 278.7 | 0 | 8 |
| | 1 Adult; 1 Child | 691.5 | 0 | 12 |
| | 2 Adults | 205.1 | 5 | 12 |
| | 2 Adults; 2 Child | 342.0 | 5 | 16 |

The following observations were made from the results on analysis of energy consumption by household profile in municipal flats:

- The sampled population in the data only covered 10 municipal flats (which indicate 1 municipal flat can be found among other building structures types).

- Observed trend among the household types of this building structure is that, there is no much difference in their electricity consumption patterns one from another, thus, arguments based on increase in household types become invalid. As the household profile with the highest monthly electricity consumption comprises of 1 Adult 1 Child (at 691.5 kw/hr), while household type of 2 Adults; and 2 Adults 2 Child have an electricity consumption of 205.1 kw/hr and 342.0 kw/hr respectively.

- The above observation differs with their gas and paraffin usage, with a 1 Adult household averaging 8 litres monthly while a 2 Adults; 2 Child averages 16 litres monthly. In the case of gas use across the household types monthly, only 2 Adults, and 2 Adults 2 Child household mostly use 5 kg of gas monthly as well as other energy fuel type in their households.

This may also relate to the types of appliances present in the households as well as the household activities of the different household types, determining how much electricity is consumed in the households.

#### 4.8.2.6 *Hostels*

Households living in hostel type of building structure generally have different types of household composition (as seen in Table 4-17). In order to analyse their energy consumption, the median of each household type was calculated.

Table 4-17: Describes the energy consumption pattern for the HH types in Hostels

| Building structure | HH Type | Electricity consumption monthly (kw/hr) | Gas consumption monthly (kg) | Paraffin consumption monthly (litres) |
|---|---|---|---|---|
| | 1 Adult | 209.8 | 5 | 12 |
| | 2 Adults | 294.0 | 5 | 12 |
| | 2 Adults; 1 Senior | 262.4 | 5 | 16 |
| Hostels | 2 Adults; 1 Senior; 1 Child | 746.1 | 5 | 12 |

The following observations were made from the results on analysis of energy consumption by household profile in hostels:

- Gas use across the different household profiles in hostels is the same at 5kgs monthly

- The use of paraffin across the different household profiles averages 14 litres monthly. Here, the household type has no impact on the quantity of paraffin purchased in a particular household monthly.

- Electricity monthly consumption rate graph is skewed, where for 1 Adult, 2 Adults, and 2 Adults; 1 Senior are almost the same at 209.8 kw/hr, 294.0 kw/hr, and 262.4 kw/hr respectively. For household with 2 Adults; 1 Senior; 1 Child, there was a spike in their monthly electricity consumption at 736.1 kw/hr.

From the above observations, it could be deduced that:

- Household types might only play a part in the overall household consumption when estimated based on total of all the energy fuel types used in the household.

### 4.9 Summary

This chapter 4 has presented the results of the study by indicating the overall energy consumption pattern and behaviour of a hybrid multi-structured urban informal settlement as well as factors that contribute to this consumption pattern by providing an analysis at different hierarchical levels of the settlement.

Based on the research objectives and the results arising from this investigation, it is clear that understanding the energy consumption pattern require insights into the societal metabolism of urban informal settlement and their connection to the wider urban system. Thus, moving beyond providing their characteristics only in terms of their physical and legal characteristics but considers different scale of analysis of the settlement.

The consumption pattern and energy fuel type used were depicted as varying dramatically by households' respondents as well as other instances. Several mechanisms of support were identified which pertains to different organisational levels, indicating that there are possibilities available for connecting urban informal settlement activities to the wider urban cities in which they are present.

The chapter analysed the results from the survey carried out in Kayamandi informal settlement, providing both qualitative and quantitative analysis and discussion on the following:

i. Housing structures
ii. Household composition and their population structure
iii. Energy access and consumption pattern
iv. Metabolised flow of the settlement: energy and money flow
v. Energy profile based on their different housing structures
vi. Energy profile based on household composition of the different housing structures

The results presented the flows of the community in a way in which both the flows and funds elements are combined to characterise the metabolic profile of societies. The analysis of the relationships existing between energy, materials and socio-economic variables, as human time, demography and economic elements, provide information about the way in which societies evolve and self-organise.

Chapter 5 provides the conclusion of the study by highlighting the significance of a holistic approach, and understanding of urban informal settlement functionality, as well as how they connect with the wider urban system. The chapter also describes the contribution of the study and the implications for policy planning and implementation, strategies required for sustainable consumption behaviour in informal settlement households as well as recommendations and suggestion for future research.

# Chapter 5 Conclusion and recommendations

This chapter highlights and synthesis of the key findings from the study. The objectives of the study were:

1 To describe the multiple household structures in an urban informal settlement, using a specific case study;
2 To examine the energy flows in the multiple housing structures in the case study; and
3 To examine the energy consumption of different household profiles for the multiple structures in the case study.

## 5.1 Multiple household structures in urban informal settlements

From the results presented in chapter 4 and from the survey carried, it was discovered that urban informal settlements exhibit various building structures, as seen in the case of Kayamandi informal settlement.

In Kayamandi, the building structures identified were categorised into RDP with backyard shacks, RDP without backyard shacks, freestanding shacks, backyard shacks (which are shacks present at the back of an RDP building), hostels, and municipal flats. It can be argued that when investigating the metabolic patterns of urban informal settlement in the hybrid category, it is essential to differentiate between the different building structures in order to accurately capture their energy and material consumption.

## 5.2 Energy flow in multiple building structures

Investigating the energy consumption patterns in multi-structured urban informal settlement presented the following conclusion:

- High electricity consumption by household can be a result of other connections from other household metered through a single meter box, i.e. as a result of indirect electricity connections as seen in the case of RDP with backyard shacks.

In addition, it was observed that access, affordability and availability of these energy fuels influence the choice of energy fuel type used, which will, in turn, influence their overall energy consumption.

Further, types of appliances used by the household will also determine their rate of consumption irrespective of their building structures.
Some key observations revealed that gas is not a common energy fuel type for households in backyard shacks, which might be attributed to its cost. This indicates that majority of households in these building structures struggle with meeting all of their energy needs due to the high cost thereby resulting to much cheaper, available and dangerous fuels (which may cause air pollution) to meet their household energy needs.

In relation to electricity consumption, the types of household appliances influence the consumption in the households across the different building structures. This indicates that solutions to energy needs and issues of access in urban informal settlements will require understanding the actual energy demand and consumption of households in such settlements and not just about trying to solve the issue of accessibility and/or affordability for the settlement.

Further, education on energy savings and efficiency might be effective if there is the knowledge and information on how households across different building structures consume their energy.

## 5.3 Energy consumption of household profiles

As observed from the results, different households present different household profiles (i.e. in their type or composition); therefore, the difference in household profile will present a different consumption pattern. Thus, it can be argued that investigation into the metabolic pattern and/or energy consumption in a multi-structured urban informal settlement should include analysis of their energy consumption investigating their different household composition and not just based on the number of people in the household.

In addition, an increase in household profile will change the household electricity consumption pattern. However, in other fuel types such as gas and paraffin, consumption might necessarily change not only depending on household composition, but also depending on the choice of the households such as availability and affordability, as well as the type of household activities in which the fuel is used.

### 5.4 Overall study

As observed from literature and study on urban informal settlement, there are gaps and limited literature on their energy demand and consumption as well as energy metabolic pattern in terms of the different housing structures present in these settlements. This is one of the reasons why these settlements are mostly excluded in policy planning and decision making towards cities' development. The methodology of the study was designed in such a way that the case study analysed and results obtained will as well inform the literature and information available on urban informal settlement for municipalities, government, policy and energy planners.

The results from the study confirmed the existence of problems faced by urban and peri-urban poor households in South Africa, which are majorly energy related, such as, lack of access to clean energy services as well as ways of dealing with the constraints on electricity consumption, legality of electricity connection, and issue of land tenure, housing and safety. Deficient energy services provided to urban poor areas result in various health related issues from the use of different kinds of energy fuel types. An example is in the use of paraffin and wood particularly during winter for space heating; the illegal electricity connections are mostly the causes of fires in these settlements; low quality of electricity service from these illegal connections, which results in voltage surges, blackout and household equipment damages.

The results can potentially inform various aspects of urban studies such as resilient cities, future urban planning and infrastructural transitioning, informal settlement upgrade and energy policy interventions.

Observed from the results were the different factors contributing to household energy consumption. One of these factors is the impact household composition has on the overall consumption pattern and behaviour as well as the quantity of energy fuel used in a household. Increase in the general population of the community does not necessarily impact on the energy consumed or energy fuel choices present in a household. However, a change in number and instances of a particular household type or composition as well as the combination of energy mix consumed in the household will affect the consumption pattern of these households. The only way of understanding this phenomenon was by analysing data at household level.

It was evident that connection to electrical supply does not imply that the households do not make use of other dangerous and risky fuel types such as kerosene and candles for cooking and lighting respectively. This calls for the need to further investigate why such behaviours are happening and whether the policies of integrated electrification programmes and Free Basic Access are meeting their intended goals.

While majority of the households are connected to the electricity grid (directly or indirectly electrified), affordability, however, remains a general problem. It further shows that connection to electricity does not affect household energy fuel choice and energy mix used for their household energy services. Nevertheless, majority of the electrified households uses electricity for lighting. Many still combine this with other fuel type such as candles and paraffin. A large percentage of the household still relies on the use of non-electric fuel for cooking and heating. An example of this fuel is paraffin. This is seen as a predominately-used fuel for space heating (where housing structures has no effect on this choice). The choice of non-electric fuel for household energy services may be attributed to the higher cost of electrical appliances with majority of the informal settlement low-income households. Other reasons may be that some of the other non-electric energy fuels are:

- freely available e.g. fuel-wood, and solar (in the case of solar water heaters installed on RDP homes rooftops, which are non-paid service),
- the fact that paraffin can be obtained in small quantities (many of the poor households have irregular income)
- easily available

The results further shows that the use of electricity as fuel option for household activities (cooking, lighting, water heating, space heating, and appliances) is less dependent on education, level of income, or even population group. This implies that an improvement in the level of income in a household and the level of education, will alone not lead to a displacement to other renewable energy sources such as solar. At the same time, it is not yet clear what factors have led to the limited use of renewable energy by the households in Kayamandi, particularly solar for lighting. Further investigation will be required to identify the various views for not utilising certain types of fuel.

Overall, the consumption challenges of urban informal settlements not only represent a consumption inequality, but also point to the problems of distributional inequality as well as energy poverty in urban informal settlements.

Arguably, the MuSIASEM approach is an appropriate framework for analysing and understanding the energy metabolism of urban informal settlements. Although this framework was developed initially for its applicability at national level, its significance and applicability is becoming recognised in understanding urban informal settlements. Depending on household categories and population dynamics, the material and energy flow in urban informal settlements can be estimated, and related to the total time required for paid work (PW). This enables the establishment of linkages between households and the whole economy by assessing the human activity labour hours used for paid work (PW) i.e. labour hours.

The MuSIASEM approach makes it possible to study the role of human activity in the stabilization of the metabolic pattern of both rich and poor households. Here, analysis of the fund element human activity does not focus only on economic capital but also on cultural capital—the conditions of reproduction of individuals and households, which is related to a person's education, experience and living conditions from the first years of life. This issue is particularly important because poor people do not have access to the economic resources required to develop their cultural or social capital, since they usually have to start working early in order to help their families.

The analytical approach using MuSIASEM was found relevant and essential in terms of:

i. Providing rich and comprehensive data at different hierarchical scales of analysis by analysing the metabolic pattern of an urban informal settlement from different levels of the community as well as based on different trends and/or factors that constitute to these patterns.
ii. According to Smit et al. (2017), MuSIASEM approach provides a form of recognition as well as a way of tracing links between informal and formal city, thereby enhancing understanding on how cities function towards sustainable transitioning and service provision such as; physical infrastructures (e.g. energy, waste management, water etc.) as well as economic, social and environmental development.
iii. Further, the approach enhances the use of different application tools and factors in analysing complex systems based on their different aspects, which are socio-technical, socio-ecological and/or socio-economic.
iv. Lastly, the analysis generates recommendations for areas for policy intervention and planning, through which municipalities and/or governments can achieve sustainable development, socially equitable cities, sustainable urban planning and proper upgrade plans and implementation.

The study established that Kayamandi informal settlement is subject to several environmental, social and economic challenges. These challenges have an impact on the resident's livelihood as well as the environment on a daily basis. Additionally, some of these issues have a detrimental impact on the health of residents, which exacerbates the need for intervention and sustainable development.

It can be asserted that the study achieves its set objectives The following section discusses the implications of the study for policy planning and implementation, a self-assessment with respect to my research study and methodology before providing the study limitations and areas requiring further research.

## 5.5 Implication for policy planning and implementation

Urban development and local economy decision-makers face huge challenges, as there are concerns over expected urbanization, as well as growth in informal settlements. However, side tracking the understanding of informal settlement and/or slums in urban areas will not address these problems. Decision makers and urban planners need to accept the significance of urban informal settlement and the role they play towards achieving an inclusive sustainable economic development at local level. One of the key ways to improving energy access and poverty reduction in urban informal settlements will be their inclusion in urban energy planning and policies.

Further, upgrading policies aimed at addressing only physical deficits, such as flows availability, locations, housing condition, fail in addressing the underlying social and political tensions and drivers of informality and their marginalisation. The shortcomings of policies of this nature are apparent in the case study considered in this research study on Kayamandi informal settlement.

Several government and global agencies have applied energy intensity as a measuring indicator in determining countries energy efficiency. However, energy intensity does not provide a comprehensive analysis for describing the energy sector (Iorgulescu & Polimeni, 2009)Applying MuSIASEM approach can enable an overall and detailed analysis on system components across different hierarchical levels as well as economic sectors, which can be seen as a better and effective analysis approach than energy intensity.

Further, the MuSIASEM approach gives insights into the challenges and complexities that surround consumption of energy through a comprehensive analysis at different hierarchical levels or scales, which can thus guide policies planners in planning for specific energy related interventions.

Policy-planning is facing or faced with the difficult challenges of acquiring a characterisation for urban informal settlement, and their issues that are neither specific (where it must be able to address a diverse range of settlement types) nor too extensive (which must have the ability of designing and implementing relevant policies in different contexts). However, these results are unachievable if formal characteristics that define informal settlements are only in terms of poor housing, low income, and lack of access to public services. This study addresses this challenge.

