

Connecting the urban informal settlement to the city: A systems approach

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Abstract

Understanding increasing urbanisation and the proliferation of slums requires a holistic scrutiny of the metabolism of cities. However, existing urban metabolic analyses exclude a detailed grasp of how urban slums function and contribute to the metabolism of cities. Furthermore, conventional urban metabolism analytical methods are not suited to capturing informal flows and processes that contribute to urban resource use. This study therefore investigated the questions: i) What are urban informal settlements and how do they connect to the broader urban context? and ii) How does a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach contribute to the study of informal settlements in the context of sustainable urban development? The first question was addressed through a critical literature review which provided the global perspective and understanding of slums. A conceptual framework was developed for classifying urban slums based on physical and legal characteristics, forming the basis upon which different slum types may be analysed. In applying the typology to South Africa, it was found to exhibit a more nuanced typology, where five distinguishable settlement types were established. However, to achieve sustainable urban development, it is argued that urban informal settlements also need to be analysed from a metabolic perspective. The study then focused on one particular slum type, using the case study of Enkanini informal settlement in Stellenbosch, and applied MuSIASEM to address question two and to demonstrate that the societal metabolic dimension of the settlement can be quantified in terms of the use of time, money and energy. The results highlight issues to be addressed through spatial, developmental and local economic policy, such as the need for improved transport linkages. Furthermore, the MuSIASEM results highlighted issues related to the introduction of a renewable energy solution, in the form of solar photovoltaic (PV) systems, to address energy access. This led to the emergence of a third research question: What are the electricity legitimacy dynamics of Enkanini informal settlement? While it is argued that MuSIASEM is a suitable approach for analysing the metabolic dimension of slums, it does not account for sociopolitical dynamics that influence the metabolic dimension. The study therefore further used Community Based System Dynamics to investigate the electricity legitimacy dynamics in the Enkanini informal settlement. Several causal relationships between the factors that affect energy fuel choice and energy access in Enkanini were found, resulting in 17 feedback loops. The use of Community Based System Dynamics

modelling identified the root cause of the resistance to solar PV energy as threatening residents' struggle for legitimacy. The key feedback loops related to community empowerment and representation. Finally, this study demonstrates the need for deeper engagement and transparent communication with the residents of informal settlements, and recognition of the non-technical, and aspirational factors that drive their energy behaviours. Whilst the Enkanini case does not deliver a comprehensive set of metabolism results, as an exploratory study into the societal metabolism of slums, it has led to and informed several subsequent studies and contributes to the development and improvement of the method for future cases.

Opsomming

Om toenemende verstedeliking en die uitbreiding van krotbuurte te verstaan, moet die metabolisme van stede holisties bestudeer word. Tog slaan bestaande stedelike metaboliese ontledings nie juis ag op die besonderhede van hoe stedelike krotbuurte funksioneer en tot die metabolisme van stede bydra nie. Daarbenewens is konvensionele stedelike metaboliese ontledingsmetodes nie geskik om die informele vloei en prosesse wat tot stedelike hulpbrongebruik bydra, vas te lê nie. Hierdie studie ondersoek dus die volgende vrae: (i) Wat is stedelike informele nedersettings, en hoe hou dit met die groter stedelike konteks verband? (ii) Hoe kan 'n multiskaal-geïntegreerde assesseringsbenadering tot samelewings- en ekosisteemetabolisme (MuSIASEM) bydra tot die studie van informele nedersettings teen die agtergrond van volhoubare stedelike ontwikkeling? Die eerste navorsingsvraag is met behulp van 'n kritiese literatuurstudie ondersoek. Uit die literatuur het die globale siening en begrip van krotbuurte geblyk. 'n Konseptuele raamwerk is ontwikkel om stedelike krotbuurte op grond van fisiese en regskenmerke te klassifiseer. Hierdie tipe klassifikasie maak die grondslag uit waarop verskillende soorte krotbuurte ontleed kan word. Wanneer die tipologie op Suid-Afrika toegepas word, blyk dit meer genuanseerd te wees, en word vyf nedersettingstipes onderskei. Om egter volhoubare ontwikkeling in die hand te werk, moet stedelike informele nedersettings ook uit 'n metaboliese oogpunt ontleed word. Dus het die studie op een bepaalde tipe krotbuurt, naamlik die gevallestudie van die informele nedersetting Enkanini op Stellenbosch, gekonsentreer en die MuSIASEM-benadering toegepas om te toon dat die metabolisme van die nedersetting volgens tyd-, geld- en energiegebruik gekwantifiseer kan word. Die resultate bring kwessies aan die lig wat deur ruimtelike, ontwikkelings- en plaaslike ekonomiese beleid hanteer moet word, soos die behoefte aan beter vervoeraansluitings. Voorts lig die MuSIASEM-resultate ook kwessies, veral in verband met die bekendstelling van 'n hernubare energieoplossing in die vorm van fotovoltaïese (FV) sonkragstelsels. Hieruit ontstaan 'n derde navorsingsvraag: Wat is die elektrisiteitslegitimititeit van Enkanini? Hoewel MuSIASEM dalk geskik is om die metabolisme van krotbuurte te ontleed, verklaar dit nie die sosiopolitieke dinamiek wat die metabolisme beïnvloed nie. Daarom het die studie ook gemeenskapsgebaseerde stelseldinamiekmodellering gebruik om die elektrisiteitslegitimititeit in Enkanini te ondersoek. Verskeie oorsaaklike verbande is gevind tussen die faktore wat energiebrandstofkeuse en energietoegang in Enkanini

beïnvloed. Hieruit is 17 terugvoerlusse geïdentifiseer. Die gemeenskapsgebaseerde stelselsdinamiekmodellering dui op teenkating teen FV sonenergie as die hoofbedreiging vir inwoners se stryd om legitimiteit. Die belangrikste terugvoerlusse hou met gemeenskapsbemagtiging en -verteenvoording verband. Laastens dui die studie op die behoefte aan sinvoller skakeling en deursigtige kommunikasie met die inwoners van informele nedersettings, sowel as aan erkenning van die nie-tegniese en aspirasiefaktore wat hulle energiegedrag bepaal. As 'n ondersoekende studie van die samelewingsmetabolisme van krotbuurte, lewer die Enkanini-geval nie 'n omvattende stel metaboliese resultate op nie, maar dien dit wel as grondslag en rigsnoer vir verskeie verdere studies en dra ook tot die ontwikkeling en verbetering van die metode vir toekomstige navorsing by.

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List of acronyms and abbreviations

CBSD	Community Based System Dynamics
DoE	Department of Energy
GDP	gross domestic product
ILO	International Labour Organization
MW	megawatt
MuSIASEM	Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism
NGO	nongovernmental organisation
PV	photovoltaic
RSA	Republic of South Africa
SDG	sustainable development goal
StatsSA	Statistics South Africa
SWH	solar water heater
UN	United Nations
UNEP	United Nations Environmental Programme
UN-Habitat	United Nations Human Settlements Programme

Glossary of terms

Informality

Informality emerges from the bottom up and is often reflected in the practices and activities that take place in the city in response to the everyday needs of urban dwellers. According to Guibrunet and Castán Broto (2015: 4), the term is applied in the case of housing, the economy and service provision.

Informal economy

The term 'informal economy' has been used to describe:

economic activities by workers and economic units that are – in law or in practice – not covered or insufficiently covered by formal arrangements. These activities are not included in the law, which means that those conducting such activities are operating outside the formal reach of the law; or they are not covered in practice, which means that – although they are operating within the formal reach of the law, the law is not applied or not enforced; or the law discourages compliance because it is inappropriate, burdensome or imposes excessive costs (ILO, 2003).

Informal settlements

Urban informal settlements are usually located in urban areas and consist of dwelling units that are made of materials such as zinc, mud, wood and plastics. They are typically disorderly and congested and are sometimes referred to as squatter settlements (StatsSA, 2008). Within this document, it is recognised that there are several settlement types in South Africa, while the term informal settlement is used interchangeably with 'slum'.

Informal city

The informal city results from informality, which encompasses patterns of spatial organisation, social relations and economic exchanges, and from the bottom-up provision of urban goods and services, including housing, employment and infrastructure where government has failed to deliver (Guibrunet and Castán Broto, 2015). Within this study, the informal city is an urban informal settlement, which encompasses a particular spatial organisation, with its own informal economy, and is

often characterised by poor infrastructure and service delivery.

Slums

The United Nations defines slums as pertaining to households that lack any one of the following: (i) access to improved water; (ii) access to improved sanitation facilities; (iii) sufficient living area – not overcrowded; (iv) structural quality/durability of dwellings; and (v) security of tenure (UN-Habitat, 2010).

CHAPTER 1: INTRODUCTION

1.1 Background and rationale

Globally, developmental and environmental challenges including increasing urbanisation, persistent poverty, unemployment, resource scarcity and climate change necessitate nation states to respond in a way that is socially equitable, environmentally sustainable, and economically viable (Lorek and Spangenberg, 2014; Davies, 2013; Swilling and Annecke, 2012). In particular, there is an increased focus on recognising urban centres or cities as being both the largest consumers of global resources and as providing possible opportunities as ‘drivers of sustainable development’ (Musango, Currie and Robinson, 2017; Klopp and Petretta, 2017). This juxtaposition has also been recognised within the sustainable development goals (SDGs) of the United Nations, particularly SDG 11 on Sustainable Cities and Communities (UN, 2016) and the New Urban Agenda (UN, 2017), which was adopted in 2016 at the UN Conference on Housing and Sustainable Urban Development (Habitat III).

If left unchecked, increasing urbanisation would suggest that the material consumption of cities may escalate, however this would be unsustainable, given resource scarcity. This points to the need to understand current urban resource use and future resource requirements (IRP, 2018). The International Resource Panel (IRP, 2018) suggests that, ‘resources should now become a central policy concern’; while the United Nations emphasises the need for accurate, timely and disaggregated data and statistics, as well as new methodologies that would ensure the quality and reliability of data (UN, 2017; UN-DESA, 2017).