An alternative way of understanding the context of urban informal settlement in terms of their energy flow was proposed, i.e. an analytical approach that is semantically open, which can be applied to characterise informal settlement by employing the concept of societal metabolism. The societal metabolism approach identifies crucial qualitative factors and elements of the system, namely the funds that define household capacity to consume energy and other flow elements(infrastructure, people and technology) and different level of scales used in describing metabolic patterns; which is at level-n (the whole community), level n-1 (households), and level n-2 (individuals). The approach allows the use of benchmark values related to typologies, instead of providing a standard accounting method, which depends on the precise flow measurement.

The flexibility of the analysis approach described in the study aimed at ensuring policy- making is less dependent on usage of standard data sets (i.e. a one size fits all). They may, however, be more or less relevant in different contexts, becoming increasingly out-dated. In relation to energy policy, the focus of the approach shifted from providing flows in order to improve funds to defining informal settlements from a deficit perspective, thereby, employing quantitative representation that does not overlook the political and social challenges that are faced by urban informal settlements.

A number of other supportive measures must accompany access to the electricity before they make strong impact as well as contribution in order to meet basic needs that relate to poverty for the poor. Similarly, as seen in the study, access to electricity does not necessary stop the informal settlement residents from also using other energy fuel types (of which some are dangerous and risky). Supportive circumstances have to accompany policy aimed at household access to electricity in informal settlements.

Municipalities and/or government requires hands-on support (in form of information and data) in order to have inclusive policy plans that address the needs of informal settlement and assist them in effectively executing policy implementation. Communication between different spheres of government (national, provincial, municipalities), however, remain a challenge towards service delivery.

### 5.6 Recommendation for future research

The study was designed as an exploratory research applied to a case study setting. Using a case study approach meant analysis of findings and data in a qualitative and quantitative way in order to provide insights into the case study.

Several factors were identified that contribute to how informal settlement or slums are understood and conceptualised, and approaches to their planning. The aspects that require further investigation include the following:

- The uncertainty at different levels that affect urban informal settlement analysis and implication of implementing upgrade policies.
- The analysis of the human activity (HA) in both the paid work (PW) and non-paid work (NPW) sector of the community. The distinction of activities is one key factor to understanding informal economy activities, thereby identifying advantage points that may help to improve sustainable economic development and productivity of the informal settlement.

The urban informal settlement as dynamics and fast changing systems. Application of complex theory and system thinking to understand urban informal settlements may lead to a holistic and in-depth understanding of the phenomenon, thus, influencing the perspective given to them and engagement.

- Exploring the economic, social and environmental implications of energy and material flows in urban informal settlements. This aspect can help towards infrastructural development and transitioning in urban informal settlements. This may enhance the consequences of these impacts whether intended or unintended and generated over time.

- Further analysis into other hierarchical levels of the economy in order to understand the different productive sectors of the economy may be required. An example is the agricultural sector (AG): as can be seen in the case of Kayamandi informal settlement, some homes consist of the presence of a backyard gardens that act as a source of food to the household on a small scale. Other aspects involve analysing the non-paid work (NPW) sector into transportation; how human activities in this sector can be productive, albeit for different reasons? According to Smit et al. (2017)time spent on transport commuting to and from work including waiting time , ideally should lessen, through improvement of public transport system, as this time may be applied into more productive activities either for paid work (PW) or on other human activity (HA), improving the quality of life of informal settlement inhabitants.

- Combining official statistical data with participatory process and local surveys as data collection presents a major challenge, thus, official informal settlement data are very limited. This is because most of life inside informal settlement happens in an informal economy with a possibility of substantial energy flows and capital level hidden. This, however, is not captured appropriately by statistics. It is highly recommended, therefore, that a combination of official data with data obtained through participatory local survey and processes be required for comparison. Similarly, a holistic approach and understanding on how informal settlements functions are required. This can as well foster an inclusive decision-making and policy plans that address the needs of informal settlement.

Given that MuSIASEM approach considers analysis at different hierarchical levels of the system, it is possible to further analyse the activity of the economy for household individuals (at the level n-2). This is a very significant approach because there is a possibility of the settlement composition changing over time (results from continuous urbanization in urban areas).

Although there are several possible research and future work, the study implication is specific and clear. That is, for informal settlement in South Africa to achieve an inclusive planning in the context of sustainable development, access to modern and clean energy services and poverty eradication, several actors and stakeholders between this chains need to engage. To do this, municipalities and government will require a new way of understanding and approaching urban informal settlements and their contribution to the sustainable development and growth of the cities.

Finally, further research direction will be on how to plan, introduce and implement enabling policies that lead to not simply the recognition of current opportunities but also the provision of more holistic views and understanding of urban sustainability. This would allow devising ways to achieve a more conducive, socially equitable and environmentally sustainable development.

## 5.7 Research limitation

The study did not attempt to examine the human activity paid work (PW) and non-paid work (NPW) sector of the society. Further research can, therefore, provide insight to the human activity for the paid work sector (HAPW) and human activity in the household sector (HAHH) through which the total human activity (THA) can be calculated. This calculation can be used in providing a four-quadrant diagram (with all other variables and indicators of MuSIASEM)[13] for the flow-fund representation of MuSIASEM. This is for urban informal settlement energy metabolism. The flow-fund representation can provide comparison between several informal settlement economies or be applied on cities. Nevertheless, it can as well be an area for further research work.

[13] The key intensive and extensive variables used in the flow-fund representation of MuSIASEM have been discussed and applied in the study according to the following: (Ramos-Martin et al., 2007; Ramos-Martín et al., 2009; Silva-Macher, 2015; Andreoni, 2017)

# Reference

Aaker, D.A. & Joachimsthaler, E., 2000. The brand relationship spectrum: The key to the brand architecture challenge. *California management review*, 42(4), pp.8–23.

Amado, M.P. et al., 2016. Regeneration of informal areas: An integrated approach. *Cities*, 58, pp.59–69. Available at: http://dx.doi.org/10.1016/j.cities.2016.05.015.

Andreoni, V., 2017. Energy Metabolism of 28 World Countries: A Multi-scale Integrated Analysis. *Ecological Economics*, 142, pp.56–69. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800916307467.

Antwi, S.K. & Hamza, K., 2015. Qualitative and Quantitative Research Paradigms in Business Research: A Philosophical Reflection. *European Journal of Business and Management*, 7(3), pp.217–225.

Ash, C. et al., 2008. Reimagining cities. *Science*, 319(5864), p.739.

Attia, S. & Khalil, H.A., 2015. Urban Metabolism and Quality of Life in Informal Areas. *REAL CORP 2015 Tagungsband*, 2(May), pp.661–674.

Baccini, P. & Brunner, P.H., 1991. *Metabolism of the anthroposphere*, Cambridge, Mass: The MIT Press. Available at: http://books.google.es/books?id=s2kYAQAAMAAJ.

Bakers, J.L., 2008. Urban Poverty : A Global View. *Urban Papers*. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Urban+Poverty:+A+Global+View#0.

Bao, C. & Fang, C. lin, 2012. Water Resources Flows Related to Urbanization in China: Challenges and Perspectives for Water Management and Urban Development. *Water Resources Management*, 26(2), pp.531–552.

Barles, S., 2010. Society, energy and materials: the contribution of urban metabolism studies to sustainable urban development issues. *Journal of Environmental Planning and Management*, 53(4), pp.439–455.

Barles, S., 2009. Urban metabolism of Paris and its region. *Journal of Industrial Ecology*, 13(6), pp.898–913.

Bettencourt, L.M.A. et al., 2007. Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the National Academy of Sciences*, 104(17), pp.7301–7306. Available at: http://www.pnas.org/cgi/doi/10.1073/pnas.0610172104.

Billen, G. et al., 2009. The food-print of Paris: Long-term reconstruction of the nitrogen flows imported into the city from its rural hinterland. *Regional Environmental Change*, 9(1), pp.13–24.

Blaxter, L., 2010. *How to research*, McGraw-Hill Education (UK).

Brewer, J., Newman, I. & Benz, C.R., 1999. *Qualitative-Quantitative Research Methodology: Exploring the Interactive Continuum*, SIU Press.

Bringezu, S., 1997. From quantity to quality: materials flow analysis. *From Paradigm to Practice of Sustainability*, 21, p.43.

Brockerhoff, M., 2000. *An urbanizing world*, Population Reference Bureau.

Broto, V.C., Allen, A. & Eriksson, A., 2011. Urban Metabolism at UCL – A working paper. , (November), p.13. Available at: https://www.bartlett.ucl.ac.uk/dpu/urban-metabolism/project-outputs/Urban_Metabolim_Report.pdf.

Brückner, M., 2012. Economic growth, size of the agricultural sector, and urbanization in Africa. *Journal of Urban Economics*, 71(1), pp.26–36.

Brunner, P.H. & Rechberger, H., 2004. Material Flow Analysis B o o k Reviews Practical Handbook of Material Flow Analysis. , 9(5), pp.337–338.

Burns, A.C. & Bush, R.F., 2002. *Marketing Research: Online Research Applications*, Prentice Hall New Jersey. Available at: https://books.google.co.id/books?id=GUFUwSPy6aQC.

Burns, N. & Grove, S.K., 1987. *The Practice Of Nursing Research*, Saunders Co., Philadelphia.

Cavana, R.Y., Delahaye, B.. & Sekaran, U., 2001. *Apllied Business Research: Qualitative and Quantitative*

*Methods*, John Wiley & Sons Australia.
Chenwi, L., 2012. Legislative and judicial responses to informal settlements in South Africa: a silver bullet? *Stellenbosch Law Review= Stellenbosch Regstydskrif*, 23(3), pp.540–563.
Chester, M., Pincetl, S. & Allenby, B., 2012. Avoiding unintended tradeoffs by integrating life-cycle impact assessment with urban metabolism. *Current Opinion in Environmental Sustainability*, 4(4), pp.451–457. Available at: http://dx.doi.org/10.1016/j.cosust.2012.08.004.
Churchill, G.A. & Iacobucci, D., 2004. *Marketing Research: Methodological Foundations*, Thomson/South-Western. Available at: https://books.google.co.za/books?id=7ekbAQAAMAAJ.
Clark, W.C. et al., 2017. Sustainability science : The emerging research program Sustainability science focuses on the dynamic. , 100(14), pp.8059–8061.
Cobbinah, P.B., Erdiaw-Kwasie, M.O. & Amoateng, P., 2015. Africa's urbanisation: Implications for sustainable development. *Cities*, 47, pp.62–72.
Codoban, N. & Kennedy, C.A., 2008. Metabolism of Neighborhoods. *Journal of Urban Planning and Development*, 134(1), pp.21–31.
Cohen, L.E.A., 2007. *Research methods in education*, Routledge. Available at: http://cw.routledge.com/textbooks/9780415368780/default.asp.
Creswell, J.W. et al., 2003. Advanced mixed methods research designs. *Handbook of mixed methods in social and behavioral research*, pp.209–240.
Creswell, J.W. & Garrett, A.L., 2008. The " movement " of mixed methods research and the role of educators. *South African Journal of Education*, 28(3), pp.321–333. Available at: http://ajol.info/index.php/saje/article/view/25155.
Currie, P., 2015. *A Resource Flow Typology of African Cities (Masters Thesis)*. Stellenbosch University.
Currie, P.K. & Musango, J.K., 2016. African Urbanization: Assimilating Urban Metabolism into Sustainability Discourse and Practice. *Journal of Industrial Ecology*, 0(0), pp.1–15. Available at: http://doi.wiley.com/10.1111/jiec.12517.
D'Alisa, G., Di Nola, M.F. & Giampietro, M., 2012. A multi-scale analysis of urban waste metabolism: Density of waste disposed in Campania. *Journal of Cleaner Production*, 35, pp.59–70. Available at: http://dx.doi.org/10.1016/j.jclepro.2012.05.017.
Daioglou, V., van Ruijven, B.J. & van Vuuren, D.P., 2012. Model projections for household energy use in developing countries. *Energy*, 37(1), pp.601–615.
Daniels, P.L., 2002. Approaches for Quantifying the Metabolism of Physical Economies: A Comparative Survey: Part II: Review of Individual Approaches. *Journal of Industrial Ecology*, 6(1), pp.65–88. Available at: http://doi.wiley.com/10.1162/108819802320971641.
Daniels, P.L. & Moore, S., 2002. Approaches for Quantifying the Metabolism of Physical Economies: A Comparative Survey: Part I: Review of Individual Approaches. *Journal of Industrial Ecology*, 5(4), pp.69–93.
Davies, R. & Thurlow, J., 2010. Formal-informal economy linkages and unemployment in South Africa. *South African Journal of Economics*.
Decker, E.H. et al., 2000. E Nergy and M Aterial F Low T Hrough the U Rban E Cosystem. *Annual Review of Energy and the Environment*, 25(1), pp.685–740. Available at: http://www.annualreviews.org.ezproxy.lib.uts.edu.au/eprint/RfqzSZHB4YrG9pU2ESbM/full/10.1146/annurev.energy.25.1.685.
DeFries, R. & Pandey, D., 2010. Urbanization, the energy ladder and forest transitions in India's emerging economy. *Land Use Policy*, 27(2), pp.130–138.
Denzin, N.K. & Lincoln, Y.S., 2000. *Handbook of qualitative research*, Thousand Oaks, Calif.: Sage Publications.
Department of Energy, 2012. A survey of energy-related behaviour and perceptions in South Africa: The residential sector. , 1(1), p.118. Available at: www.energy.gov.za.
Dinarès, M., 2014. Urban Metabolism : A review of recent literature on the subject. , 60, pp.551–571.