1.2 The need for inclusive urban metabolism assessments

The notion of Sustainable Development is highly contested, encompassing interpretations based on divergent worldviews with a myriad of perspectives positioned on a continuum between the extremes (Mebratu, 1998; Sneddon, Howarth, and Norgaard, 2005; Gallopin, 2003). The concept has its historical roots from the United Nations Conference on the Human Environment in Stockholm in 1972 and has led to the emergence of the term 'sustainable development' in 1987 (Rogers, Jalal and Boyd, 2005). Over time, and due to various influences, the concept has sprouted various definitions, principles, criteria, conceptual frameworks and indicators, making it difficult to reach consensus on one clearly defined and widely accepted understanding of these terms. Sustainable development, however is generally presented as the relationship among economic development, environmental quality and social equity (Rogers et al., 2005).

Within the South African context, the mandate for sustainable development was first entrenched within the nation's Bill of Rights in the 1996 Constitution (Montmasson-Clair, 2012). Sustainable development is defined by the South African National Framework for Sustainable Development (NFSD), as follows:

South Africa aspires to be a sustainable, economically prosperous and self-reliant nation state that safeguards its democracy by meeting the fundamental human needs of its people, by managing its limited ecological resources responsibly for current and future generations, and by advancing efficient and effective integrated planning and governance through national, regional and global collaboration (DEA, 2018).

As a developing nation, South Africa faces pressing challenges of unemployment, poverty, inequality and environmental degradation (Du Toit and Neves, 2007; Peter and Swilling, 2011; Swilling and Annecke, 2012). For this reason, the nation set five strategic priority areas for action and intervention to reach a state of sustainable development. These priority areas include (DEA, 2018):

- Enhancing systems for integrated planning and implementation;
- Sustaining our ecosystem and using natural resources efficiently;
- Economic development via investing in sustainable infrastructure;

- Creating sustainable human settlements; and
- Responding appropriately to emerging human development, economic and environmental challenges.

Furthermore, South Africa has embraced the notion of an inclusive green economy as a pathway to sustainable development, and therefore views it as an opportunity to simultaneously address several socioeconomic issues related to poverty, social justice and equality (Smit and Musango, 2015).

On a global scale, South Africa has been party to several international conventions and agreements related to sustainable development (Allen, 2012a, 2012b; Montmasson-Clair, 2012) including Agenda 2030 and its 17 Sustainable Development Goals or Global Goals (see Figure 1.1). The Sustainable Development Goals came into effect in 2016 and will remain in effect until 2030, replacing the Millennium Development Goals, and includes new focal areas such as ‘climate change, economic inequality, innovation, sustainable consumption, peace and justice’ (UNDP, 2018).



Figure 1.1: List of Sustainable Development Goals

Source: UNDP, 2018

It is recognised that the goals are interconnected, 'meaning that success in one affects success for others' (UNDP, 2018), but of particular interest, are goals 7 and 11. Sustainable development goal 7: Affordable and Clean energy, relates to (UN, 2018):

- i) achieving universal access to affordable, reliable and modern energy services by 2030;
- ii) substantially increasing the share of renewable energy in the global energy mix;
- iii) doubling the global rate of energy efficiency;
- iv) enhancing international cooperation to facilitate access to clean energy research and technology and promote investment in energy infrastructure and clean technology; and
- v) expanding infrastructure and upgrading technology to supply modern and sustainable energy services for all people living in developing countries.

Whereas, sustainable development goal 11: Sustainable cities and communities, aims to achieve the following (UN, 2018):

- i) ensure access to adequate, safe and affordable housing and basic services and upgrade of slums;
- ii) provide access to safe, affordable, accessible and sustainable transport systems for all;
- iii) enhance inclusive and sustainable urbanisation and capacity for participatory, integrated and sustainable human settlement planning and management in all countries;
- iv) improve efforts that protect and safeguard cultural and natural heritage;
- v) significantly reduce deaths and number of people affected by direct economic losses relative to global gross domestic product related to disasters;
- vi) reduce adverse per capita environmental impact of cities;
- vii) provide universal access to safe, inclusive and accessible green and public spaces;

- viii) support positive economic, social and environmental links between urban, peri-urban and rural areas;
- ix) substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation of climate change, resilience to disasters, and develop and implement holistic disaster risk management at all levels; and
- x) support least developed countries in building sustainable and resilient buildings utilizing local materials.

From the discussion on the South African stance on sustainable development as well as the objectives of the global goals, it is clear that there is a drive for growth and development that is not only economically viable and environmentally sustainable, but that such growth also be inclusive and socially equitable. This would suggest that methods utilised for contributing towards achieving these goals would need to be broad and inclusive as well.

The implementation of the sustainable development goals however has not been without issues, and one of the areas that have been identified for improvement relates to data.

To fully implement and monitor progress on the SDG's, decision makes need data and statistics that are accurate, timely, sufficiently disaggregated, relevant, accessible and easy to use...

...It will also demand innovative ways to produce and apply data and statistics in addressing the multi-faceted challenges of sustainable development (UN, 2017).

In this regard, Musango et al. (2017) suggest that "urban metabolism assessment is a relevant concept for spatial planning and urban development in order to support a resource efficiency transition". However, while there is theoretical merit to the potential of urban metabolism to support urban planning and design; practical implementation has been limited (Musango et al., 2017). Furthermore,

conventional urban metabolism studies tend to focus on formalised resource flows; utilising secondary, highly aggregated data; ignoring political contexts; and excluding informal settlements or slums in their analyses (Guibrunet, Sanzana Calvet, and Castán Broto, 2016; Currie and Musango, 2016; Guibrunet and Castán Broto, 2015; Newell and Cousins 2015; Attia and Khalil 2015; Pincetl, Bunje and Holmes, 2012).

Considering that a third of the global urban population live in slums and that the majority of projected urbanites may end up in slum conditions (IRP, 2018; UN-DESA, 2015), this approach may be inadequate for sustainable and equitable urban policy and planning. Therefore, in order to contribute to achieving Sustainable Development Goal 11 targets and indicators, a broader, more inclusive approach to understanding urban metabolism is vital.

1.3 The need for systems approach for inclusive urban metabolism assessments

Giddings, Hopwood, and O'Brien (2002), suggest that the three spheres or sectors of sustainable development cannot be viewed as separate, but should rather be considered as 'nested' within one another. In order to integrate the three spheres, Hardi and Zdan (In Giddings et al. 2002) suggest that one needs to take a "whole systems approach that appreciates emergent properties, complexity and interactions". Gallopin (2003) concurs with this view and suggests that a systems approach is perhaps more useful than analytical approaches because of its focus on relationships, connections and context (Gallopin, 2003). Furthermore, Blewitt (2008) states that some phenomena cannot adequately be analysed, using linear, reductionist methods as they offer too many 'variables, uncertainties and possibilities'. This is where systems thinking offers a possible solution in that it is able to view problems and possibilities as simultaneously multidimensional, dynamic and evolving (Blewitt, 2008).

General systems theory provides a unifying analytical and explanatory framework, which entails considering the various agents interacting in the world as systems (Clayton & Radcliffe, 1996). It associates the concept of system with the principle of holism and developed from the need for an intelligent and sophisticated form of reductionism to compensate for the classical reductionist paradigm, which attempts to explain the whole based on a study of the component parts (Morin, 1992; Clayton & Radcliffe, 1996). Holism, in contrast seeks explanation at the level of totality (Morin, 1992).

Systems theory invokes certain general principles related to systems and focuses on identifying and describing the connections between components rather than just focusing on the component parts themselves as a way to explain the whole. Morin (1992) explains that a system should not only be considered in terms of the relations between the whole and the parts, but that the complex nature of these relations should also be taken into consideration. The perspective from complexity assists in creating a deeper understanding of systems whilst recognising that one cannot know everything (Cilliers, 2000a). This makes one more sensitive and cautious in choosing methods of analysis; in making decisions; planning for the future and in being more aware of the temporal and spatial boundaries of such decisions, that is their context (Cilliers, 1998; 2000a; 2000b; 2003; Max-Neef, 2004). Complexity theory evolved as an alternative way of thinking regarding certain phenomena that are not easily explained by a modernist, rational approach and recognises that “in a system, there are more possibilities than can be actualised” (Luhmann In: Cilliers, 1998).

The meaning of complexity and the complexity perspective also emerges as creating a space between modern and postmodern approaches (Emmeche, 2004). According to Cilliers (1998), a modernist approach to dealing with complexity involves finding secure points of reference from which everything else could be derived but, he argues: “this strategy in fact constitutes an avoidance of complexity” (Cilliers, 1998). Postmodernity exists in contrast to the modernist approach (Bauman, 1992). Having many proponents with different interpretations, Bauman (1992), prefers to view it as ‘a state of mind’. Being first and foremost self-

critical, this perspective does not aim to replace one truth for another or to create a grand narrative but is marked by an 'all-deriding, all-eroding, all-dissolving destructiveness,' or rather a constructive destructiveness to 'find the truth of the truth' (Bauman, 1992).

Taken to its extreme, postmodernism is criticised for being relative and subversive, but according to Cilliers (1998), complexity is able to bridge the two approaches and avoid such extremes. Such a post-structural approach is deemed to be much more sensitive to the complex nature of phenomena (Cilliers, 1998). Emmeche (2004) concurs with the view that the science of complexity is situated between modern and 'postmodern science', as elements of both can be found in complexity studies. These elements include unification and plurality, which strive for a general theoretical framework for understanding a complex system as well as taking a more modest stance or sensitivity to issues such as entangledness, diversity and heterogeneity (Emmeche, 2004).

Complexity theory and the complexity perspective therefore does not negate the usefulness of modernist reductionist thinking in certain circumstances, but rather highlights its limitations in dealing specifically with complex systems (Cilliers, 1998). An appreciation of the complex nature of the issues that we face today also requires an understanding of systems theory and how complexity adds to this view.

Systems thinking requires a trans-disciplinary approach. It evolved from the natural sciences and requires input from social science and philosophy (Clayton and Radcliffe, 1996). Scientific knowledge develops our understanding of geological, biological and other processes but is partial and subject to disagreement, which brings about a degree of risk or uncertainty (Clayton and Radcliffe, 1996). The social sciences, economic and psychological research, gives direction on which policies to implement and what effects they may have on society, whereas philosophy and psychological analysis helps to reveal the rational and irrational assumptions that underlie human decisions (Clayton and Radcliffe, 1996). The various inputs are necessary, as questions regarding the environment are inseparable from social, economic and cultural values (Clayton and Radcliffe,

1996). Therefore, in contrast to a reductionist approach, which focuses on the parts rather than the whole, a systems approach goes beyond focusing on the parts and looks at the relationships and interconnections between parts as well, which leads to a richer understanding of the whole (Clayton and Radcliffe, 1996).

Furthermore, complexity theory and systems thinking combine both traditional scientific knowledge and narrative knowledge:

These two forms of knowledge have been separated to the point of being incommensurable whereby even though narrative knowledge may include certain aspects of scientific knowledge; scientific knowledge can only be legitimised separately (Lyotard In Cilliers, 1998:129).

This split between the two types of knowledge has led to the decline of the scientific metanarrative due to the diversity and complexity faced by science today (Cilliers, 1998). The aim is not to create a new consensus but to increase knowledge by increasing the number of discourses, including those previously deemed unscientific yet form part of the totality of human knowledge (Cilliers, 1998). This entails allowing previously marginalised voices an equal opportunity; and increasing the diversity of views, which leads to richer information (Cilliers, 1998). The concern that there would be an overload of information is negated by the fact that complex systems, such as the human social system, are self-organising and capable of combating entropy (Lyotard In Cilliers, 1998). This allows the system to generate meaning and not noise or chaos (Lyotard In Cilliers, 1998). These new meanings, brought about by rich, dynamic interactions, increase our ways of producing and reproducing knowledge (Lyotard In Cilliers, 1998).

This study therefore adopts complexity theory and systems thinking as an appropriate approach for understanding how informal settlements are connected to the broader urban environment. Where conventional urban metabolism assessments fall short of taking a broader, more integrated approach in assessing the metabolism of cities, this study combines the use and application of a Multi-

scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach and Community Based System Dynamics, to fill this gap.

1.3.1 MuSIASEM

The first method is a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM), used to understand the use of time, money and energy within an informal settlement (Giampietro and Mayumi, 2000a; 2000b; Giampietro, Mayumi and Bukkens, 2001). The MuSIASEM approach was developed as a framework for the integrated assessment of sustainability issues across various scales. It integrates biophysical, economic, social and demographic analyses. It also integrates various theoretical concepts from different fields, namely: non-equilibrium thermodynamics applied in ecological analysis (e.g. Odum, 1996); complex systems theory (e.g. Kauffmann, 1993, Morowitz, 1979) and bio-economics (e.g. Georgescu-Roegen, 1975).

According to Giampietro, Mayumi and Sorman (2012):

The very concept of metabolism entails: (1) the existence of an integrated set of processes (anabolism and catabolism) for the stabilization of a given dissipative pattern; and therefore (2) the need of representing such a process simultaneously on multiple scales. This fact implies a series of epistemological challenges..."

MuSIASEM takes a systems approach, utilising quantitative storytelling to deal with multiple non-equivalent definitions of complex issues (Kovacic et al., 2016). Quantitative storytelling stems from hierarchy theory, which is a branch of complexity theory that considers the role of the observer in the analysis of complex systems. The use of quantitative storytelling: i) highlights the role of the analyst as actively influencing what should be observed and how; ii) uses quantitative information to assess the quality of scientific information used to influence policy; iii) compares different narratives, drawing attention to the ambiguous and subjective nature of quantification; iv) acknowledges complexity as a means of dealing with uncertainty; and v) is considered 'particularly useful when dealing with fast changing and complex systems', such as urban informal settlements (Kovacic

et al., 2016).

Furthermore, MuSIASEM utilises Georgescu-Roegen's flow-fund model to deal with these epistemological challenges (Giampietro et al., 2001). As the proponent of Entropy Law and one of the first economists to theorise that natural resources are irreversibly degraded through the economic process (Georgescu-Roegen, 1971), Georgescu-Roegen was critical of the 'mechanistic epistemology which dominated the orientation of the founders of the Neoclassical School' (Georgescu-Roegen, 1975). He argued that the ultimate goal of the economic process is about increasing the level of enjoyment of life associated with human activities, rather than to produce as many goods and services as possible (Giampietro et al., 2012).

Building on the theories of Georgescu-Roegen, Giampietro et al. (2012) adopt an analysis based on the metabolic pattern of society as autopoietic systems, or systems that aim to reproduce themselves. Furthermore, they suggest that a study of the typologies of metabolic patterns (for example as presented by different socio-economic groups) would allow them to quantify – to an extent - the notion of 'enjoyment of life' or desirability, using the fund-flow model and that it would assist in linking improvements with 'enjoyment of life' or establishing a 'better metabolic pattern' (Giampietro et al., 2012). Further categories of analysis include 'Viability', related to external constraints, or matching available resources with required resources and sinks; as well as viability related to internal constraints.

MuSIASEM has been extensively applied at a country level, using mainly secondary, highly aggregated data collected through desktop study, whilst there has been a limited application at the informal settlement level. The tools necessary for producing disaggregated data, collected using a bottom-up approach, however had not yet been established and would need to be developed as part of this study. This study thus contributed to the development of the MuSIASEM method through the development of an appropriate and context specific tool to capture disaggregated data at the micro level, with specific focus on an informal settlement in Stellenbosch, South Africa.

Furthermore, the MuSIASEM model only provides a snapshot at one point in time and is inadequate for capturing issues related to energy fuel choice and energy access in Enkanini informal settlement. In order to examine the dynamics and future implications of the energy flows, a Community Based System Dynamics approach was applied, which would highlight the socio-political context of Enkanini and assist in analysing the 'desirability' of the current metabolic pattern of the settlement.

1.3.2 Community Based System Dynamics modelling

The role of System Dynamics as a paradigm and its location within social theory has been widely debated (see for example Burrell-Morgan, 1979; Lane, 2001a; 2001b; Pruyt, 2006). System Dynamics Modelling stems from Dynamic Systems Theory, which argues for the need to consider the entire or 'whole' system, to provide meaningful analysis, and is often used in multi-domain problems (Musango, 2012). Furthermore, System Dynamics is recognised as a systems thinking tool to visualise and understand complex problems (Maani and Cavana, 2012).

Although Community Based System Dynamics stems from the field of System Dynamics and Group Model Building, Hovmand (2014) acknowledges that Community Based System Dynamics itself has not been linked to a specific social theory. However, based on certain assumptions and practices, it may be possible to recognise where Community Based System Dynamics is situated within the recognised paradigms as developed by Pruyt (2006) (see Table 1.1).

Table 1.1: Extended paradigms

	Positivist	Postpositivist	Critical Pluralism	Pragmatism	Transformative Emancipatory critical	Constructivist
Ontology	(Naïve) realism	(Transcendental) realism	(Critical) realism	(Pragmatism) realism	Relativism	Relativism
Epistemology	Objective	(Probably) objective	Subjective	Objective and subjective	Subjective (and objective)	Subjective
Axiology	Value-free	Controllable value-ladenness	Concerned by value-ladenness	Unconcerned with value-ladenness	Non-neutral value ladenness	Value-bound
Method(ologie)s	Purely quantitative	Primarily quantitative	Quantitative and qualitative	Quantitative and qualitative	Qualitative, quantitative, mixed	Qualitative
Causality	Knowable real causes	Reasonably stable causal relationships (not necessarily used)	Causality is key to understanding of real world	Maybe causal relationships but not exactly knowable		Indistinguishable causes and effects
Logic	Deductive	Primarily deductive	Deductive and inductive	Deductive and inductive	Deductive and inductive	Inductive
Approaches of model	Refutable but not refuted	Validated model, results closest to the real world	Do models lead to real insight and understanding?	Closest to goal or own value system?	Advancing justice, democracy and oppressed?	Confidence in constructed model
Approaches of strategies	Optimal strategy	Probably optimal strategy or most appropriate strategy	Potential to structural transformation	Close to goal or own value system	Advancing justice, democracy and oppressed?	Any strategy (if agreed to)

Source: Pruyt (2006)

According to Pruyt (2006), System Dynamics may be classified as belonging to one of six categories, namely:

i) Positivist

Positivist system dynamics is very rare, as the ontological position is that modeled systems correspond to the real world while the epistemological position is that stock and flow diagrams and causal loop diagrams are good objective representations of the real world. This position relies solely on quantitative data.

ii) Postpositivist

The postpositivist position still relies on realism and objectivity, yet slightly less rigorously than the positivist tradition. The main focus is still on quantitative data collection, and while the position recognises that knowledge created is influenced by the researcher's theories and values, it posits that value-laden interpretation of the model can be controlled or eliminated.

iii) Critical pluralist

Critical pluralists maintain that reality is external however in terms of epistemology, it is suggested that one can access or understand the real world through subjective mental models. The position places more emphasis on the possibility of value-ladenness as impacting methodology, basic assumptions and boundaries. In this case, models are context and time specific and are designed with decision-makers. It utilises quantitative simulation which is qualitatively analysed. The main aim is to understand the underlying structures that lead to a particular type of behaviour or pattern of events. This paradigm is widely used within mainstream System Dynamics.

iv) Pragmatist

This paradigm assumes that reality exists yet is interpreted and partially reconstructed, and that modelling reality is not possible but rather that models are chosen that are closest to personal perceptions of world-views and value systems. Pragmatists assume there is no universal causality and that real causality within socio-economic systems cannot be exactly determined. Pragmatists are less concerned with structural causality, and more interested in using system dynamics to create

models that 'just work or help to reach a goal'. This paradigm may be found in the use of soft variable and reference modes (Musango, 2012).

v) Transformative – emancipatory – critical

The focus of this paradigm is to advance democracy and justice by assisting the marginalised, disadvantaged and oppressed. The area of causality is not well defined, but the paradigm does try to compensate for the weakness in mainstream System Dynamics in representing or engaging a wider stakeholder base.

vi) Constructivist

Finally, constructivists consider that systems do not exist in reality and take a subjective approach to epistemology, in that models represent a particular perspective. The paradigm relies on qualitative interpretation, even of quantitative inputs, and assumes that causality cannot be distinguished, but is rather given meaning through subjective interpretation. This paradigm has been applied in modelling for learning and shared interpretation.