Durand-Lasserve, A. & Royston, L., 2002. *Holding their ground: Secure land tenure for the urban poor in developing countries*, Earthscan.
Duvigneaud, P. & Denaeyer-De Smet, S., 1977. *L'Écosystème Urbain Bruxellois*,
Dzioubinski, O. & Chipman, R., 1999. *Trends in consumption and production: household energy consumption*, United Nations, Department of Economic and Social Affairs.
Eurostat, 2001. *Economy-wide material flow accounts and derived indicators*,
Facchini, A. et al., 2017. The energy metabolism of megacities. *Applied Energy*, 186, pp.86–95. Available at: http://dx.doi.org/10.1016/j.apenergy.2016.09.025.
Falconí-Benítez, F., 2001. Integrated Assessment of the Recent Economic History of Ecuador. *Population and Environment*, 22(3), pp.257–280. Available at: http://dx.doi.org/10.1023/A:1026647829660.
Fernández, J.E., 2014. Urban metabolism of the global south.
Ferrão, P. & Fernández, J.E., 2013. *Sustainable urban metabolism*, MIT press.
Fischer-kowalski, M., 1998a. Society's Metabolism. , 2(I).
Fischer-kowalski, M., 1998b. Society ' s Metabolism : The Intellectual History of Materials Flow Analysis , Part I , 1860-1970. *Journal of Industrial Ecology*, 2(1), pp.61–78.
Fischer-Kowalski, M. & Haberl, H., 2007. *Socioecological transitions and global change: Trajectories of social metabolism and land use*, Edward Elgar Publishing.
Fisher-Kowalski and Hüttler, W., 1999. Society ' s Metabolism :The Intellectual History of Materials Flow Analysis, Part II, 1970-1998. *Journal of Industrial Ecology*, 2(4), pp.107–136.
Fox, S., 2012. Urbanization as a Global Historical Process : Theory and Evidence from sub-Saharan Africa. *Population and development review*, 38(2), pp.285–310.
Gaya, R.F., 2010. Working on strategies towards urban sustainability. , (November).
GCRO, 2012. Scoping study into the energy metabolic flows in the Gauteng City-region. *Guateng City-Region Observatory*, (May), pp.1–58.
Georgescu-Roegen, N., 1971. The law of entropy and the economic process.
Giampietro, M., 2003. *Multi-scale integrated analysis of agroecosystems*, CRC press.
Giampietro, M.. et al., 2013. *An Innovative Accounting Framework for the Food-Energy-Water Nexus: Application of the MuSIASEM approach to three case studies*,
Giampietro, M. & Bukkens, S.G.F., 2015. Analogy between Sudoku and the multi-scale integrated analysis of societal metabolism. *Ecological Informatics*, 26(P1), pp.18–28.
Giampietro, M. & Mayumi, K., 1997. A dynamic model of socioeconomic systems based on hierarchy theory and its application to sustainability. *Structural Change and Economic Dynamics*, 8(4), pp.453–469.
Giampietro, M. & Mayumi, K., 2000a. Multiple-scale integrated assesment of societal metabolism: Introducing the approach. *Population and Environment*, 22(2), pp.109–153.
Giampietro, M. & Mayumi, K., 2000b. Multiple-scale integrated assessment of societal metabolism: introducing the approach. *Population & Environment*, 22(2), pp.109–153.
Giampietro, M. & Mayumi, K., 2000c. Multiple-scale integrated assessments of societal metabolism: Integrating biophysical and economic representations across scales. *Population and Environment*, 22(2), pp.155–210. Available at: http://download.springer.com/static/pdf/231/art%253A10.1023%252FA%253A1026643707370.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1023%2FA%3A1026643707370&token2=exp=1460538055~acl=%2Fstatic%2Fpdf%2F231%2Fart%25253A10.1023%25252FA%25253A1026 [Accessed April 13, 2016].
Giampietro, M., Mayumi, K. & Bukkens, S.G.F., 2001. Multiple-scale integrated assessment of societal metabolism: An analytical tool to study development and sustainability. *Environment, Development and Sustainability*, 3(4), pp.275–307.
Giampietro, M., Mayumi, K. & Ramos-Martin, J., 2009. Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. *Energy*, 34(3), pp.313–322. Available at: http://www.liphe4.org/pdf/Giampietro_et_al_2009.pdf

[Accessed April 13, 2016].
Giampietro, M., Mayumi, K. & Sorman, A.A.H., 2011. The metabolic pattern of societies : where economists fall short /. Available at: http://books.google.es/books?hl=es&lr=&id=yreoAgAAQBAJ&oi=fnd&pg=PP1&dq=The+Metabolic+Pattern+of+Societies:+where+economists+fall+short&ots=xdf8lFqWm9&sig=BmTWYH2211L0UnElpniZLy8kqtA.
Giampietro, M., Sorman, A.H. & Gamboa, G., 2010. Using the MuSIASEM approach to study metabolic patterns of modern societies. In *Energy Options Impact on Regional Security*. Springer, pp. 37–68.
Girardet, H., 2010. Regenerative cities written for the world council and Hafen city University Hamburg HCO Commission on Cities and Climate Change. Ham-burg: Hafen city University.
Google Maps, 2017. Map of Kayamandi. *Google*. Available at: https://www.google.co.za/maps/place/Kayamandi,+Stellenbosch,+7600/@-33.9197254,18.8448739,1861m/data=!3m1!1e3!4m5!3m4!1s0x1dcdb284a7419115:0xfdec21bf31df56e9!8m2!3d-33.9182957!4d18.844751?hl=en [Accessed October 20, 2017].
Guibrunet, L. & Broto, V.C., 2015. The sustainability of the informal city : An urban metabolism approach. , pp.1–24.
Guibrunet, L., Calvet, M.S. & Broto, V.C., 2016. Flows, system boundaries and the politics of urban metabolism: Waste management in Mexico City and Santiago de Chile. *Geoforum*.
Haberl, H., 1997. Human Appropriation of Net Primary Production as an Environmental Indicator: Implications for Sustainable Development. *Ambio*, 26(3), pp.143–146. Available at: http://www.jstor.org/stable/4314572.
Hammer, M. et al., 2003. *Material flow analysis on the regional level: questions, problems, solutions*, Hamburg: Hamburg University: Forschungsprojekt NEDS c/o HWP.
Hammer, M., 2003. *Material flow analysis on the regional level: questions, problems, solutions*, Forschungsprojekt NEDS c/o HWP.
Hanya, T. & Ambe, Y., 1976. A Study on the Metabolism of Cities. Science for a Better Environment. HESC. *Science Council of Japan, Tokyo*.
Harrison, P., 1992. The policies and politics of informal settlement in South Africa: A historical perspective. *Africa Insight*, 22(1), pp.323–350.
Hayes, B., Bonner, A. & Douglas, C., 2013. An introduction to mixed methods research for nephrology nurses. *Renal Society of Australasia Journal*, 9(1).
Henczel, S., 2001. *The information audit: A practical guide*, Walter de Gruyter.
Hendriks, C. et al., 2000. Material Flow Analysis: a tool to support environmental policy decision making. Case-studies on... *Local Environment. Aug2000*, 5(3), pp.311–328.
Hittleman, D.R. & Simon, A.J., 1997. *Interpreting Educational Research: An Introduction for Consumers of Research*, Merrill.
Holden, E., 2004. Ecological footprints and sustainable urban form. *Journal of Housing and the Built Environment*, 19(1), pp.91–109.
Holmes, T. & Pincetl, S., 2012. Metabolism Literature Review. *Center for Sustainable Urban Systems, UCLA INSTITUTE OF THE ENVIRONMENT URBAN*, pp.1–28.
Huang, C.-L. et al., 2012. Using material/substance flow analysis to support sustainable development assessment: A literature review and outlook. *Resources, Conservation and Recycling*, 68, pp.104–116. Available at: http://dx.doi.org/10.1016/j.resconrec.2012.08.012.
Huang, L. & Bohne, R.A., 2012. Embodied air emissions in Norway's construction sector: input-output analysis. *Building Research & Information*, 40(5), pp.581–591. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84865839427&partnerID=tZOtx3y1.
Huang, S., 1998. Urban ecosystems , energetic hierarchies , and ecological. , (July 1997), pp.39–51.
Huang, S.-L.& & Chen, C.-W., 2009. Urbanization and Socioeconomic Metabolism in Taipei: An

Emergy Synthesis. *Journal of Industrial Ecology*, 13(1), pp.75–94.
Huang Shu-Li & Hsu Wan-Lin, 2003. Material Flow Analysis And Emergy Evaluation of Taipei's Urban Construction. *Landscape and Urban Planning*, 63(2), pp.61–74. Available at: http://www.airitilibrary.com/Publication/Index/10181067-200108-28-2-187-209-a.
Huchzermeyer, M. et al., 2006. Policy, data and civil society: reflections on South African challenges through an international review.
Hunter, M. & Posel, D., 2012. Here to work: the socioeconomic characteristics of informal dwellers in post-apartheid South Africa. *Environment and Urbanization*, 24(1), pp.285–304.
IEA, 2008. World Energy Outlook 2008. *World Energy Outlook 2008*. Available at: http://www.worldenergyoutlook.org/publications/weo-2008/.
IEA, 2015. World Energy Outlook 2015. *World Energy Outlook 2015*, p.718.
Iorgulescu, R.I. & Polimeni, J.M., 2009. A multi-scale integrated analysis of the energy use in Romania, Bulgaria, Poland and Hungary. *Energy*, 34(3), pp.341–347.
Karekezi, S. & Majoro, L., 2002. Improving modern energy services for Africa's urban poor. *Energy Policy*, 30(11–12), pp.1015–1028.
Kennedy, C., Cuddihy, J. & Engel-Yan, J., 2007. The Changing Metabolism of Cities. *Journal of Industrial Ecology*, 11(2), pp.43–59. Available at: http://onlinelibrary.wiley.com/doi/10.1162/jie.2007.1107/abstract%5Cnhttp://onlinelibrary.wiley.com/store/10.1162/jie.2007.1107/asset/jie.2007.1107.pdf?v=1&t=i1ryry03&s=dede3c892d2cc10e39035a37803eb5640f1358ea [Accessed July 5, 2016].
Kennedy, C., Pincetl, S. & Bunje, P., 2011. The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution*, 159(8–9), pp.1965–1973. Available at: http://www.sciencedirect.com/science/article/pii/S0269749110004781 [Accessed March 16, 2016].
Khalifa, M.A., 2011. Rede fi ning slums in Egypt : Unplanned versus unsafe areas. *Habitat International*, 35(1), pp.40–49.
Kothari, C., 2004. *Research methodology: methods and techniques*, Available at: http://books.google.com/books?hl=en&lr=&id=8c6gkbKi-F4C&oi=fnd&pg=PR7&dq=Research+Methodology:+Methods+and+Techniques&ots=iGnHoSUbpN&sig=MCLUW6fq3hl5GDq0RanXjegF9Gg.
Kovacic, Z. et al., 2016. Probing uncertainty levels of electrification in informal urban settlements: A case from South Africa. *Habitat International*, 56, pp.212–221.
Kovacic, Z. & Giampietro, M., 2016. Between theory and quantification: An integrated analysis of metabolic patterns of informal urban settlements. *Energy Policy*. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421516303524.
Kovanda, J., 2014. Resources , Conservation and Recycling Incorporation of recycling flows into economy-wide material flow accounting and analysis : A case study for the Czech Republic. *"Resources, Conservation & Recycling"*, 92, pp.78–84.
Kuznecova, T., Romagnoli, F. & Rochas, C., 2014. Energy Metabolism for Resilient Urban Environment: A Methodological Approach. *Procedia Economics and Finance*, 18(0), pp.780–788. Available at: http://www.sciencedirect.com/science/article/pii/S2212567114010028 [Accessed March 23, 2016].
Lederer, J. & Kral, U., 2015. Theodor Weyl. , 19(5), pp.695–703.
Leedy, P.D. & Ormrod, J.E., 2005. *Practical research*, publisher not identified.
Lewis, J. & Ritchie, J., 2003. Generalising from qualitative research. *Qualitative research practice: A guide for social science students and researchers*, 2, pp.347–362.
Liang, S. et al., 2012. Sustainable urban materials management for air pollutants mitigation based on urban physical input e output model. *Energy*, 42(1), pp.387–392. Available at: http://dx.doi.org/10.1016/j.energy.2012.03.038.
Liu, G., Yang, Z. & Chen, B., 2011. Four angle model for the urban metabolism integrated analysis. In *Procedia Environmental Sciences*. pp. 81–86. Available at:

http://dx.doi.org/10.1016/j.proenv.2011.03.052.
Loiseau, E. et al., 2012. Environmental assessment of a territory: An overview of existing tools and methods. *Journal of Environmental Management*, 112, pp.213–225. Available at: http://dx.doi.org/10.1016/j.jenvman.2012.07.024.
Lotka, A.J., 1956. Elements of mathematical biology.
Lotka, J., 1922. Contribution to the Energetics of Evolution. *Proceedings of the National Academy of Sciences of the United States of America*, 8(6), pp.147–151.
Maclaren, V.W., 1996. Urban Sustainability Reporting. *Journal of the American Planning Association*, 62(2), pp.184–202.
Makinde, O. et al., 2017. ENERGY METABOLISM IN MULTI-STRUCTURED URBAN INFORMAL SETTLEMENTS IN SOUTH AFRICA. In *SAIIE28 Proceedings*. Vaal, pp. 85–100.
Malhotra, N.K., 2004. *Review of Marketing Research*, M.E. Sharpe. Available at: https://books.google.co.za/books?id=sYiSI4dmHZMC.
Marshall, G., 1998. Snowballing technique. *A dictionary of sociology*, pp.201–216.
Mayumi, K., 1991. Temporary emancipation from land : from the industrial revolution to the present time. , 1, pp.35–56.
Miranda, R.F.C., Grottera, C. & Giampietro, M., 2016. Understanding slums: analysis of the metabolic pattern of the Vidigal favela in Rio de Janeiro, Brazil. *Environment, Development and Sustainability*, 18(5), pp.1297–1322.
Mostafavi, N., Farzinmoghadam, M. & Hoque, S., 2014. A framework for integrated urban metabolism analysis tool (IUMAT). *Building and Environment*, 82, pp.702–712. Available at: http://www.sciencedirect.com/science/article/pii/S0360132314003412 [Accessed February 13, 2016].
Mun, I. & Galindo, A., 2005. Urban form and the ecological footprint of commuting . The case of Barcelona. *Ecological Economics*, 55, pp.499–514.
Musango, J.K., 2014. Household electricity access and consumption behaviour in an urban environment: The case of Gauteng in South Africa. *Energy for Sustainable Development*, 23, pp.305–316. Available at: http://dx.doi.org/10.1016/j.esd.2014.06.003.
Newcombe, K., Kalma, J.D. & Aston, A.R., 1978. The metabolism of a city. The case of Hong Kong [urbanization, flow and end use of energy, iron, steel, glass, plastics, cement]. *Ambio*.
Newman, P.W.G. et al., 1996. Human settlements. In: Australian State of the Environment Report. *Department of Environment, Sport and Territories, Canberra, Australia*.
Newman, P.W.G., 1999. Sustainability and cities: Extending the metabolism model. *Landscape and Urban Planning*, 44(4), pp.219–226. Available at: http://www.esf.edu/cue/documents/newman_metab.pdf [Accessed April 4, 2016].
Nicks, S., 2012. Spatial Planning-Planning a Sustainable Stellenbosch. *Sustainable Stellenbosch: opening dialogues. Stellenbosch: African Sun Media*, pp.24–30.
Niza, S., Rosado, L. & Ferrao, P., 2009. Urban metabolism. *Journal of Industrial Ecology*, 13(3), pp.384–405.
Njoh, A.J., 2003. Urbanization and development in sub-Saharan Africa. *Cities*, 20(3), pp.167–174.
Nuissl, H. & Heinrichs, D., 2013. Slums: Perspectives on the definition, the appraisal and the management of an urban phenomenon. *Erde*, 144(2), pp.105–116.
Odum, H.T., 1996. *Environmental accounting: emergy and environmental decision making*, Wiley.
Onwuegbuzie, A.J. & Leech, N.L., 2005. On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies. *International Journal of Social Research Methodology*, 8(5), pp.375–387.
Pachauri, S., 2004. An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. *Energy Policy*, 32(15), pp.1723–1735.
Pacione, M., 2009. *Urban Geography: A Global Perspective*, Routledge.
Parnell, S. & Pieterse, E.A., 2014. Africa's urban revolution.