Community Based System Dynamics is an adaptation of mainstream System Dynamics and Group Model Building, which emerged as a result of the need to engage with less sophisticated audiences to improve learning and understanding of the systems that they are part of. According to Hovmand (2014), Community Based System Dynamics is a useful method for involving community members or stakeholders who are embedded in a particular system, to bring about system insights and recommendations, while empowering and mobilising communities to advocate for and implement changes based on these insights.

The connection to mainstream System Dynamics initially places Community Based System Dynamics within the Critical-pluralist paradigm. However, the use of soft variables and qualitative models incorporating subjective perspectives moves it more towards the Pragmatist paradigm. While the focus on marginalised communities drive it towards the Transformative-emancipatory paradigm by promoting democracy and justice.

Against the background of sustainable development and the theoretical stance from complexity theory and systems thinking, discussed in section 1.2 and 1.3, it is argued that Community Based System Dynamics does not postulate a narrow, a-priori viewpoint, but rather takes a pragmatic approach to involving a wider group of stakeholders, recognising the value of different forms of knowledge, and the need for models that incorporate both quantitative and qualitative inputs, whilst promoting the values of democracy and justice through giving validation and voice to the oppressed. This however does not imply that scientific rigor and causality are disregarded, but rather that the notion of what is included in the construct of knowledge is reconsidered and made more accessible.

Both MuSIASEM and Community Based System Dynamics take a systems approach to analysis and allow for the representation of marginalised communities in the urban sustainability narrative. The combination of the two methods also allow for combining both quantitative and qualitative data leading to a rich picture of the material reality of informal settlements and their connections with the wider urban system.

Therefore, this study argues that a broader, more inclusive approach to urban metabolism assessment in the context of sustainable development would:

- i) take a whole systems approach to analysing urban metabolism and thereby include informal settlements in the evaluation of urban metabolism assessments;
- ii) adopt a bottom-up approach to data collection, designed to be context specific in order to recognise patterns across typologies, and highlight inequalities;
- iii) utilise methodologies that are transdisciplinary in nature and capable of dealing with complexity and uncertainty; and
- iv) allow for the collection of disaggregated data to represent age, gender and socio-economic conditions.

1.4 Problem statement

Increasing urbanisation requires greater understanding of the resource consumption of cities. One form of analysis relies on systems thinking to trace the metabolism of the city. However, informal settlements, which are a growing and persistent phenomenon with their own internal metabolism, are not being accounted for, partly owing to a lack of urban metabolism methodologies that capture the societal metabolism of slums. These spaces are thus ignored, and become 'blind spots' in the larger picture, reducing the quality and accuracy of knowledge and understanding of how the city system functions, while limiting effective planning and policy.

1.4.1 Thesis statement

In order to improve urban and developmental policy and planning initiatives, new methods are required to assess and understand what informal settlements are, how they function, and how they contribute to the metabolism of the city.

1.5 Research questions

The associated research questions are as follows:

- What are urban informal settlements, and how do they connect to the broader urban context?
- How does a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach contribute to the study of informal settlements in the context of sustainable urban development?
- What are the electricity legitimacy dynamics of Enkanini informal settlement?

1.6 Significance of the study

This research project is of significance to a wide audience, and is envisaged to have theoretical, methodological and practical relevance. The study contributes to the body of knowledge on urban metabolism and developmental policy and

planning, as well as on systems thinking. In practice, the study is also beneficial to a number of stakeholders in the following ways:

- **Development planning**

Understanding the phenomenon and processes of informal settlements and their inhabitants may improve sustainable and equitable development through improved engagement processes.

- **Urban metabolism studies**

The inclusion of informal settlements in urban metabolic analysis is a theoretical contribution to the urban metabolism research field. This study broadens the scope for knowledge and understanding through a whole systems approach that accounts for informal settlements and has an impact on future planning and policy, leading to more sustainable and equitable cities.

- **Methodological contribution**

The results of this study have implications for local development strategies, as well as serving to inform the urban planning environment.

- Local, regional and national government officials and departments tasked with creating policies and plans under the auspices of the sustainable development goals may expand their efforts in linking and supporting activities within urban informal settlements. Examples include: Stellenbosch Municipality; Departments at different levels related to human settlements, economic development, transport and social development.
- NGOs and civil society networks that operate in informal settlements may become more aware of the potential linkages on resources flows and the green economy sphere. Examples include Shack/Slum Dwellers International; Sustainability Institute.
- International bodies concerned with social development and environmental sustainability may use the study as a basis for further research and informed discussion on connecting SDG 11 with regard to slums or informal

settlements. This includes, among others, UN-Habitat, UNEP, UN-DESA and World Council for City Data.

1.7 Research strategy

The research strategy, presented in Figure 1.2, involved a number of steps in order to address the research questions associated with the research problem.

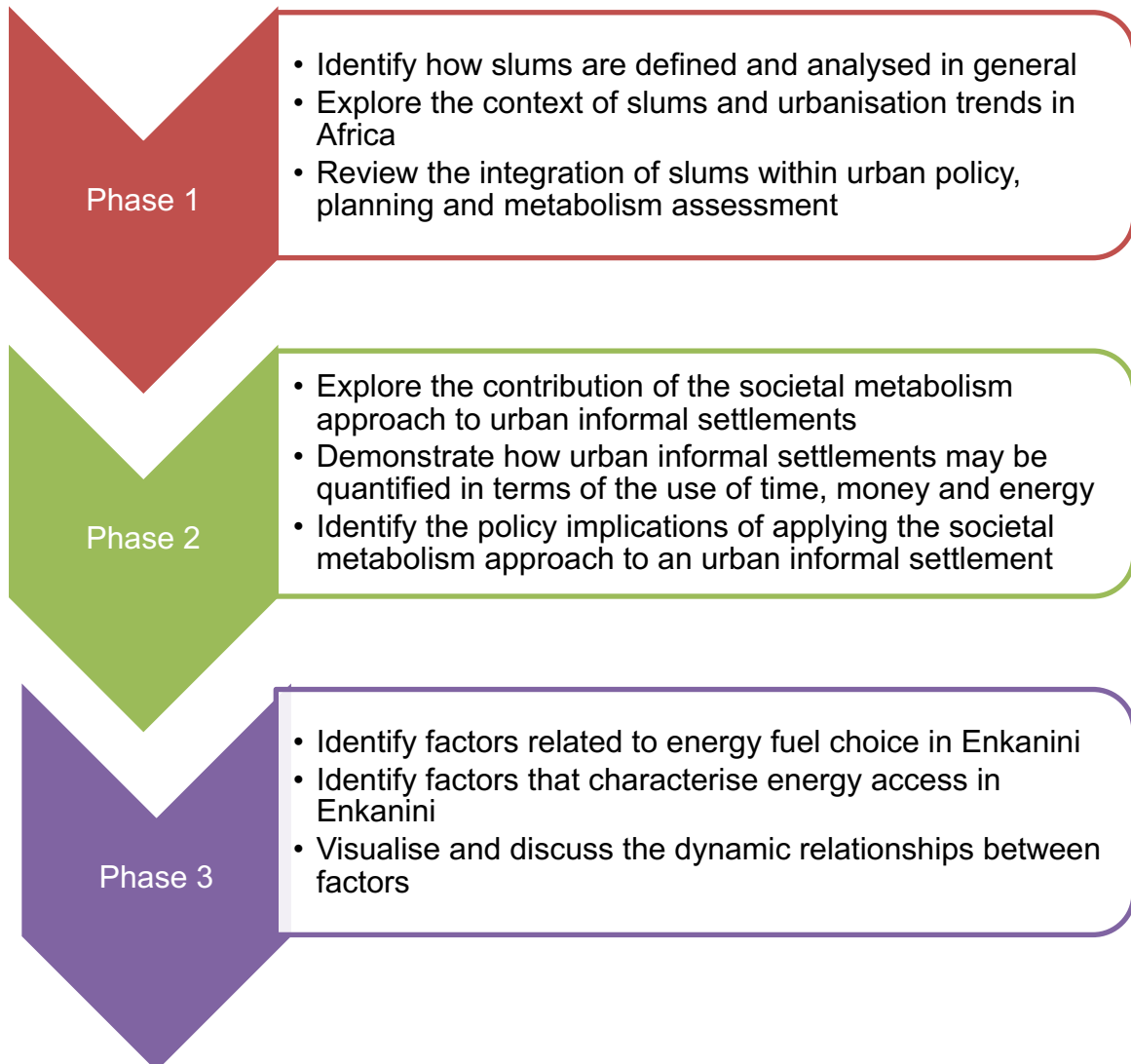


Figure 1.2: Research strategy

The first phase of the research partly addressed research question one and involved a critical literature review, in order to define what slums are and how they are dealt with in urban policy and planning. This led to the development of a general typology of slums. However, having considered the sociopolitical context

of slums in South Africa, this led to the emergence of a South African typology of slums.

Phase two involved a case study of the Enkanini informal settlement in Stellenbosch, using a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach. This was achieved through the development and administration of a detailed survey, exploring the use of time, money and energy within the settlement. Phase two addressed research question two and partly contributed to the research regarding how the settlement is connected to the broader town through labour practices, income generation and expenditure, and use of services.

During phase two it became evident that there were some issues related to energy fuel choice and energy access within Enkanini settlement. The initial survey tool was not designed to explore this in depth and it was deemed necessary, given the objective to understand energy flows in the settlement, to return to Enkanini to explore these issues in greater detail. Phase three involved three one-day workshops, with each day dedicated to a particular energy user group, in order to identify the factors that affect energy fuel choice and energy access in Enkanini. Community Based System Dynamics was utilised as a framework for designing the workshops and for visualising the results as a series of causal loop diagrams. Phase three therefore addressed research question three.

1.8 Organisation of the study

This thesis was written as a series of articles (see Appendix A), constituting Chapters 2, 3 and 4, in order to address the identified research questions, set out in section 1.5. Certain outputs of the study were also presented at five international conferences (see Appendix B). Each article was published, or submitted for publication, as a stand-alone piece in different internationally recognised, high-impact journals. Therefore, although every effort has been made to avoid or minimise repetition of literature between articles, some overlap occurs, pertaining to the rationale, methodological description, and certain results of the study. Furthermore, a fourth article emanated from this work; however, as the lead author

is Dr Kovacic, an excerpt from the published article can be found in Appendix A. My contributions to the fourth article were limited to the data collection, analysis and write-up of the results pertaining to the Enkanini case study.

The organisation of the study is illustrated in Figure 1.3.

Chapter 1

- Chapter 1 explains the background of and rationale for the study. The research problem is specified, and associated research questions are identified, followed by an identification of the beneficiaries of the study in an effort to demonstrate its significance. The scope of the study is defined in terms of its limitations and assumptions, and the research strategy is outlined. This is followed by an outline of the general structure of the thesis.

Chapter 2

- Chapter 2 comprises the first article of the series. The chapter identifies global trends in urbanisation and slum proliferation, as well as how slums are dealt with in urban policy and planning. This leads to the development of an argument for including slums in urban metabolism assessments. The way in which slums or informal settlements are defined and analysed are then critiqued, which leads to the development of a general typology of slums. A South African typology of slums also emerges from the literature once the sociopolitical context of the country is taken into account. The MuSIASEM approach used in this study is introduced and certain key results pertaining to human activity, monetary flows and energy are described.

Chapter 3

- Chapter 3 encompasses the second article which describes in greater detail the methodology, case study, data collection process and tools, and presents the results of the data analysis in terms of divulging: human activity, measured in time; household sector activities; paid work sector activities; and land use and infrastructure mapping related to: i) energy access; ii) livelihood activities; and iii) water, waste and sanitation infrastructure.
- The implications of adopting a societal metabolism approach to urban informal settlements is described in terms of theoretical, methodological, societal and urban agenda policy implications.

Chapter 4

- Chapter 4 is the third article, which explores the issues that affect energy fuel choice and energy access in Enkanini within the context of Sustainable Development Goals 7 and 11. It describes the Community Based System Dynamics method; the setting, study design and participants; and the modelling process and outputs, and presents the results as pertaining to:
 - The factors that influence energy fuel choice, energy bias and energy switching in Enkanini informal settlement.
 - The issues that characterise energy access in Enkanini informal settlement.
 - The key feedback loops influencing energy fuel choice and energy access in Enkanini informal settlement.

Chapter 5

- Chapter 5 provides the conclusions and recommendations. It further indicates the contribution of the study to theory and practice, discusses the key findings and limitations of the study, and presents areas for future research.

Figure 1.3: Organisation of the study

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CHAPTER 2: CONCEPTUALISING *SLUM* IN AN URBAN AFRICAN CONTEXT^{1,2}

2.1 Chapter overview

Chapter 2 addresses the first research question: What are urban informal settlements and how do they connect to the broader urban context? This entailed conceptualising the notion of a slum or urban informal settlement in relation to an urban metabolism framework. Using one informal settlement case study, key results were provided to demonstrate how an urban informal settlement is connected to the broader urban environment in terms of the use of time, money and energy. The writing and development of this chapter were principally the responsibility of the writer and resulted in the publishing of a paper in the journal *Cities*.

Abstract

Increasing urbanisation and the proliferation of slums require a holistic understanding of the urban metabolism of cities. However, existing urban metabolic analyses exclude a detailed understanding of how urban slums function and contribute to biophysical, including energy, flows. This chapter aims at filling this gap by critically investigating the notion of the urban slum in general, the extent to which it differs in the African context, specifically in South Africa, and broadening the understanding of the urban slum based on the concept of urban metabolism, using the Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach, which was applied to the Enkanini informal settlement in Stellenbosch, South Africa. The analysis shows that South Africa has

¹ A paper based on this chapter was published in the journal *Cities*. The reference is: Smit, S., Musango, J.K., Kovacic, Z. and Brent, A.C. 2017. Conceptualising slum in an urban African context. *Cities*, 62: 107–109.

² Certain outputs were presented at the 22nd Annual International Sustainable Development Research Society Conference (ISDRS 2016), 13–15 July 2016, Lisbon, Portugal; and the PhD colloquium of the Innovation for Sustainable Development Network (inno4sd); Africa-Europe Dialogue Symposium on Innovation for Sustainable Development, 29 November – 1 December 2017, Pretoria, South Africa.

a more nuanced typology of the notion of urban slums categorised as: (i) townships; (ii) housing-turned-slum; (iii) squatter camps; (iv) site and service settlements; (v) transit camps; and (vi) hybrid multi-structured settlements. Beyond these definitions, the case study illustrates that urban slums, however defined, are complex systems with their own internal flows and processes that are connected in a myriad ways to the larger urban system. The investigation into the use of time, money and energy in the Enkanini case further revealed the productive (hypercyclic) and consumptive (dissipative) nature of the components of the urban informal settlement. This type of analysis reveals new insights into the linkages between urban informal settlements and the city.

Keywords: informal settlement; urban metabolism; multi-scale analysis; urban slums; urban Africa; South Africa

2.2 Introduction

The urban age is unfolding, with more than half of the world population now living in cities and urbanisation set to increase by a further 2,5 billion people by the year 2050 (UN-DESA, 2014; UN-Habitat, 2015). This increase is mainly expected to be dominant in Asia and Africa (UN-DESA, 2014; UN-Habitat, 2014a, 2014b). The Africa-wide urbanisation level is projected to reach 58% by 2050, thereby increasing the number of urban dwellers from 400 million in 2010 to 1.26 billion by 2050 (UN-Habitat, 2014b).

This situation places excessive strain on cities to plan for and manage the increase in urbanites and their demand for housing, employment and access to basic infrastructure and services: a situation that is becoming vastly untenable for many cities, particularly those in the developing world. Most urban economies in developing countries are unable to meet these basic needs. Beyond the pressures of population growth, there are several other factors, including economic growth, housing market dynamics and urban planning that actively creates spaces of exclusion and segregation (Roy et al., 2014; Amado et al., 20152016), that leave the informal economy to provide most of the new employment and housing in these environments – commonly referred to in various terms such as *informal settlement*,

slum, shantytown, squatter camp, favela, ghetto, bidonvilles, Katchi Abadis and campamentos (Guibrunet and Castán Broto, 2015; UN-Habitat, 2010).

A quarter of the world's population lives in slums (UN-Habitat, 2014b), with the majority of slum dwellers stemming from the developing world (UN-Habitat, 2010; 2014b; 2015b). More than 880 million people in developing countries are currently living and working in slums (UN-DESA, 2015a). Despite a slight decline in the global urban slum population, sub-Saharan Africa continues to have the highest prevalence of slum conditions, while most of additional population in cities are expected to end up being slum populations (UN-DESA, 2015a).

At the same time, sustainable urban development has been identified as one of the most pressing global challenges of the twenty-first century (UN-Habitat, 2015a), while the concepts of societal metabolism (Martinez-Alier, 1987; Fischer-Kowalski, 1998; Giampietro, Mayumi, and Ramos-Martin, 2009) and urban metabolism have become fundamental to the development of sustainable cities and communities. The notion of societal metabolism is described as analysing the “metabolism of human society” through a characterisation of the processes that a society employs to transform energy and material to ensure its continued existence (Giampietro et al., 2009; Fischer-Kowalski, 1998; Kovacic and Giampietro, 2016) and has been applied to urban metabolism studies (see for example Ramos-Martin et al., 2009).

Kennedy, Cuddihy, and Enege-yan (2007) define urban metabolism as “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste”. The limitation of this definition however, is that it fails to take into consideration the emergent properties of the concept, particularly in the African context. To account for this, Currie (2015) defines urban metabolism as “complexity of socio-technical and socio-ecological processes by which flows of materials, energy, people and information shape the city, service the needs of its populace, and impact the surrounding hinterland”. In practice, it is argued that urban metabolism provides a “big picture quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes

for an urban region” (Kennedy, Pincetl, and Bunje, 2011), and as a suitable method for quantifying energy consumption patterns (Pincetl, Bunje, and Holmes, 2012).

Metabolic studies, incorporating various resource accounting and management strategies, have typically been undertaken at national level (Kennedy et al., 2007). However, these approaches have been criticised for being too broad, representing “just static accounting”, generally lacking an interdisciplinary approach, and omitting valuable information regarding social and institutional drivers and geographic specificity (Huang et al., 2015; Ferrão and Fernandez, 2013; Pincetl et al., 2012; Kennedy et al., 2007). Pincetl et al. (2012) therefore suggest an expansion of the urban metabolism method for “analysing both the biophysical material and energy parameters of cities, as well as the human, social, policy, economic, and related systems that both structure and govern specific urban metabolic process”. At the same time, Kennedy et al. (2007) suggest that a full evaluation of urban sustainability requires a broad scope of analysis.