Payne, G., 2001. Urban Land Tenure Policy Options: Title or Rights? *Habitat International*, 25(June), pp.415–429.
Pieterse, E., 2014. 11| Filling the void: an agenda for tackling African urbanisation. *Africa's urban revolution*, p.200.
Pivo, G., 1996. Toward sustainable urbanization on mainstreet Cascadia. *Cities*, 13(5), pp.339–354.
Quinlan, C. et al., 2011. *Business research methods*, South-Western Cengage Learning Andover, Hampshire, UK.
Ramos-Martín, J., Canellas-Bolta, S., et al., 2009. Catalonia's energy metabolism: Using the MuSIASEM approach at different scales. *Energy Policy*, 37(11), pp.4658–4671.
Ramos-Martín, J., Cañellas-Boltà, S., et al., 2009. Catalonia's energy metabolism: Using the MuSIASEM approach at different scales. *Energy Policy*, 37(11), pp.4658–4671. Available at: http://www.sciencedirect.com/science/article/pii/S0301421509004352 [Accessed March 23, 2016].
Ramos-Martin, J. & Giampietro, M., 2005. Multi-scale integrated analysis of societal metabolism: learning from trajectories of development and building robust scenarios. *International Journal Of Global Environmental Issues*, 5(3–4), pp.225–263.
Ramos-Martin, J., Giampietro, M. & Mayumi, K., 2007. On China's exosomatic energy metabolism: An application of multi-scale integrated analysis of societal metabolism (MSIASM). *Ecological Economics*, 63(1), pp.174–191.
Raupova, O., Kamahara, H. & Goto, N., 2014. Resources , Conservation and Recycling Assessment of physical economy through economy-wide material flow analysis in developing Uzbekistan. *"Resources, Conservation & Recycling"*, 89, pp.76–85.
Rock, D., 2011. The location shall be called Kaya Mandi: A history of Kaya Mandi.
Roy, A., 2005. Urban informality: Toward an epistemology of planning. *Journal of the American Planning Association*, 71(2). Available at: http://oxfordhandbooks.com/view/10.1093/oxfordhb/9780195374995.001.0001/oxfordhb-9780195374995-e-33.
Roy, D. et al., 2014. The emergence of slums: A contemporary view on simulation models. *Environmental Modelling and Software*, 59(2014), pp.76–90. Available at: http://dx.doi.org/10.1016/j.envsoft.2014.05.004.
Sagar, A.D., 2005. Alleviating energy poverty for the world's poor. *Energy Policy*, 33(11), pp.1367–1372.
Schandl, H. & Capon, A., 2012. Cities as social-ecological systems: Linking metabolism, wellbeing and human health. *Current Opinion in Environmental Sustainability*, 4(4), pp.375–377. Available at: http://dx.doi.org/10.1016/j.cosust.2012.09.001.
Schipper, L.J., Haas, R. & Sheinbaum, C., 1996. Recent trends in residential energy use in OECD countries and their impact on carbon dioxide emissions: a comparative analysis of the period 1973–1992. *Mitigation and Adaptation Strategies for Global Change*, 1(2), pp.167–196.
Schneider, F., Buehn, A. & Montenegro, C.E., 2010. Shadow Economies all over the World: New Estimates for 162 Countries from 1999 to 2007.
Sekaran, U., 2000. *Research methods for business: A skill-building approach*, Wiley. Available at: https://books.google.co.za/books?id=0aAsAAAACAAJ.
Shrestha, R.M. et al., 2008. Modern energy use by the urban poor in Thailand: a study of slum households in two cities. *Energy for Sustainable Development*, 12(4), pp.5–13. Available at: http://dx.doi.org/10.1016/S0973-0826(09)60003-X.
Silva-Macher, J.C., 2015. A Metabolic Profile of Peru: An Application of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) to the Mining Sector's Exosomatic Energy Flows. *Journal of Industrial Ecology*, 0(0), p.n/a-n/a. Available at: http://doi.wiley.com/10.1111/jiec.12337.
Skuse, A. & Cousins, T., 2007. Spaces of Resistance : Informal Settlement , Communication and Community Organisation in a Cape Town Township. , 44(May), pp.979–995.

Smit, S. et al., 2017. Conceptualising slum in an urban African context. *Proceedings of the 22nd Annual International Sustainable Development Research Society Conference*, 62, pp.107–119. Available at: http://dx.doi.org/10.1016/j.cities.2016.12.018.

Smit, S., 2015. Towards an "inclusive green economy" for South Africa: engaging with the informal economy (Masters' Thesis). , (March), p.174.

Smit, S. & Musango, J.K., 2015. Towards connecting green economy with informal economy in South Africa: A review and way forward. *Ecological Economics*, 116, pp.154–159.

Smith, T.M. & Smith, R.L., 2006. Community Ecology. *Elements of Ecology (6th Edition), Pearson Education Inc., publishing as Benjamin Cummings, San Francisco, California*, pp.6–16.

Sorman, A.H. & Giampietro, M., 2011. Generating better energy indicators: Addressing the existence of multiple scales and multiple dimensions. *Ecological Modelling*, 223(1), pp.41–53. Available at: http://dx.doi.org/10.1016/j.ecolmodel.2011.10.014.

Srinivas, H., 2015. Defining squatter settlements. GDRC research output E-036. Kobe, Japan: Global Development Research Center.

Sustainable Energy Africa, 2014. Tackling Urban Energy Poverty in South Africa. , (January), pp.1–12.

Swilling, M. & Annecke, E., 2012. *Just transitions: Explorations of sustainability in an unfair world*, Cape Town:UCT press.

Tavernia, B.G. & Reed, J.M., 2009. Spatial extent and habitat context influence the nature and strength of relationships between urbanization measures. *Landscape and Urban Planning*, 92(1), pp.47–52.

Tellis, W., 1997. Application of a case study methodology . *The Qualitave Report*, 3(3), pp.1–19.

Thomas, P.., 2010. Research Methodology and Design. *Research Methodology and Design*, pp.291–334. Available at: http://umkn-dsp01.unisa.ac.za/handle/10500/4245.

Truran, G., 2007. Household energy poverty and paraffin consumption in South Africa. , (1955).

Turok, I., 2015. Upgrade informal settlements: South Africa. *New Agenda: South African Journal of Social and Economic Policy*, 2015(57), pp.11–15.

UN, 2015. The Millennium Development Goals Report. *United Nations*, p.72. Available at: https://visit.un.org/millenniumgoals/2008highlevel/pdf/MDG_Report_2008_Addendum.pdf.

UN-DESA, 2013. World Population Prospects: The 2012 Revision. Highlights and Advance Tables. *Population and development review*, 36, pp.775–801. Available at: http://esa.un.org/unpd/wpp/Documentation/publications.htm.

UN-Habitat, Chapter 1 : Development Context and the Millennium Agenda. *The Challenge of Slums: Global Report on Human Settlements 2003*, (September 2005), pp.1–23.

UN-Habitat, 2015a. Habitat Iii Issue Papers 22 – Informal Settlements. *United Nations Conference on Housing and Sustainable Urban Development*, 2015(May), pp.0–8. Available at: http://unhabitat.org/wp-content/uploads/2015/04/Habitat-III-Issue-Paper-22_Informal-Settlements-2.0.pdf.

UN-Habitat, 2009. *Planning sustainable cities: Global Report on Human Settlements. 2009*,

UN-Habitat, 2010a. *State of the World's Cites 2010/2011: Bridging The Urban Divide*, Available at: http://unhabitat.org/wpdm-package/cities-for-all-bridging-the-urban-divide-state-of-the-world-cities-20102011/?wpdmdl=111329.

UN-Habitat, 2003. *The Challenge of Slums - Global Report on Human Settlements*, Available at: http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=1156%5Cnhttp://www.loc.gov/catdir/toc/ecip045/2003013446.html.

UN-Habitat, 2014a. *The State of African Cities 2014*, Available at: http://jas.sagepub.com/content/early/2014/09/05/0021909614547604.abstract.

UN-Habitat, 2015b. *UN-HABITAT Global Activities Report 2015: Increasing Synergy for Greater National Ownership*,

UN-Habitat, 2010b. United Nations-Human Settlements Programme. The Challenge of Slums,

Global report on Human Settlements; revised and updated version (April,2010). *The Challenge of Slums: Global Report on Human Settlements*.
UN-Habitat, 2016. *Urbanization and Development: Emerging Futures*, Available at: http://wcr.unhabitat.org/main-report/.
UN-Habitat, 2015c. World atlas of slum evolution. Working document produced for the United Nations Human Settlements Programme prepared December 2015).
UN-Habitat, 2014b. *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352)*, Available at: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf.
UNDESA/PD, 2012. *World urbanization prospects: The 2011 revision. new york: United nations department of economic and social affairs/population division*,
UNDP, 2016. Sustainable development goals. *United Nations Deveopment Programme*. Available at: http://www.undp.org/content/undp/en/home/%0Asdgoverview/post-2015-development-agenda.html [Accessed February 21, 2017].
UNEP, 2013. *CITY LEVEL DECOUPLING: URBAN RESOURCE FLOWS AND THE GOVERNANCE OF INFRASTRUCTURE TRANSITIONS*,
UNEP, 2007. Global Environment outlook 4: Environment for development. Nairobi: UNEP. *United Nations Environment Programme 2007*.
Urban Foundation, 1991. Informal housing: Urban debate 2010. Braamfontein. *Urban Foundation (South Africa)*.
Valentine, G.A. & Heiken, G., 2000. The need for a new look at cities. *Environmental Science & Policy*, 3(5), pp.231–234.
Wackernagel, M. & Rees, W., 1996. *Our ecological footprint: reducing human impact on the earth*, New Society Publishers.
Wang, Q., 2014. Effects of urbanisation on energy consumption in China. *Energy Policy*, 65, pp.332–339. Available at: http://dx.doi.org/10.1016/j.enpol.2013.10.005.
Wang, Y., Wang, L. & Shao, H., 2014. Ecological footprint analysis applied to a coal-consumption county in China. *Clean - Soil, Air, Water*, 42(7), pp.1004–1013.
Warren-Rhodes, K. & Koenig, A., 2001. Escalating Trends in the Urban Metabolism of Hong Kong: 1971–1997. *AMBIO: A Journal of the Human Environment*, 30(7), pp.429–438. Available at: http://www.bioone.org/doi/abs/10.1579/0044-7447-30.7.429%5Cnhttp://dx.doi.org/10.1579/0044-7447-30.7.429 [Accessed July 5, 2016].
Watson, V., 2009. " The planned city sweeps the poor away . . . " §: Urban planning and 21st century urbanisation. , 72, pp.151–193.
WCED, 1987. Our Common Future: Report of the World Commission on Environment and Development. *Medicine, Conflict and Survival*, 4(1), p.300.
Weber, B.H. et al., 1989. Evolution in thermodynamic perspective: an ecological approach. *Biology and Philosophy*, 4(4), pp.373–405.
Weisz, H. & Steinberger, J.K., 2010. Reducing energy and material flows in cities. *Current Opinion in Environmental Sustainability*, 2(3), pp.185–192. Available at: http://dx.doi.org/10.1016/j.cosust.2010.05.010.
Wolman, A., 1965. The metabolism of cities. *Scientific American*, 213(3), pp.179–190.
World Bank & UNCHS Habitat, 1999. Cities Alliance for Cities Without Slums. *World Bank and UNCH(Habitat)*, p.23.
Yin, K.R., 2009. Case study research: Design and methods. *Applied social research methods series*, 5, p.356.
Yin, R.K., 2003. *Case Study Research: Design and Methods*, SAGE Publications. Available at: https://books.google.co.za/books?id=BWea_9ZGQMwC.
Zhang, Y., 2013. Urban metabolism: A review of research methodologies. *Environmental Pollution*, 178, pp.463–73. Available at: http://www.sciencedirect.com/science/article/pii/S0269749113001851 [Accessed March

23, 2016].
Zhang, Y., Yang, Z. & Yu, X., 2009. Evaluation of urban metabolism based on emergy synthesis: A case study for Beijing (China). *Ecological Modelling*, 220, pp.1690–1696.
Zhang, Y., Zhang, J. & Yang, Z., 2010. Network relationship analysis of urban energy metabolic system. *Procedia Environmental Sciences*, 2(2), pp.1407–1412.

# Chapter 6 LIST OF APPENDICES

## Appendix A: Consent form

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

**STELLENBOSCH UNIVERSITY CONSENT TO PARTICIPATE IN RESEARCH**

---

Title: ***Energy Metabolism in a Multi-Structured Urban Informal Settlement***

*You are asked to participate in a research study conducted by Olufolake A. Makinde as part of my Masters in engineering degree studies, from the Industrial Engineering Department at Stellenbosch University. You were selected as a possible participant in this study because you are a member/ head of the household in which the research study is conducted for data collection.*

### 1. Purpose of the study

The questionnaire is designed in order to access the following information on time, money and energy use in different household in an informal settlement: questions will be asked on the energy fuel types that is used in each household for lighting, cooking, water heating, and space heating and, for household appliances. The questionnaire will also look into the amount of money that is been spent on the energy fuel types that is used for the various energy services. Also human activity type and time spent on each activity, income structure and type, type of electricity used, cost electricity used (weekly, monthly and annually)

### 2. Procedures

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

i. Fill the questionnaires, which will be given.
ii. Include the appropriate data from your household as stated on the questionnaires

### 3. Potential risks and discomforts

All rights are reserved by participant in choosing to participate in this survey, also each participant remain anonymous in research write up and confidentiality of information given will be highly maintained. Participant can also choose to withdraw during the process of the survey.

### 4. Potential benefits to subjects and/or to society

The subject will not benefit directly from the research. However, the research has the potential on informing future government and municipalities policies and decisions on energy and environmental planning in informal settlement/economy (with respect to infrastructure transition i.e. different housing types and structures).

### 5. Payment for participation

Participant will not be receiving any payment or gifts for their participation.