Despite the call for more in-depth urban metabolic analysis (Kennedy and Hoorweg, 2012; Pincetl et al., 2012; Kennedy et al., 2011; Brunner, 2007), existing metabolic analyses for developing countries (e.g. Conke and Ferreira, 2015; Currie et al. 2015; Hoekman, 2015; Piña and Martínez, 2014) generally exclude a detailed understanding of how urban slums function and contribute to biophysical and energy flows.

Thus far, few studies have analysed the societal metabolism of urban informal settlements (see Attia and Khalil, 2015; Royden-Turner, 2012), while the majority of studies that have done so apply a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach (see for example Smit et al., 2018; Kovacic and Giampietro, 2016; Kovacic et al., 2016; and Miranda, Santos and Giampietro, 2015).

Given the prolific and persistent phenomenon of slums, coupled with the need for urban planning that results in more sustainable and just cities, this chapter addresses the first research question of this study, through two sub-questions as follows: (i) What are the shortcomings of generalised conceptualisations of slums?

(ii) What are the contributions of the societal metabolism approach to the understanding of slums? These questions are addressed through a critical literature review which provides the global perspective and understanding of slums; the context of slums and urbanisation trends in Africa; a typology of slums in South Africa; and a review of the integration of slums within urban policy and planning. Further, a case study is used to illustrate how societal metabolic analysis changes our understanding of slums.

2.3 Global context for understanding of slums

At a global level, the concept of slums is described by the United Nations Human Settlement Programme (UN-Habitat, 2010) as the physical and spatial manifestation of urban poverty and intracity inequality. A slum household is described as being deprived of any of the following conditions, listed in Table 2.1, namely: (i) access to improved water; (ii) access to improved sanitation facilities; (iii) sufficient living area – not overcrowded; (iv) structural quality/durability of dwellings; and (v) security of tenure (UN-Habitat, 2010).

Table 2.1: Indicators and thresholds for defining slums³

Characteristic	Indicator	Definition
Access to water	Improved drinking water sources (MDG Indicator 7.8) (SDG – Goal 6.1)	A household has improved drinking water supply if it uses water from sources that include: <ul style="list-style-type: none"> • Piped water into dwelling, plot or yard; • Public tap or stand pipe; • Tube well or borehole; • Protected dug well; • Protected spring; and • Rainwater collection.
	Access to improved sanitation facilities (MDG Indicator 7.9) (SDG – Goal 6.2)	A household is considered to have access to improved sanitation if it uses: <ul style="list-style-type: none"> • Flush or pour flush to piped sewer system, septic tank or pit latrine; • Pit latrine with slab; • Composting toilet; and • Ventilated improved pit latrine. <p>The excreta disposal system is considered improved if it is private or shared by a reasonable number of households.</p>
Durable housing	a. Location	A house is considered durable if it is built on a non-hazardous location. Hazardous sites include: <ul style="list-style-type: none"> • Geologically unstable areas (landslide or earthquake and flood areas); • Garbage dumpsites; • High industrial pollution areas; and • Unprotected high-risk zones (e.g. railroads, airports, energy transmission lines).
	b. Permanency of structure	Permanency of a housing structure is determined by: <ul style="list-style-type: none"> • Quality of construction materials used for wall, floor and roof; and • Compliance with local building codes, standards and bylaws.
Overcrowding Security of tenure	Sufficient living area	A house has sufficient living area for household members if not more than three members share the same room.
	Security tenure	Households have secure tenure when they have effective protection against forced evictions through: <ul style="list-style-type: none"> • Evidence of documentation (formal title deed to either land or residence or both); and • De facto or perceived protection against eviction.

Source: UN-Habitat, 2010.

³ The first two indicators in Table 2.1 may be linked with SDG 6, whereas the only reference to the notion of slums pertains to SDG 11 on sustainable cities and communities, and in particular to SDG 11.1, which refers to the upgrading of slums (UNDP, 2016). As for the last three indicators, these are not explicitly mentioned in the SDGs.

The five deprivations have previously been associated with specific millennium development goals (MDGs) (see Table 2.1). However, the millennium development goals have since been replaced with the sustainable development goals (SDGs) for the period 2016 to 2030 (UNDP, 2016). Within Sustainable Development Goal 11 on sustainable cities and communities, the only reference to slums relates to Target 11.1: “By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums” (UNDP, 2016). The Inter-Agency and Expert Group on the Sustainable Development Goal Indicators Report (UN-DESA, 2015c) found the goals for SDG Target 11.1 to be feasible and relevant. However, the report indicated the importance of creating consensus on the definition of the term slum, as the lack of a definition has an impact on the application and measurement of this specific target.

While the UN definition, described in section 2.3, has provided the basis for slum estimates (e.g. UN-Habitat, 2016a; 2015a; 2010; and Baker, 2008), it fails to incorporate other essential basic characteristics such as “access to modern and clean energy” as a condition for defining or measuring a slum. This is problematic, considering only 43% of the African population have access to electricity (IEA, 2015).

Although UN-Habitat (2010) recognises that slums are multidimensional and that the term includes a multitude of different settlement types and communities, the quantification of slums, based solely on deprivations, as illustrated in Table 2.1, assumes that slums are homogenous. This erroneously suggests that ‘one-size-fits-all’ solutions may be appropriate. However, such approaches negate the multidimensional and differing contextual realities of slums. Further, the analysis of slums based solely on their physical, geographical and legal characteristics depoliticises these spaces, disregarding the institutional and social structures that lead to their creation – thus looking only at the symptoms and not the causes associated with their emergence (Kovacic and Giampietro, 2016). In contrast, future planning for sustainable cities would necessitate an understanding and recognition of these differences, thus calling for the development of a typology of slums.

Several interrelated factors contribute to the formation of slums, including: (i) income inequality; (ii) lack of economic growth; (iii) in-migration; (iv) poverty; (v) lack of affordable housing; and (vi) weak governance (Amado et al., 2016; UN-Habitat, 2003). Therefore, a number of qualifying definitions, characteristics and attributes should be considered when analysing the urban slum (see Table 2.2).

Table 2.2: Major categories of slum spatial analysis

Origins and age	Historic city-centre slums Slum estates Consolidating informal settlements Recent slums
Location and boundaries	Central Scattered slum Islands Peripheral
Size and scale	Large slum settlements Medium-size slum estates Small slums
Legality and vulnerability	Illegal Informal
Development stages: dynamic and diagnosis	Communities/individuals lacking incentive or capacity for improvement Slums with ongoing individual- and community-led development Intervention-led improved slums Upgraded slums

Source: UN-Habitat, 2003

Slums are generally defined and analysed along various dimensions including: (i) physical characteristics – as pertaining to housing typology, and access to services and infrastructure; (ii) social characteristics based on income, employment and economic activity; and (iii) legal characteristics related to land ownership and adherence to planning regulations (Srinivas, 2015; Turok, 2015). Further attempts at analyses include: references to unsafe areas and unplanned areas (Khalifa, 2011), and as related to spatial or geographic location (Kohli et al., 2011).

On the basis of physical, infrastructural and legal characteristics mentioned above, it may be argued that the conventional categorisation of slums fluctuates between formal and informal, legal and illegal, and planned and unplanned. This study does not propose a definitive or exhaustive description of these categories. However, the following may assist in interpretation:

- i. Formal is considered as settlement development driven by official, including government, entities; housing structure conforms to standard building regulations; activities are sufficiently covered by the law.
- ii. Informal is development driven by informal settlers, outside or alongside official channels; housing structure does not comply with standard building regulations; activities that are not covered or sufficiently covered by the law (that is, they are not explicitly illegal).
- iii. Legal is explicitly within the bounds of the law; there is security of tenure and/or legal claim to land; provision for health and safety; activities fall within land use regulation.
- iv. Illegal is explicitly in contravention of the law; no security of tenure or legal claim to land; not within the bounds of health and safety law; activities fall outside of land use regulation.
- v. Planned is related to formal settlement layout; infrastructure and service provision is designed and provided by formal entities in a manner that conforms to formal and legal requirements.
- vi. Unplanned is settlement layout seemingly unstructured, infrastructure and service provision by informal entities or actors, not necessarily conforming to formal and legal requirements.

Based on these characteristics, four distinguishable settlement types were conceptualised, as illustrated in Figure 2.1.

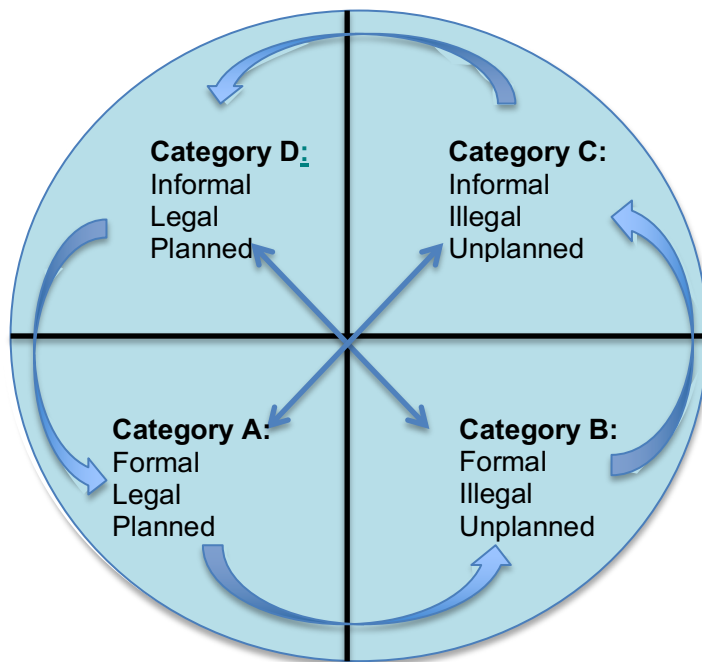


Figure 2.1: Slum types based on conventional categorisation

Each of the four distinguishable settlement types has the following characteristics:

Category A: Formal, Legal, Planned

Housing structure is formal, adhering to legal requirements, and spatial aspects of settlement are planned.

Category B: Formal, Illegal, Unplanned

Housing structure is initially formal, but owing to overcrowding and lack of maintenance, it no longer adheres to legal requirements in terms of health and safety and building regulations. The settlement may also evolve into a hybrid of formal and informal structures, thereby altering spatial aspects towards unplanned.

Category C: Informal, Illegal, Unplanned

Housing structure is informal, in contravention of legal requirements and planning regulations.

Category D: Informal, Legal, Planned

Housing structure remains informal, while infrastructure is formally provided, and settlement layout is planned.

These categories are useful for recognising the physical, infrastructural and legal dimensions of slums, and for providing a typology or framework from which more in-depth analysis of slums may emerge. As Nuisl and Heinrichs (2013) assert, the UN definition (UN-Habitat, 2010), from which these categories stem, “is probably the most feasible starting point for the discussion on the slum phenomenon”. However, employing the classifications and categories (from Figure 2.1) as the sole basis for understanding slums offers limited explanatory power with regard to the persistence and growth of the slum phenomenon in urban development. This is because the definition does not: (i) encapsulate the societal and environmental aspects needed for sustainable and equitable urban planning; (ii) give insight into the material and resource consumption or production at different levels (including individuals and households) for slums; (iii) acknowledge the connections between slums and the city; and (iv) directly address or include urban development conditions, household conditions, poverty and social exclusion.

Furthermore, it should be noted that settlement types are not static and may evolve and/or devolve over time. Each settlement type may also be recognised as having a unique set of issues that need to be addressed, thereby creating a framework for deeper analysis of the different slum types and particularly as related to several transitions occurring on the African continent, discussed in the following section. Examples of each settlement type are discussed in more depth in section 2.6, as related to the South African context.

2.4 Slums and urbanisation in the African context

The African continent offers a unique perspective on urbanisation as the continent is experiencing several interrelated transitions simultaneously. These transitions, which have an impact on urban planning and management, are discussed in the sub-sections below.

2.4.1 Political transition

The number of democratically elected governments in Africa is increasing. However, there are still many countries which are far from having truly democratic governance systems, while others still struggle to escape the status of the “fragile” or “failed state” (UN-Habitat, 2014a). In most cases, effective governance is lacking, a key issue in managing and engaging informality. For example, Smit and Musango (2015b) describe some of the major challenges in connecting the green economy to the informal economy as related to: (i) conceptual and definitional uncertainty; (ii) lack of capacity and capability; (iii) lack of political will; (iv) lack of models for successful engagement or modes for bridging the informal and formal; and (v) lack of community organisation.

These issues are pertinent, particularly at local government level, whose purview it is to engage with informal actors and who have direct impact on the legal and regulatory environment. Roy et al. (2014) describe local politics as playing a major role in the growth of slums in cities, using as illustration the case of Mumbai, where slums are allowed to grow as “vote banks” to support certain political agendas, while hindering “slum upgradation”.

Achieving sustainable and equitable urban planning therefore requires a better understanding of the role of governance and politics in the management of slums. Further, developing new approaches for engaging informal actors in the planning process is crucial.

2.4.2 Demographic changes

Africa, with its unprecedented population growth, is becoming the fastest growing continent (UN-DESA, 2015b; UN-Habitat, 2014a). With the demographic growth, the majority of Africans (nearly 64% by 2050) are projected to live in urban centres, while the majority of these urban dwellers will end up in slums (UN-DESA, 2014; UN-Habitat, 2014a). In terms of planning for the future of cities, urban planners therefore need to have a better understanding of these demographic changes in general, and more specifically in terms of the growth in and of informal settlements.

2.4.3 Economic transition

Africa has recently experienced real growth in gross domestic product (GDP), as well as an increase in households that have moved into the “middle class” category (UN-Habitat, 2014a). Africa’s economic transition, however, is currently unable to cater for the increased demand for employment and housing, leaving the majority of urban dwellers reliant on the informal economy for subsistence. For example, in sub-Saharan Africa, the informal economy accounts for up to 72% of employment, rendering it significant in the context of sustainable development and poverty eradication (Smit and Musango, 2015a), while the global informal economy is estimated to be worth USD10 trillion (Roy et al., 2014).

The urban informal population thus contributes to the wider economy and for this reason Roy et al. (2014) suggest the need to recognise the linkages between the formal and informal economy in any discussion about slums. However, this is rarely taken into account especially with regard to the green economy agenda (Smit and Musango, 2015a; 2015b). Policy planning for future urbanisation would therefore need to take the informal economy into account and consider ways of integrating urban informal populations into the city for enhancing livelihood strategies.

2.4.4 Technology and infrastructure transition

Africa has a huge infrastructure backlog with little access to technologies and services (Un-Habitat, 2014a). While this may offer an opportunity for future economic growth and development, the choice of infrastructure and technologies is critical for sustainable development. However, these choices are affected by different levels of uncertainty, which have an impact on the analysis of urban informal settlements and the implementation of upgrading policies (Kovacic et al., 2016).

Urban informal settlements are characterised by a lack of urban planning and low provision or absence of public services. This implies that an inadequate understanding of uncertainty can undermine the effectiveness of informal settlement upgrading while deepening social inequalities (Kovacic et al., 2016). The expectation that urban informal dwellers will embrace technological solutions

without participative and integrated approaches is problematic (Smit et al., forthcoming). This indicates the need for alternative approaches such as the Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach (Giampietro et al., 2009; Giampietro and Mayumi, 2000a; 2000b). Kovacic et al. (2016) argue that MuSIASEM is appropriate for dealing with methodological, technical and epistemological uncertainties that characterise urban informal settlements. For sustainable and equitable urban planning, it is thus essential to consider the needs of urban informal dwellers, while recognising the social and political challenges associated with these types of interventions (Smit et al., 2018; Kovacic et al., 2016).

2.4.5 Environmental sustainability transition

As previously indicated, the ability of African cities to absorb projected levels of urbanisation may be untenable owing to a general lack of institutional and infrastructural capacity. This leaves the majority of the projected additional urban dwellers to reside in slums or informal settlements. At the same time, African economies are subject to high levels of resource depletion while suffering the effects of climate change, large infrastructure deficits, and land and water shortages (UN-Habitat, 2014a). This reduces production capacities and increases the related costs for the African nations. It is therefore essential to consider infrastructure choices that satisfy growing demands and the respective resource constraints (UN-Habitat, 2014a). However, to make appropriate and robust infrastructure choices, urban planners need to be better informed on the material reality of slums and how they contribute to the metabolism of the city.

2.5 Sustainable urban planning approaches to slums

The conceptualisation of and approach to slums in urban policy and planning are diverse, and often contradictory, in terms of their characterisation, whether slums are a problem, and how they and their inhabitants should be treated (Turok, 2015; Nuissl and Heinrichs, 2013; Hunter and Posel, 2012). For example, Weiss (2014) argues that the post-apartheid landscape of South Africa has rendered “urban planning frameworks prone to reinforcing the marginalization of informal stakeholder engagement, ultimately perpetuating a socio-spatial inequality such

programs set out to mitigate”. Furthermore, where there is little or no government support for slum livelihoods, and where slums are not integrated into the broader urban environment, long-term inequality and inter-generational disadvantage is perpetuated or even created, through lack of planning for or attention to slums in urban planning (Amado et al., 2016; UN-Habitat, 2015b).

This points to the need for a systems approach, where informal settlements are considered as (i) ‘integral parts of the city’ (Turok, 2015); (ii) affecting the living standards and opportunities of their inhabitants; and (iii) influencing and being influenced by the developmental perspectives of the cities and societies in which they occur (Nuisl and Heinrichs, 2013).

Clayton and Radcliffe (1996: 6) state that in order to understand sustainability, one requires “some understanding of the behaviour of systems in general and of human and environmental systems in particular”. Clayton and Radcliffe (1996: 12) point out that a systems approach to sustainability requires taking into account the diverse agents interacting in the world as systems. The systems approach is also promoted as appreciative of emergent properties, complexity and interactions (Hardi and Zdan in Giddings, Hopwood and O'Brien, 2002). It focuses on relationships, connections and context specificity (Gallopín, 2003). It is therefore [generally] argued that this approach is useful when analysing the connections between urban informal settlements and the city. By considering the city as a complex system with informal settlements as a subsystem, one may be able to make inferences about current or future interactions, and particularly as related to resource requirements.

Where metabolism studies have focused on cities, particularly within the developing nation context, several issues arise, including: data scarcity and data gaps (Currie et al., 2015; Ferrão and Fernandez, 2013). Ferrão and Fernandez (2013) argue that despite the challenges faced by African cities, urban metabolism work can play a unique role in the urban developing context. Guibrunet and Castán Broto (2015) compound this notion, stating that the resource consumption of cities simultaneously challenges resource scarcity, resource distribution and social equity, and that there is great potential for urban metabolism to be applied as a

planning framework to achieve cities that are both sustainable and just. Guibrunet and Castán Broto (2015) point to the need for applying urban metabolism to informal settlements, describing informality as an “integrant aspect of how cities function” and stating the need to understand the co-dependency between urban informal processes and the configuration of the infrastructure that influences the flow of materials.

However, it is not enough simply to add urban informal settlement data to city data, especially if values are aggregated on a per capita calculation. This would ignore the inherent inequalities within the city. Satterthwaite (1997), for example, contends that methods such as the ecological footprint of cities should not obscure the fact that particular enterprises and richer groups contribute disproportionately to the transfer of environmental costs from rich to poor areas, thereby constituting “environmental racism”, “as polluting industries or wastes are systematically located in lower-income areas”.