**6. Confidentiality**

Any information that is obtained in connection with 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 means of:

- No audio/video recording of the activity will be carried out in the process of the survey.

In other to maintain proper confidentiality and anonymity of each participant and the information given.

1.) The project names will be replaced by ID codes in the documentation

2.) The document will contain no direct quotes or links to any personal identifiers

**7. Participation and withdrawal**

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you do not want to answer and remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. [*If appropriate, describe the anticipated circumstances under which the subject's participation may be terminated by the investigator without regard to the subject's consent.*]

**8. Identification of investigators**

If you have any questions or concerns about the research, please feel free to contact [O.A Makinde *(Principal PI) [18073395@sun.ac.za; Tel: 0638618535),* Dr. J Musango (Supervisor) *[Josephine.Musango@spl.sun.ac.za; Tel: 0218084338]*

**9. 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.

**SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE**

The information above was described to [*me/the subject/the participant*] by [*name of relevant person*] in [*Afrikaans/English/Xhosa/other*] and [*I am/the subject is/the participant is*] in command of this language or it was satisfactorily translated to [*me/him/her*]. [*I/the participant/the subject*] was given the opportunity to ask questions and these questions were answered to *[my/his/her]* satisfaction.

*[I hereby consent voluntarily to participate in this study/I hereby consent that the subject/participant may participate in this study.*] I have been given a copy of this form.

____________________________________

**Name of Subject/Participant**

____________________________________

**Name of Legal Representative (if applicable)**

____________________________________ ______________

**Signature of Subject/Participant or Legal Representative** **Date**

**SIGNATURE OF INVESTIGATOR**

I declare that I explained the information given in this document to________________[*name of the subject/participant]* and/or [his/her] representative__[*name of the representative]*. [He/she] was encouraged and given ample time to ask me any questions. This conversation was conducted in [*Afrikaans/*English/*Xhosa/*other*] and [*no translator was used/this conversation was translated into* ____________________________________________by______________________].

_____________________________________ _____________

**Signature of Investigator** **Date**

## Appendix B: Interview questionnaires

These interview questionnaire were constructed and prepared bythe project team consisting of the author; Olufolake Makinde and the supervisor namely; Prof. Josephine K. Musango, Prof. Alan Brent and Suzanne Smit.

**Research topic:** Energy Metabolism in a Hybrid / Multi-Structured Urban Informal Settlement

Carried out at: Kayamandi Informal Settlement , Stellenbosch Municipality , Western Cape, South Africa

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

Dear Participant, thank you for being part of this study. As part of my Master in engineering studies, I would like to ask you to please complete the following short questionnaire and answer the few questions that follow. Your responses are confidential and anonymous; also, your right and privacy will be protected.

Date_______________ Time______________________

Interviewer_________________ Location (General area)

________________________

Building structure____________

Number of backyard shacks

Gender of Interviewee (Please circle) M / F

1. What is your preferred language? (Indicate with x)

| | |
|---|---|
| English | |
| IsiXhosa | |
| Afrikaans | |
| Other (please specify) | |

2. How old are you? ___________________
3. Do you rent out backyard space? How much do you charge per month? ________________
4. Do you charge for water and electricity and how much per month? ____________
5. Are you the head of the household? Y / N
6. How many people live in the household? ________________

**Indicate the age and sex for each person**

| Person no | Age | M | F |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |

| | | | |
|---|---|---|---|
| **9** | | | |

**7.** How many people in the household do paid work? ________________
(Repeat for every working person, indicating Male or Female)

**Person 1 (M / F)**

What type of work do you do? ______________________________________

Is the work full time or part-time? (Please circle) FT / PT

How many hours do you work per day? ____________________

How many days do you work per week? ____________________
Do you get paid per day, week or month? (Please circle) Day / Week / Month

How much do you get paid? __________________________
How do you get to work? (Please mark with x)

| | |
|---|---|
| Taxi | |
| Walking | |
| Train | |
| Bicycle | |
| Personal car | |
| Bus | |
| Other (Please specify | |

How long does it take you to get to work? ____________________ (Minutes)

How far do you have to travel to work? ____________________ Km

**Person 2 (M / F)**

What type of work do you do? ______________________________________
Is the work full time or part-time? (Please circle) FT / PT

How many hours do you work per day? ____________________

How many days do you work per week? ____________________
Do you get paid per day, week or month? (Please circle) Day / Week / Month

How much do you get paid? __________________________
How do you get to work? (Please mark with x)

| | |
|---|---|
| Taxi | |
| Walking | |
| Train | |
| Bicycle | |
| Personal car | |
| Bus | |
| Other (Please specify | |

How long does it take you to get to work? ____________________ (Minutes)

How far do you have to travel to work? ____________________ Km

**Person 3 (M / F)**

What type of work do you do? ______________________________
Is the work full time or part-time? (Please circle) FT / PT

How many hours do you work per day? ________________ How many days do you work per week? ________________
Do you get paid per day, week or month? (Please circle) Day / Week / Month

How much do you get paid? ______________________
How do you get to work? (Please mark with x)

| | |
|---|---|
| Taxi | |
| Walking | |
| Train | |
| Bicycle | |
| Personal car | |
| Bus | |
| Other (Please specify | |

How long does it take you to get to work? ________________ (Minutes)

How far do you have to travel to work? ________________ Km

**Person 4 (M / F)**

What type of work do you do? ______________________________
Is the work full time or part-time? (Please circle) FT / PT

How many hours do you work per day? ________________ How many days do you work per week? ________________
Do you get paid per day, week or month? (Please circle) Day / Week / Month

How much do you get paid? ______________________
How do you get to work? (Please mark with x)

| | |
|---|---|
| Taxi | |
| Walking | |
| Train | |
| Bicycle | |
| Personal car | |
| Bus | |
| Other (Please specify | |

How long does it take you to get to work? ________________ (Minutes)
How far do you have to travel to work? ________________ Km

8. How many people in the household are unemployed? _______
9. How many people in the household are retired? _____
10. How many people in the household are in full-time education? __________
(Complete for each relevant person)

**10a).** How many hours/minutes per week are spent on education?
(Indicate Adult (A), Child (C) or Senior (S) and Male (M) or Female (F))

| **Person type (A, C, S and M/F)** | **Attending classes** | **Doing homework** | **Travelling to and from class** |
|---|---|---|---|
| P1 | | | |
| P2 | | | |

| | | | |
|---|---|---|---|
| P3 | | | |
| P4 | | | |
| P5 | | | |

**11.** How many hours/minutes per day are spent doing unpaid work?
(Indicate Adult (A), Child (C) or Senior (S) and Male (M) or Female (F))

| **Person type (A, C, S and M/F)** | **Caring for others (e.g. babysitting; looking after elderly)** | **Housekeeping (cleaning and maintaining the house)** | **Cooking** | **Food gardening** |
|---|---|---|---|---|
| **P1** | | | | |
| **P2** | | | | |
| **P3** | | | | |
| **P4** | | | | |
| **P5** | | | | |

**12.** How many hours/minutes per day does each person spend on the following:
(Indicate for each person Adult (A), Child (C) or Senior (S) and Male (M) or Female (F))

| **Person type ( A, C, S and M/F)** | **Collecting fuel, wood or water** | **Leisure and social activities (incl., watching TV, Radio, sports, playing pool, hanging out with friends)** | **Eating, personal care** | **Sleeping** |
|---|---|---|---|---|
| **P1** | | | | |
| **P2** | | | | |
| **P3** | | | | |
| **P4** | | | | |
| **P5** | | | | |

**13.** What are the other sources of household income per week?

| **Income source** | **Amount (Rand)** |
|---|---|
| Government grants | |
| Donations | |
| Interest on savings | |
| Rental income | |
| Personal loans | |
| Small business | |
| Other (please specify) | |

**14.** What is the total household income per week? ______

**15.** How much does the household spend in total per week/month on:
(Please indicate monthly expenses with (M) and weekly with (W)).

| Expense | Amount (Rand) – indicate monthly or weekly |
|---|---|
| Food | |
| Travel | |
| Leisure (Going out, playing pool etc.) | |
| Mobile phones (Contract, calls and data) | |
| Medical expenses | |
| Personal care (Hair, nails etc.) | |
| Household expenses (Toiletries, cleaning products, appliances | |
| House maintenance | |
| Insurance (Life, car, medical, etc.) | |
| Informal/small business | |
| Savings | |
| Clothes | |
| Paying in to Stokvel | |
| Sending money to relatives living elsewhere<br>(indicate where relatives are living – Town/Province) | |
| Education | |
| Water | |
| Loan repayment | |
| Rent | |
| Other (Please specify) | |

**16.** Does the household receive any government grants? Y / N
(If No, continue to Q 17)
16a) How much does the household receive in total from the following grants?

| Grant type | Amount |
|---|---|
| Disability | |
| Childcare | |
| Pension | |
| Social relief | |
| Other (Please specify) | |

**17.** How does the household manage cash shortfalls? (Please tick)

| | |
|---|---|
| Loans from friends | |
| Loans from family | |
| Loans from bank | |
| Savings | |
| Stokvel | |
| Other (Please specify) | |

**18.** How does the household manage cash surplus? (Please tick)

| | |
|---|---|
| Invest in own business | |
| Spend on leisure activities | |
| Spend on personal care | |
| Save | |
| Repay loans | |
| Lend to family or friends | |
| Send money to family/ friends {living in (Province / Municipality)} | |
| Other (Please specify) | |

**19.** Does the household have access to electricity? Y / N (If No, continue to Q 20)

**19a.** How is the electricity supplied?

| | |
|---|---|
| Direct via municipality | |
| Indirect through neighbor | |
| Other (please specify) | |

**19b.** How much does the electricity cost per week? ______________________________

**20.** Please indicate which fuel type you use for the following activities: (Please tick)

| | **Cooking** | **Lighting** | **Water heating** | **Space Heating** | **Electric goods** | **Other (specify)** |
|---|---|---|---|---|---|---|
| Paraffin | | | | | | |
| Wood | | | | | | |
| Gas | | | | | | |
| Candles | | | | | | |
| Coal | | | | | | |
| Solar | | | | | | |
| Biogas | | | | | | |
| Batteries | | | | | | |
| Car Batteries | | | | | | |
| Generator(petrol/diesel) | | | | | | |
| Eskom electricity | | | | | | |
| Other (please specify) | | | | | | |

**21.** –Please, indicate (in %) the proportion of fuels you use for the following activities:

| | **Cooking** | **Lighting** | **Water heating** | **Space Heating** | **Electric goods** | **Other (specify)** |
|---|---|---|---|---|---|---|
| Paraffin | | | | | | |
| Wood | | | | | | |
| Gas | | | | | | |
| Candles | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Coal | | | | | | |
| Solar | | | | | | |
| Biogas | | | | | | |
| Batteries | | | | | | |
| Car Batteries | | | | | | |
| Generator(petrol/diesel) | | | | | | |
| Eskom electricity | | | | | | |
| Other (please specify) | | | | | | |

**22.** Where do you get the fuels? (Please tick)

| | **Collect from environment** | **Buy from Spaza shop** | **Buy from shops in town** | **Produce own** | **Other (specify)** |
|---|---|---|---|---|---|
| Paraffin | | | | | |
| Wood | | | | | |
| Gas | | | | | |
| Candles | | | | | |
| Coal | | | | | |
| Solar | | | | | |
| Biogas | | | | | |
| Batteries | | | | | |
| Car Batteries | | | | | |
| Generator(petrol/diesel) | | | | | |
| Eskom electricity | | | | | |
| Other (please specify) | | | | | |

**23.** How much of each fuel type do you use per week?

| | **Kg** | **Unit** | **Litres** |
|---|---|---|---|
| Paraffin | | | |
| Wood | | | |
| Gas | | | |
| Candles | | | |
| Coal | | | |
| Solar | | | |
| Biogas | | | |
| Batteries | | | |
| Car Batteries | | | |
| Generator(petrol/diesel) | | | |
| Eskom electricity | | | |
| Other (please specify) | | | |

**24.** What is the unit cost per fuel type?

| | **R/Kg** | **R/Unit** | **R/Litres** |
|---|---|---|---|
| Paraffin | | | |
| Wood | | | |
| Gas | | | |

| | | | |
|---|---|---|---|
| Candles | | | |
| Coal | | | |
| Solar | | | |
| Biogas | | | |
| Batteries | | | |
| Car Batteries | | | |
| Generator(petrol/diesel) | | | |
| Eskom electricity | | | |
| Other (please specify) | | | |

**25.** How much does the household spend per week on each fuel types (on the average)? (Indicate in Rand)

| | **R/Unit** |
|---|---|
| Paraffin | |
| Wood | |
| Gas | |
| Candles | |
| Coal | |
| Solar | |
| Biogas | |
| Batteries | |
| Car Batteries | |
| Generator(petrol/diesel) | |
| Eskom electricity | |
| Other (please specify) | |

**26.** What energy services does the household use?

**<u>Energy services</u>**

**a. Lighting services**

| **Type of Appliances** | **Number of appliances** | **Brand / type/ size** | **Year of purchase** | **Hours of use per day** | **Hours of use per week** |
|---|---|---|---|---|---|
| Fluorescent Light bulbs (Energy saving) | | | | | |
| Incandescent light bulbs | | | | | |
| Gas lantern lamps | | | | | |
| Paraffin lamps | | | | | |
| Electric lantern | | | | | |
| Battery lamp | | | | | |
| Others (specify) | | | | | |

**b. Cooking services**

| **Type of Appliances** | **Number of appliances** | **Type/ size of burner** | **Year of purchase** | **Quantity of fuel use per month Kg/litres/units** | **Hours of use per day** | **Hours of use per week** |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| Gas stove | | | | | | |
| Paraffin stove | | | | | | |
| Electric stove | | | | | | |
| Wood burning stove | | | | | | |
| Others (specify) | | | | | | |

**c. Water heating**

| Type of Appliances | Number of appliances | Type of fuel used | Hours of use per day | Hours of use per week |
|---|---|---|---|---|
| Stove | | | | |
| Kettle | | | | |
| Solar water heater | | | | |
| Others (specify) | | | | |

**d. Space heating**

| Type of Appliances | Type/ size | Year of purchase | Quantity of fuel use per month Kg/litres/units | Hours of use per day | Hours of use per week |
|---|---|---|---|---|---|
| Gas heater | | | | | |
| Paraffin heater | | | | | |
| Electric heater | | | | | |
| Imbawula (charcoal heater) | | | | | |
| Others (specify) | | | | | |

**e. Cooling** (fan / air conditioning) please tick

| Type of Appliances | Number of appliances | Type/ size | Year of purchase | Type of fuel used | Hours of use per day | Hours of use per week |
|---|---|---|---|---|---|---|
| Fan | | | | | | |
| Air conditioner | | | | | | |
| Others (specify) | | | | | | |

f. Washing

| Type of Appliances | Number of appliances | Type/ size | Year of purchase | Hours of use per day | Hours of use per week |
|---|---|---|---|---|---|
| Washing machine | | | | | |
| Electric kettle | | | | | |
| Others (specify) | | | | | |

**g. Home Entertainment Appliances**

| Type of Appliances | Number of appliances | Type/ size | Year of purchase | Energy fuel type used | Hours of use per day | Hours of use per week |
|---|---|---|---|---|---|---|
| Television | | | | | | |
| Home theatre | | | | | | |
| DVD | | | | | | |
| Ac Radio | | | | | | |
| Dc radio /Hi-Fi | | | | | | |
| DSTV | | | | | | |
| Other | | | | | | |

**h. Small appliances**

| Type of Appliances | Number of appliances | Type/ size | Year of purchase | Energy fuel type used | Quantity of fuel per month Kg/litres/units | Hours of use per day | Hours of use per week |
|---|---|---|---|---|---|---|---|
| AC Fridge | | | | | | | |
| DC Fridge | | | | | | | |
| Iron | | | | | | | |
| Hair dryer | | | | | | | |
| Microwave | | | | | | | |
| Freezers | | | | | | | |
| Coffee machine | | | | | | | |
| Security gate | | | | | | | |
| Other (please specify) | | | | | | | |

**i. IT appliances (charging)**

| Type of Appliances | Number of appliances | Year of purchase | Type /size | Energy fuel type used | Quantity of fuel per month Kg/litres /units | Hours of use per day (charging) | Hours of use per week (charging) |
|---|---|---|---|---|---|---|---|
| Computers | | | | | | | |
| Cell-phone | | | | | | | |
| Printers | | | | | | | |
| Other (please specify) | | | | | | | |

**27.** Any other comments on the use of time, money or energy in the household:

________________________________________

________________________________________

________________________________________

________________________________________

# Appendix C : Population strucutre

Table 6-1: Data on Population Structure

| Age range | Female | Male | Total population surveyed |
|---|---|---|---|
| 0-5 | 3 | 6 | 9 |
| 5-10 | 14 | 16 | 30 |
| 10-15 | 13 | 19 | 32 |
| 15-20 | 22 | 19 | 41 |
| 20-25 | 14 | 14 | 28 |
| 25-30 | 40 | 12 | 52 |
| 30-35 | 17 | 24 | 41 |
| 35-40 | 24 | 11 | 35 |
| 40-45 | 13 | 15 | 28 |
| 45-50 | 11 | 8 | 19 |
| 50-55 | 2 | 7 | 9 |
| 55-60 | 3 | 2 | 5 |
| 60-65 | 0 | 1 | 1 |
| 65-70 | 3 | 1 | 4 |
| 75-80 | 0 | 1 | 1 |
| | 179 | 156 | 335 |

## Appendix D: Household profile

Table 6-2: Household (HH) type of an urban informal settlement consisting of their different composition pattern.

| Household profile (A: Adult; S: Senior; C: Child) | Number of households |
|---|---|
| 1 Adult | 26 |
| 1 Adult; 1 Senior | 7 |
| 1 Adult; 1 Child | 4 |
| 2 Adults | 17 |
| 1 Adult; 1 Senior; 1 Child | 1 |
| 1 Adults; 2 Senior | 1 |
| 2 Adults; 1 Senior | 11 |
| 2 Adults; 1 Child | 15 |
| 3 Adults | 4 |
| 1 Adult; 1 Senior; 2 Child | 2 |
| 1 Adult; 2 Senior; 1 Child | 1 |
| 2 Adults; 1 Senior; 1 Child | 7 |
| 2 Adults; 2 Senior | 1 |
| 2 Adults; 2 Child | 1 |
| 3 Adults; 1 Senior | 4 |
| 3 Adults; 1 Child | 3 |
| 4 Adults | 2 |
| 1 Adult; 1 Senior; 3 Child | 1 |
| 2 Adults; 1 Senior; 2 Child | 1 |
| 3 Adults; 1 Senior; 1 Child | 2 |
| 3 Adults; 2 Child | 1 |
| 4 Adults; 1 Child | 1 |
| 2 Adults; 1 Senior; 3 Child | 1 |
| 2 Adults; 2 Senior; 2 Child | 1 |
| 2 Adults; 3 Senior; 1 Child | 1 |
| 3 Adults; 1 Senior; 2 Child | 2 |
| 3 Adults; 3 Senior | 1 |
| 5 Adults; 1 Senior; 1 Child | 1 |

# Appendix E: Household monetary flows

According to the money flows in the informal settlement, it presents a low monetary throughput. However, Kayamandi presents its own internal economy connected to the much bigger Stellenbosch Municipality and formal economy. The flow of money through the settlement is traced by analysing the income and expenditure of the residents for various goods and services.

However, it is worth noting that from their human activity, Kayamandi informal settlement is a labour net provider to the Stellenbosch Municipality wherein it is connected. Where about 54% of the working age population of the sample data are employed in different sector of the economy.

From the sample of the human activity and household composition, the monetary flow of the economy is observed. As these two factors contribute to the income and expenditure structure of each households in the settlement. Other factors that contribute to the household income profile of an informal household include:

- Government grants (e.g. childcare, disability, pension, social relief etc.),
- Rentals (as observed in the case of RDP house with backyard shacks),
- Informal and / or small business,
- Interest on savings,
- Personal loans, and
- Other sources (such as income from family; observed in the case of household with people in education).

## *Household Income profile*

The represented household income profile was obtained from the surveyed data on their: Paid-Work (PW) sector, and from other sources of income such as; Government grants, Rentals, Small business (informal or formal), Interest on savings, and Personal loans.

The total monthly income distribution of the household respondents is skewed (Figure 6-1). It is observed that majority of the household respondent has one or more source of income from either (rentals, government grant, paid-work (PW), and/ family, interest on savings, and small business) with only about 2.5% having no source of income (whether that obtained from the PW sector, grants, rentals or from other income sources).

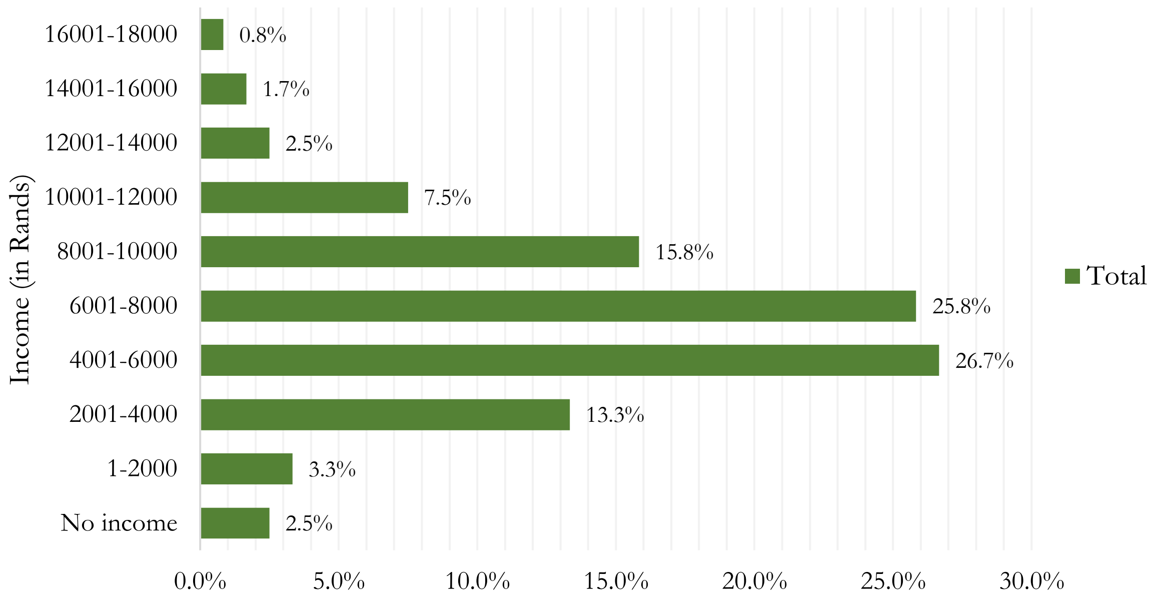


Figure 6-1: Household monthly income (in Rands per month)

However, focusing on the sample of households employed in paid work sector (such as Services and Government (SG) sector, Productive sector (Energy, building and manufacturing), and in the primary sector (Agriculture). Figure 6-2 shows households in PW sector, where those with income less than R5000 per month accounted for 40.2% of the paid work (PW) sector, where households with the highest income group (greater than R15000) only constituted 0.9% of the population sample obtained from the respondents.

In general, the figures presented in the surveyed data (Figure 6-1) indicate that urban informal household comprises of low-income households, with most household highly dependent on government grants or aid provided through childcare. However many of this households are burdened with relatively high costs for the energy consumed.

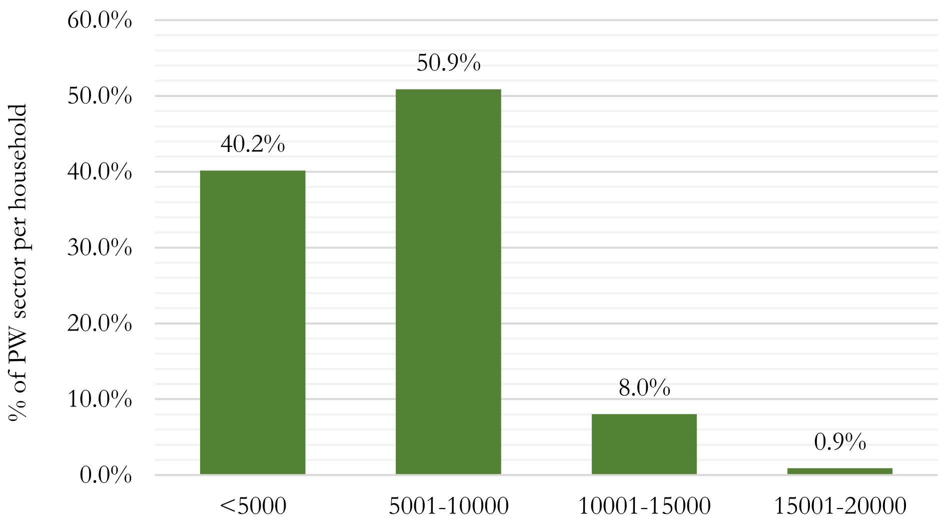


Figure 6-2: Monthly paid work (PW) income from the sampled households

However, the sampled population for the paid work (PW) sector only reflected 112 households, because a proportion of 6.7% of the sampled population were discovered to be unemployed (representing 8 households from the total 120 sampled households). Where majority of the household comprises of single adult (1 Adult) male or female. Source of income for these households are either from one or from more of the friends, family, pension grants from the government, child-care grants.

Similarly observed from the sampled population is that 57% of households in the informal settlement rely majorly on government grants (mostly from childcare, with some from pension for those with retired person in the household), whilst the 43% indicating 'No' to government grant comprise of 72.1% of households with only adults in their household composition.

The majority of the residents hail from provinces outside of Kayamandi (which is in Western Cape Province) with a large part of this group hailing from Eastern Cape Province. From the surveyed sample, based on their income flow, most of the households still holds familial ties and assets, thus prompting them to expend their cash surpluses to these other Provinces (a significant portion of their income is sent monthly; approximately two-thirds of the sampled population) which implies that they consume just part of their income in their day-to-day activities. Which also indicate that money flow extends beyond the boundary of Stellenbosch Municipality to these other regions (including outside of South Africa). The settlement as well has a distributive role, whereby, the resident generated monetary flows also feeds into the substance of the wider community and municipality. Figure 6-3 presents the money flow from household income and/ or cash surplus sent to different region.

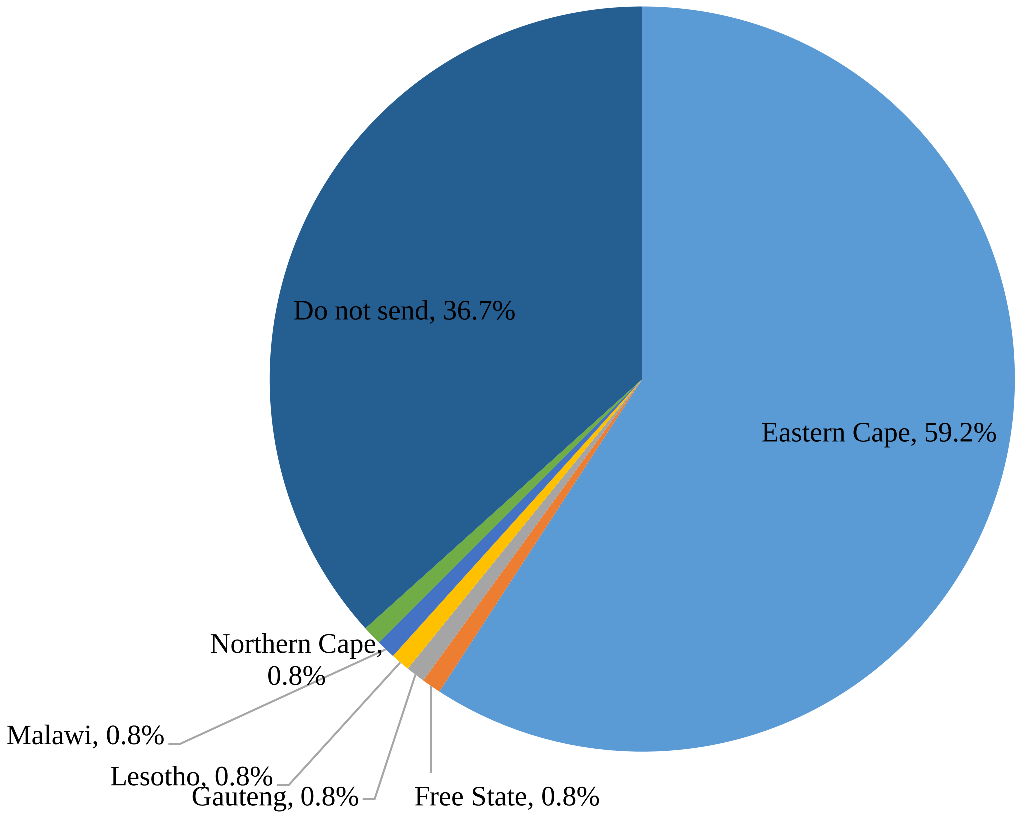



Figure 6-3: Money flow outside the settlement borders to another region.

Urban informal settlement are seen to supply different types of services as well as some being informal, they are different qualitatively from those supplied from the city. For example, from the question asked on the household management on income, about 7.6% of the sampled data indicated Stokvel[14] rather than bank for a means of obtaining loans when they have cash shortfall, while 73.3% save cash surplus money. This observation provides more insight on reason why informal settlements are not just a temporal phenomenon, but also rather a continuous existence even when there is improvement in their income and standard of living.

### *Household expenditure profile*

With respect to monetary flows, informal settlements present very low monetary throughput. As seen in the case of Kayamandi (Figure 6-4), the expenditure pattern is different across various households.

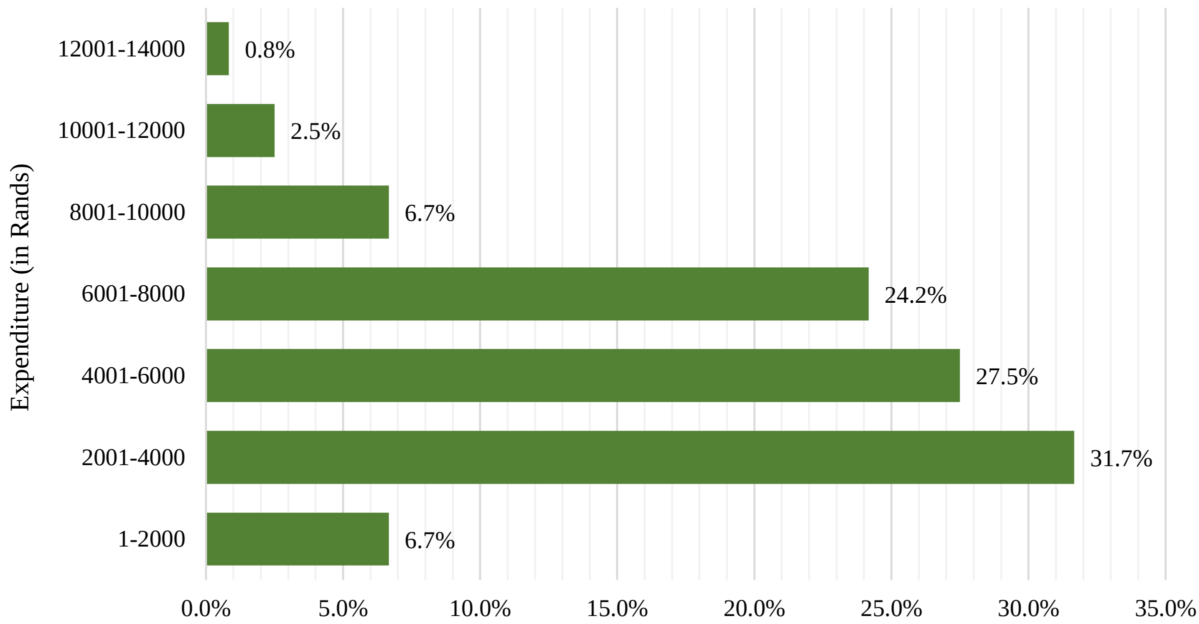


Figure 6-4: Respondents household expenditure (in Rands) per month

However, there is a significant internal economy, which is partially ascribed to informal and/ or small business (economic) activities. With most of this households earning low-income, large percentage of their income goes into food, savings, clothing and fuel and energy expenses. Households with children in education either paying as low as 200 Rand or as high as 1000 Rand, which still shows the level of poverty based on the household income structure in urban informal settlement.

The money flow pattern is traced through the household's expenditure on goods and services. One factor that influences this pattern is the household income, although, some basic goods in the household are always constant (such as, food and clothing). In particularly, the household goods and services are highlighted in (Figure 6-5), where Food constituted the largest expenditure at 18.0%, followed by Savings at 14.0%, and Clothing constituting the third largest expenditure at 9.8% of the overall budget from the sampled population.

---

[14] Stokvel is a savings scheme or credit unions in South Africa, where members of this account provides either weekly, fortnightly , or monthly basis to a joint and centralised fund accounts

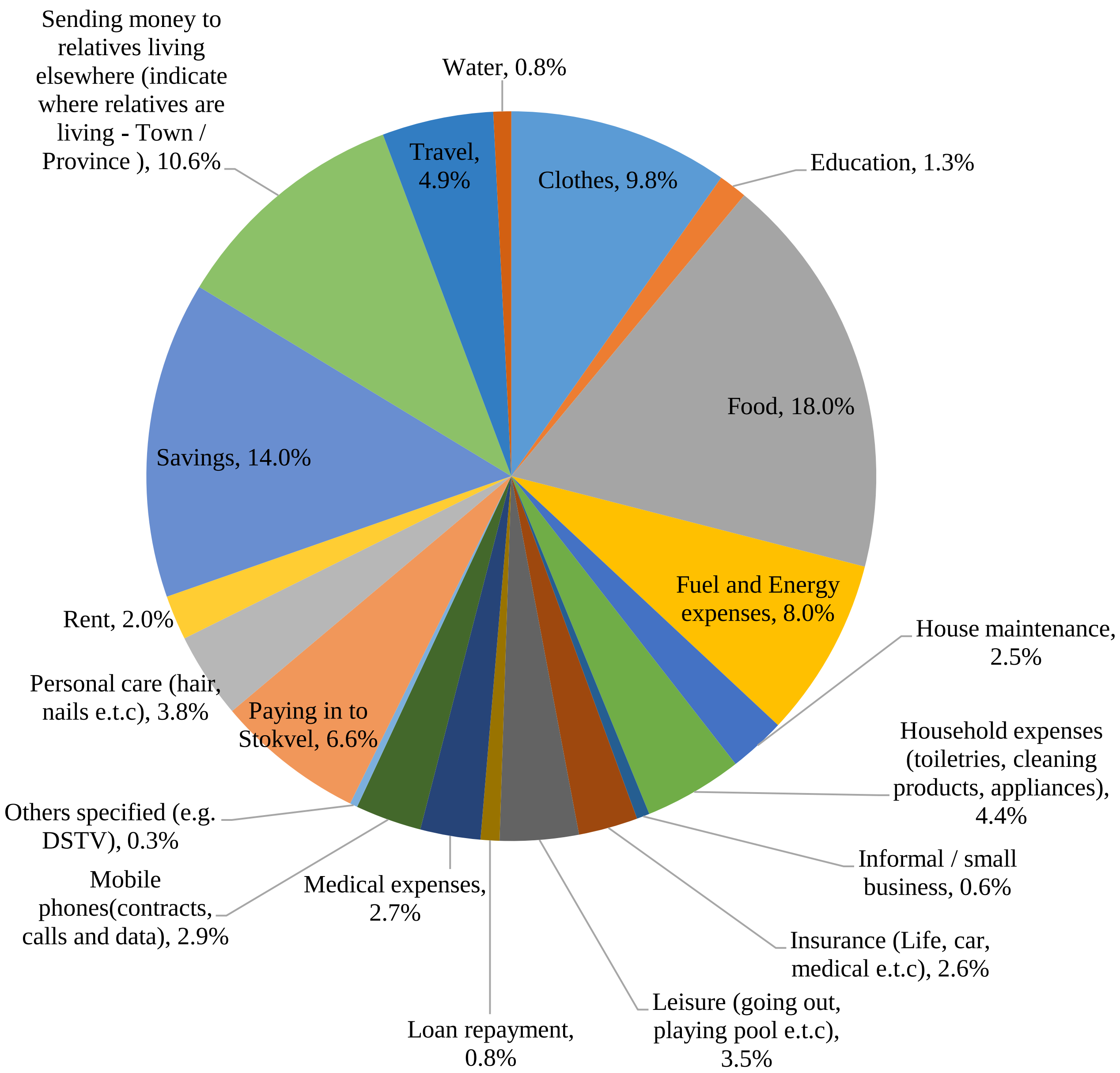



Figure 6-5: Breakdown of household (HH) expenses
Source: (119 households)

Table 6-3 presents the average household expenditure in Kayamandi informal settlement. Showing the amount spends by households on average monthly on their various household expenditure.

Table 6-3: Average monthly household expenditure

| Household Expenditure | Amount in Rands |
|---|---|
| Food | **975.25** |
| Travel | **267.57** |
| Leisure (going out, playing pool etc.) | **189.13** |
| Mobile phones(contracts, calls and data) | **158.88** |
| Medical expenses | **144.63** |
| Personal care (hair, nails etc.) | **206.13** |
| Household expenses (toiletries, cleaning products, appliances) | **236.67** |
| House maintenance | **136.33** |
| Insurance (Life, car, medical etc.) | **142.50** |
| Informal / small business | **30.92** |
| Savings | **761.37** |
| Clothes | **529.04** |
| Paying in to Stokvel | **357.21** |
| Sending money to relatives living elsewhere | **575.08** |
| Education | **68.58** |
| Water | **42.81** |
| Loan repayment | **45.25** |
| Fuel and Energy expenses | **431.82** |
| Rent | **107.25** |
| Others specified (e.g. DSTV) | **18.41** |
| Overall household expenditure (of the sampled population) | **5 424.80** |

On the other hand, South African households averagely spend at least 14% of their total monthly income on their energy needs, which is higher than international benchmark of 10% set for energy poverty, with increase in electricity prices are a threat to all South African households (Department of Energy, 2012).

Most households in urban informal settlement from the data on their building structures live in a low-income housing and are generally plagued with a very low thermal performance, with this housing having no proper roofing or ceiling (such as in the case of hostels, and shacks, as seen in Table 4-1). Which therefore leads to either excessive heat or cold depending on the seasons, which thus pushes up the energy expenditure as residents, try to keep themselves warm during winter season.

In addition, from the responses received during the face-to-face interview and the focus group[15], it increases indoor air pollution, which relates to respiratory illness from using paraffin for heating. Majority of the energy fuel used in urban informal settlement households are risky and dangerous with many the cause of shack fires.

[15] Suzanne Smit (PhD student at the School of Public Leadership, Stellenbosch University) held a focus group discussion with different household representatives form Enkanini informal settlement, Stellenbosch Municipality, 2017 on applying system dynamics to understand energy access and choices in urban informal household. The households represented the following categories: Electricity users (indirect connection, as the community is yet to be connected to the electricity grid), solar users, and households with neither of the two-energy fuel source.

# Appendix F: Household activities energy fuel type and cost

Table 6-4: Household monthly energy fuel cost with respect to their monthly income

| Monthly income ( in Rands) | Monthly fuel cost (in Rands) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1-201 | 201-400 | 401-600 | 601-800 | 801-1000 | 1001-1200 | 1201-1400 | 1401-1600 |
| No income | 0.8% | 1.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 1-2000 | 1.7% | 1.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 2001-4000 | 0.8% | 9.2% | 2.5% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% |
| 4001-6000 | 1.7% | 14.3% | 7.6% | 0.8% | 0.8% | 0.8% | 0.0% | 0.0% |
| 6001-8000 | 0.8% | 9.2% | 11.8% | 1.7% | 0.0% | 0.8% | 0.8% | 0.8% |
| 8001-10000 | 0.8% | 5.0% | 6.7% | 3.4% | 0.0% | 0.0% | 0.0% | 0.0% |
| 10001-12000 | 0.0% | 3.4% | 2.5% | 0.8% | 0.0% | 0.8% | 0.0% | 0.0% |
| 12001-14000 | 0.0% | 0.8% | 0.8% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% |
| 14001-16000 | 0.0% | 0.0% | 0.8% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% |
| 16001-1800 | 0.0% | 0.0% | 0.0% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% |

Source: own data (119 households)

Table 6-5: Main source of household energy fuel type for cooking

| Energy fuel type | % of household using the energy fuel type for cooking |
|---|---|
| Paraffin | 21.0% |
| Gas | 25.3% |
| Eskom Electricity | 53.8% |

Table 6-6: Main source of household energy fuel type for lighting

| Energy fuel type | % of household using the energy fuel type for lighting |
|---|---|
| Paraffin | 11.4% |
| Candles | 27.4% |
| Solar | 2.5% |
| Generator (petrol/diesel) | 0.5% |
| Eskom Electricity | 58.2% |

Table 6-7: Main source of household energy fuel type for water heating

| Energy fuel type | % of household using the energy fuel type for water heating |
|---|---|
| Paraffin | 21.0% |
| Gas | 8.8% |
| Solar | 6.1% |
| Eskom Electricity | 64.1% |

Table 6-8: Main source of household energy fuel type for space heating

| Energy fuel type | % of household using the energy fuel type for space heating |
|---|---|
| Paraffin | 72.9% |
| Coal | 0.9% |
| Gas | 0.9% |
| Eskom Electricity | 25.2% |

Table 6-9: Main source of household energy fuel type for electrical goods

| Energy fuel type | % of household using the energy fuel type for Electrical goods |
|---|---|
| Solar | 2.5% |
| Eskom Electricity | 97.5% |

## Appendix G: Energy consumption for household activities based on housing / building structures

**Housing Structure: RDP homes (without backyard shacks)**

| | Household activities |
|---|---|
| Energy fuel type | Cooking |
| Gas | 4 |
| Electricity | 3 |
| LP Gas & Electricity | 3 |
| Total number of sampled population households | 10 |

| | Household activities |
|---|---|
| Energy fuel type | Lighting |
| Paraffin | 0 |
| Electricity | 9 |
| Paraffin + Electricity | 1 |
| Total number of sampled population households | 10 |

| | Household activities |
|---|---|
| Energy fuel type | Water Heating |
| Gas | 0 |
| Electricity | 8 |
| Gas + Electricity | 2 |
| Total number of sampled population households | 10 |

| | Household activities |
|---|---|
| Energy fuel type | Space heating |
| Paraffin | 7 |
| Electricity | 2 |
| No space heating | 1 |
| Total number of sampled population households | 10 |

| | Household activities |
|---|---|
| Energy fuel type | Electrical appliances |
| Electricity | 10 |
| Total number of sampled population households | 10 |

**Housing structure: RDP (with backyard shacks)**

| | Household activities |
|---|---|
| Energy fuel type | Cooking |
| Electricity | 19 |
| LP Gas & Electricity | 2 |
| Paraffin & Electricity | 7 |
| LP Gas & Paraffin & Electricity | 1 |
| Total number of sampled population households | 29 |

| | Household activities |
|---|---|
| Energy fuel type | Lighting |
| Electricity | 9 |
| Paraffin & Electricity | 2 |
| Candles & Electricity | 17 |
| LP Gas & Paraffin & Electricity | 1 |
| Total number of sampled population households | 29 |

| | Household activities |
|---|---|
| Energy fuel type | Water heating |
| Electricity | 15 |
| Solar & Electricity | 11 |
| Paraffin & Electricity | 3 |
| Total number of sampled population households | 29 |

| | Household activities |
|---|---|
| Energy fuel type | Space heating |
| Paraffin | 12 |
| Gas | 1 |
| Electricity | 11 |
| Paraffin & Electricity | 1 |
| No space heating | 4 |
| Total number of sampled population households | 29 |

| | Household activities |
|---|---|
| Energy fuel type | Electrical appliances |
| Electricity | 29 |
| Total number of sampled population households | 29 |

**Housing structure : Backyard shacks**

| | Household activities |
|---|---|
| Energy fuel type | Cooking |
| Paraffin | 0 |
| Electricity | 11 |
| Paraffin & Electricity | 18 |
| LP Gas & Electricity | 1 |
| Total number of sampled population households | 30 |

| | Household activities |
|---|---|
| Energy fuel type | Lighting |
| Electricity | 2 |
| Paraffin & Electricity | 3 |
| Candles & Electricity | 25 |
| Total number of sampled population households | 30 |

| | Household activities |
|---|---|
| Energy fuel type | Water Heating |
| Electricity | 7 |
| Gas & Electricity | 1 |
| Paraffin & Electricity | 22 |
| Total of number of sampled population households | 30 |

| | Household activities |
|---|---|
| Energy fuel type | Space heating |
| Paraffin | 20 |
| Coal | 1 |
| Electricity | 2 |
| Paraffin & Electricity | 1 |
| No space heating | 6 |
| Total number of sampled population households | 30 |

| | Household activities |
|---|---|
| Energy fuel type | Electrical appliances |
| Electricity | 30 |
| Total number of sampled population households | 30 |

**Housing structure: Hostels**

| | Household activities |
|---|---|
| Energy fuel type | Cooking |
| LP Gas | 2 |
| Electricity | 1 |
| LP Gas & Electricity | 5 |
| Total number of sampled population households | 8 |

| | Household activities |
|---|---|
| Energy fuel type | Lighting |
| Electricity | 4 |
| Paraffin & Electricity | 4 |
| Total number of sampled population households | 8 |

| | Household activities |
|---|---|
| Energy fuel type | Water heating |
| Electricity | 7 |
| Paraffin & Electricity | 1 |
| Total number of sampled population households | 8 |

| | Household activities |
|---|---|
| Energy fuel type | Space heating |
| Paraffin | 7 |
| No space heating | 1 |
| Total number of sampled population households | 8 |

| | Household activities |
|---|---|
| Energy fuel type | Electrical appliances |
| Electricity | 8 |
| Total number of sampled population households | 8 |

**Housing structure: Municipal flats**

| | Household activities |
|---|---|
| Energy fuel type | Cooking |
| Electricity | 4 |
| LP Gas & Electricity | 2 |
| Total number of sampled population households | 6 |

| | Household activities |
|---|---|
| Energy fuel type | Lighting |
| Electricity | 5 |
| Candles & Electricity | 1 |
| Total number of sampled population households | 6 |

| | Household activities |
|---|---|
| Energy fuel type | Water heating |
| Electricity | 5 |
| LP Gas & Electricity | 1 |
| Total number of sampled population households | 6 |

| | Household activities |
|---|---|
| Energy fuel type | Space heating |
| Paraffin | 5 |
| No space heating | 1 |
| Total number of sampled population households | 6 |

| | Household activities |
|---|---|
| Energy fuel type | Electrical appliances |
| Electricity | 6 |
| Total number of sampled population households | 6 |

**Housing structure: Freestanding shacks**

| | Household activities |
|---|---|
| Energy fuel type | Cooking |
| LP Gas | 13 |
| Electricity | 1 |
| Paraffin & Electricity | 9 |
| LP Gas & Electricity | 10 |
| Paraffin & LP Gas | 1 |
| Paraffin & LP Gas & Electricity | 3 |
| Total number of sampled population households | 37 |

| | Household activities |
|---|---|
| Energy fuel type | Lighting |
| Solar | 3 |
| Electricity | 9 |
| Paraffin & Electricity | 11 |
| Candles & Electricity | 10 |
| Solar & Electricity | 2 |
| Generator & Electricity | 1 |
| Paraffin & Candles & Electricity | 1 |
| Total number of sampled population households | 37 |

| | Household activities |
|---|---|
| Energy fuel type | Water heating |
| Paraffin | 1 |
| LP Gas | 3 |
| Electricity | 13 |
| Paraffin & Electricity | 11 |
| LP Gas & Electricity | 9 |
| Total number of sampled population households | 37 |

| | Household activities |
|---|---|
| Energy fuel type | Space heating |
| Paraffin | 20 |
| Electricity | 5 |
| Paraffin & Electricity | 5 |
| No space heating | 7 |
| Total number of sampled population households | 37 |

| | Household activities |
|---|---|
| Energy fuel type | Electrical appliances |
| Solar | 3 |
| Electricity | 34 |
| Total number of sampled population households | 37 |

## Appendix H: Total energy consumption per household by building structures and household type

| Building structure | HH Type | Electricity consumption (monthly) | Gas consumption (monthly) | Paraffin consumption (monthly) |
|---|---|---|---|---|
| RDP (without backyard shacks) | 1 Adult | 412.692 | 0 | 20 |
| | 2 Adults | 899.164 | 0 | 0 |
| | 2 Adults; 1 Child | 5798.272 | 9 | 5 |
| | 1 Adult | 329.532 | 0 | 8 |
| | 2 Adults; 1 Senior | 149.128 | 5 | 16 |
| | 1 Adult | 133.52304 | 5 | 0 |
| | 3 Adults | 244.128 | 5 | 12 |
| | 5 Adults; 1 Senior; 1 Child | 1123.704 | 5 | 12 |
| | 2 Adults; 1 Senior | 193.95312 | 5 | 0 |
| | 1 Adult | 175.484 | 5 | 12 |

| Building structure | HH Type | Electricity consumption (monthly) | Gas consumption (monthly) | Paraffin consumption (monthly) |
|---|---|---|---|---|
| Municipal Flats | 1 Adult | 225.464 | 0 | 0 |
| | 2 Adults | 205.072 | 5 | 12 |
| | 1 Adult | 396.404 | 0 | 12 |
| | 2 Adults; 2 Child | 341.952 | 5 | 16 |
| | 1 Adult | 278.684 | 0 | 8 |
| | 1 Adult; 1 Child | 691.532 | 0 | 12 |

| Building structure | HH Type | Electricity consumption (monthly) | Gas consumption (monthly) | Paraffin consumption (monthly) |
|---|---|---|---|---|
| Hostels | 2 Adults; 1 Senior | 262.36 | 5 | 16 |
| | 2 Adults | 339.784 | 5 | 8 |
| | 1 Adult | 234.96 | 5 | 12 |
| | 1 Adult | 184.576 | 5 | 0 |
| | 2 Adults | 248.248 | 5 | 12 |
| | 2 Adults; 1 Senior; 1 Child | 746.144 | 5 | 12 |
| | 2 Adults | 393.624 | 0 | 12 |
| | 2 Adults | 158.192 | 5 | 12 |

| Building structure | HH Type | Electricity consumption (monthly) | Gas consumption (monthly) | Paraffin consumption (monthly) |
|---|---|---|---|---|
| Free Standing | 2 Adults | 189.74 | 5 | 20 |
| | 2 Adults; 1 Child | 263.96 | 5 | 12 |
| | 2 Adults; 1 Senior; 1 Child | 330.088 | 9 | 20 |
| | 1 Adult; 1 Senior; 3 Child | 440.912 | 9 | 12 |
| | 3 Adults; 1 Child | 121.792 | 0 | 8 |
| | 2 Adults; 1 Senior; 1 Child | 304.14 | 3 | 0 |
| | 1 Adult | 0.224 | 5 | 0 |
| | 1 Adult; 1 Child | 0.096 | 5 | 0 |
| | 2 Adults; 1 Child | 326.044 | 5 | 16 |
| | 3 Adults; 1 Senior; 1 Child | 311.272 | 5 | 8 |
| | 2 Adults | 535.888 | 5 | 0 |
| | 3 Adults | 382.616 | 5 | 5 |
| | 1 Adult | 138.324 | 5 | 0 |
| | 3 Adults; 1 Senior | 405.38 | 0 | 20 |
| | 2 Adults; 2 Senior | 332.816 | 9 | 40 |
| | 2 Adults; 3 Senior; 1 Child | 115.108 | 3 | 8 |
| | 2 Adults; 1 Senior | 511.216 | 0 | 40 |
| | 2 Adults | 303.588 | 0 | 12 |
| | 1 Adult | 0.096 | 5 | 0 |
| | 2 Adults; 1 Child | 233.304 | 5 | 8 |
| | 2 Adults | 167.496 | 5 | 16 |
| | 2 Adults; 1 Child | 192.032 | 5 | 12 |
| | 1 Adult | 232.716 | 9 | 0 |
| | 2 Adults; 1 Senior | 184.072 | 5 | 12 |
| | 2 Adults; 1 Senior | 152.404 | 0 | 20 |
| | 1 Adult | 204.512 | 5 | 8 |
| | 3 Adults; 1 Child | 565.212 | 5 | 0 |
| | 3 Adults; 1 Senior; 1 Child | 690.616 | 0 | 12 |
| | 1 Adults; 2 Senior | 450.376 | 0 | 8 |
| | 3 Adults; 1 Child | 482.004 | 0 | 20 |
| | 2 Adults; 1 Senior; 1 Child | 448.536 | 0 | 12 |
| | 2 Adults; 1 Child | 465.972 | 0 | 8 |
| | 1 Adult | 149.244 | 5 | 0 |
| | 1 Adult | 166.744 | 5 | 8 |
| | 2 Adults; 1 Senior | 243.704 | 5 | 16 |
| | 1 Adult; 1 Senior | 166.54 | 5 | 0 |
| | 2 Adults; 1 Child | 161.484 | 5 | 12 |

| Building structure | HH Type | Electricity consumption (monthly) | Gas consumption (monthly) | Paraffin consumption (monthly) |
|---|---|---|---|---|
| RDP (with backyard shacks) | 1 Adult; 1 Child | 413.352 | 0 | 20 |
| | 2 Adults; 1 Senior; 2 Child | 672.504 | 0 | 8 |
| | 2 Adults; 1 Senior | 540.48 | 0 | 16 |
| | 4 Adults | 580.688 | 0 | 20 |
| | 2 Adults; 1 Child | 355.112 | 0 | 12 |
| | 3 Adults; 1 Senior | 366.824 | 0 | 12 |
| | 2 Adults; 1 Senior; 1 Child | 570.064 | 0 | 8 |
| | 2 Adults; 2 Senior; 2 Child | 777.576 | 0 | 16 |
| | 3 Adults; 1 Senior | 446.428 | 0 | 20 |
| | 2 Adults; 1 Child | 607.944 | 0 | 16 |
| | 2 Adults; 1 Child | 466.92 | 5 | 12 |
| | 2 Adults; 1 Senior; 3 Child | 657.968 | 0 | 16 |
| | 2 Adults; 1 Child | 434.812 | 0 | 0 |
| | 1 Adult; 1 Senior | 365.82 | 0 | 0 |
| | 3 Adults; 1 Senior; 2 Child | 650.104 | 0 | 20 |
| | 3 Adults; 3 Senior | 593.2 | 5 | 0 |
| | 2 Adults; 1 Senior; 1 Child | 776.552 | 5 | 20 |
| | 3 Adults | 742.392 | 0 | 20 |
| | 2 Adults | 620.624 | 0 | 0 |
| | 3 Adults | 852.072 | 0 | 0 |
| | 2 Adults; 1 Senior | 514.584 | 0 | 20 |
| | 2 Adults | 616.504 | 0 | 8 |
| | 2 Adults; 1 Senior | 1151.112 | 0 | 16 |
| | 1 Adult; 2 Senior; 1 Child | 330.784 | 0 | 16 |
| | 4 Adults | 1358.392 | 0 | 12 |
| | 2 Adults; 1 Senior | 655.872 | 0 | 20 |
| | 3 Adults; 1 Senior | 1213.296 | 5 | 0 |
| | 2 Adults; 1 Senior; 1 Child | 674.072 | 0 | 0 |
| | 1 Adult; 1 Senior | 490.944 | 0 | 8 |

| Building structure | HH Type | Electricity consumption (monthly) | Gas consumption (monthly) | Paraffin consumption (monthly) |
|---|---|---|---|---|
| Backyard shacks | 2 Adults; 1 Child | 417.772 | 0 | 20 |
| | 1 Adult | 320.224 | 0 | 8 |
| | 2 Adults | 604.74 | 0 | 20 |
| | 1 Adult | 333.564 | 0 | 8 |
| | 1 Adult | 334.464 | 0 | 8 |
| | 3 Adults; 1 Senior; 2 Child | 369.772 | 0 | 8 |
| | 2 Adults | 617.768 | 0 | 16 |
| | 1 Adult | 204.512 | 0 | 8 |
| | 2 Adults | 265.62 | 0 | 12 |
| | 1 Adult; 1 Senior | 414.724 | 0 | 8 |
| | 1 Adult | 549.424 | 0 | 0 |
| | 4 Adults; 1 Child | 728.48 | 0 | 8 |
| | 2 Adults | 413.452 | 0 | 4 |
| | 1 Adult | 337.312 | 0 | 8 |
| | 1 Adult; 1 Senior | 422.68 | 0 | 8 |
| | 1 Adult; 1 Senior; 2 Child | 437.108 | 0 | 0 |
| | 2 Adults; 1 Child | 347.612 | 0 | 8 |
| | 2 Adults; 1 Child | 425.488 | 0 | 8 |
| | 1 Adult | 172.36 | 0 | 8 |
| | 1 Adult; 1 Child | 451.724 | 0 | 8 |
| | 1 Adult | 410.158 | 0 | 8 |
| | 1 Adult; 1 Senior; 2 Child | 318.936 | 0 | 12 |
| | 1 Adult; 1 Senior; 1 Child | 415.976 | 0 | 12 |
| | 1 Adult; 1 Senior | 122.864 | 0 | 8 |
| | 1 Adult | 157.584 | 0 | 8 |
| | 1 Adult | 318.164 | 0 | 0 |
| | 2 Adults; 1 Child | 512.116 | 0 | 8 |
| | 2 Adults | 373.936 | 5 | 0 |
| | 3 Adults; 2 Child | 509.124 | 0 | 12 |
| | 1 Adult; 1 Senior | 414.696 | 0 | 8 |