Similarly, Turok (2015) argues for the need to treat individual settlements differently, while acknowledging the specific functions that they perform in contributing to the wider urban system. From a different perspective, Attia and Khalil (2015) propose that where informalisation is synonymous to urbanisation, a profound study of informal areas and their potential role in achieving sustainable cities becomes essential. According to Guibrunet and Castán Broto (2015), this would entail urban metabolism studies that engage with urban informality explicitly in order to uncover the environmental, social and economic aspects of resource distribution, as well as to unpack the politics embedded in material flows. Furthermore, Roy et al. (2014) argue that a mechanism that is capable of extracting key patterns of informal urban flows at different hierarchical levels and scales is essential in order to better understand the growth and emergence of slums.

It is the contention of this study that the conceptualisation and analysis of slums from a metabolic perspective may potentially address the shortcomings of conventional slum analysis, providing a more in-depth understanding of the phenomenon of slums and highlighting leverage points for future interventions aimed at addressing sustainable and equitable urban development, while

dispelling the myths that represent informal settlements only as “areas of decline and depravation” or as separated and distinct from what is deemed formal (Guibrunet and Castán Broto, 2015). As Guibrunet and Castán Broto (2015) assert, urban informality is a defining characteristic of how cities function and as such it is essential to assess its role in urban sustainability.

2.6 Understanding typology of slums in the South African context

The emergence of slums in South Africa is closely tied to the social and political history of the nation. Roy (2005) compounds the need to understand the political context, suggesting that informality should be considered as produced by the state itself and not as the object of state regulation. Therefore, the phenomenon of slums in South Africa can be viewed in terms of its political history and transformation, which has given rise to a multitude of slum types. During the apartheid era, between 1948 and 1991, urban planning was aligned with the racial segregation and social engineering policies of the government at the time (Hunter and Posel, 2012; Christopher, 2005). This gave rise to a number of settlement types, namely: (i) townships, locations, RDP neighbourhoods; (ii) housing-turned-slums; (iii) squatter camps; (iv) site and service informal settlements; (v) transit camps; and (vi) hybrid, multi-structured settlements.

It should be noted that although different categories of settlements are identified in this chapter, the different settlement types exist on a continuum between legal and illegal; formal and informal; and planned and unplanned, as illustrated in Figure 2.1. In considering the political context of South Africa, a further category of description emerges, related to the notion of legitimacy/illegitimacy. Roy (2005) argues that informality should be understood as produced by the state itself through its legal and planning apparatus which determine what is informal or not, who is deserving or not. Legitimacy here therefore highlights the complex political struggle associated with recognition by the state and as negated through the implementation of technical solutions that do not address sociopolitical issues (see Kovacic et al., 2016). The issue of legitimacy is used to indicate the possible stance taken by formal or government entities based on the provision of infrastructure and level of legal compliance.

The typology of settlement types in South Africa, therefore builds on the conventional framework (described in Figure 2.1) to include a deeper consideration of the societal and political aspects that impact informal settlements, as represented by legitimacy/illegitimacy. The different settlement types are discussed in the subsections below.

2.6.1 Townships / locations / RDP neighbourhoods

The 'township model' was established in 1918, prompted by health concerns and the Health Act, which included regulations to coordinate and control development (Harrison, 1992). The Native Urban Areas Act of 1923, restricted the influx of black people into urban areas, while at the same time empowering local authorities "to set aside land for blacks and provide formal housing within segregated areas, known as locations" (Harrison, 1992). Christopher (2005) describes these spaces as legal ghettos; that is "places of ethnic or racial group segregation, isolation and concentration", exhibiting relative longevity. These areas were planned for and created based on racial classification, resulting in ghettos specific to African, Indian, coloured and white communities (Christopher, 2005; Wilkinson, 1998). Forming part of a comprehensive system of social control, residential segregation or isolation was key to the apartheid project whereby each group would live in physically separate suburbs to reduce inter-group contact (Christopher, 2005; Wilkinson, 1998).

The legislative foundation of the apartheid city was removed with the advent of democracy in 1994, leading to a renewed impetus for the state to provide housing through the Reconstruction and Development Programme (RDP) (Wilkinson, 1998), and resulting in the creation of RDP neighbourhoods. Most of the proposed funding was allocated to contractors to build new units for the poor. However, these units have been criticised for being "too small, of poor quality, and in locations far from livelihoods and services" (Bradlow, Bolnick and Shearing, 2011). Bradlow et al. (2011) describe the new form of spatial development as enhancing, rather than dismantling the apartheid urban legacy. Wilkinson (1998) further problematises the RDP strategy for its "supply side approach", which is limited in addressing the fundamental social and spatial divisions of the country's cities. The heritage of

“systemic state ghetto planning” (Christopher, 2005), “splintered urbanism” (Swilling, 2011) and what the National Development Plan describes as the “apartheid geography” of the country (NPC, 2012) therefore remain an obstacle for any real change. Townships/locations/RDP neighbourhoods may be described as belonging to category A: Formal, Legal, Planned, Legitimate.

2.6.2 Housing-turned-slums

The second category of slums emerged from hostel-type accommodation, including the provision of barracks and compounds, which were built “as predominantly single-sex accommodation to house and control (usually) male workers who were employed by institutions such as the railways, municipality or large industrial employers” (Chenwi, 2012; Wilkinson, 1998). But owing to the lack of maintenance, gross overcrowding and high intensity of use, these buildings rapidly deteriorated (Chenwi, 2012; Wilkinson, 1998). According to Chenwi (2012), these spaces are prone to power struggles and violence over the allocation of accommodation, leading to a breakdown in formal systems of revenue collection with little formal reinvestment. Chenwi (2012) describes these spaces as different from ‘traditional’ informal settlements, relating more to ‘housing-turned-slum’. In other words, where these types of settlements may have started out as Formal, Legal, Planned, Legitimate (Category A), they have devolved over time, becoming unsafe and unhealthy, thus regressing to Category B: Formal, Illegal, Unplanned, Illegitimate.

2.6.3 Squatter camps

The political transition in South Africa formally commenced in February 1990 and established and strengthened property rights for previously disenfranchised black South Africans (Nathan and Spindler, 2001). The process involved the deregulation of historical territorial separation and population migration, and the strengthening of land tenure rights for newly enfranchised groups. However, owing to slow processes of land restitution, weak governance and the influx of economic migrants, new settlement types emerged in the form of, among others, squatter camps.

Squatting differs from site and service informal settlements (Category D), focusing instead on the illegal occupation of land or buildings. Squatter settlements can be the result of organised 'invasions' of land, which may occur overnight, or they can be the result of a gradual process of occupation and incremental growth (UN-Habitat, 2003). These types of settlements are generally considered as unwanted and may be classified as Category C: Informal, Illegal, Unplanned, Illegitimate. Although squatter camps and informal settlements existed before the fall of apartheid, the notable difference relates to the state's approach to them. According to Nathan and Spindler (2001), the government's laws and policies following the democratic elections favoured squatter group-rights to land settlement rather than squatter removal and relocation as under apartheid.

In this process, the squatters became beneficiaries of a new public interest, where land settlement, rather than removal, was prioritised. New laws made squatter evictions costly. This also made squatting a new and lucrative first-possession, contestable, rent-seeking activity to acquire expectative and later informally tradable property rights (Nathan and Spindler, 1991: 670).

Since democracy in 1994, government approaches to housing policies have varied greatly. A full discussion on the different policies and plans fall outside the scope of this study. However, the approaches may be summarised as including: benign neglect; forced evictions and demolition; resettlement or relocation; slum upgrading; and the adoption of enabling strategies or nurturing of self-reliance (Nuisl and Heinrichs, 2013; Arimah, 2009) through the following mechanisms:

- providing housing for all through the Reconstruction and Development Programme (Ndinda, Uzodike and Winaar, 2011; Huchzermeyer, 2010);
- relying on market approaches to housing provision (Ndinda et al., 2011);
- introduction of housing subsidy schemes including integrated residential development subsidies; informal settlement upgrading subsidies for informal dwellers; consolidation subsidies; emergency housing assistance subsidies; community residential units; institutional subsidies; People's Housing Process; social housing subsidies and rural subsidies for those with informal rights to land (Ndinda et al., 2011);
- eradication of informal settlements (Huchzermeyer, 2010);

- incremental upgrading of informal settlements (Huchzermeyer, 2010); and
- temporary relocations – giving rise to transit camps (Turok, 2015; Hunter and Posel, 2012).

2.6.4 Site and service informal settlements

This type of settlement refers to informal housing which has been constructed in the context of official ‘site and service’ schemes (Urban Foundation, 1991). In the late 1960s, the state took a decision to freeze all formal, legal, planned township development outside the designated ‘homelands’, leading to the emergence of informal settlements on the periphery of urban areas.

During the period 1967 to 1979, the state was committed to providing public housing, but few houses were built in this period. By the early 1980s a housing crisis had developed. The housing crisis, coupled with the lack of state funding, forced government to abandon its official policy of public housing with its high zoning and building standards – which discouraged lower quality housing and led to the emergence of site and service schemes (Harrison, 1992). The newly adopted strategy for black housing restricted government’s role “to providing infrastructure and services while the private sector and individuals would be responsible for the construction of the houses” (Harrison, 1992). These schemes involved legally established settlements, offering legal tenure and varying levels of servicing, with the potential for promoting incrementally upgraded housing from unconventional informal shelters to more formal housing (Urban Foundation, 1991). Site and service settlements still exist and for similar reasons pertaining to housing backlogs, these informal settlement types may be classified as Category D: Informal, Legal, Planned, Legitimate.

2.6.5 Transit camps

Transit camps are described as ‘temporary’ relocation areas, where shack dwellers are transferred, while they await access to formal housing, as the municipalities formalise layouts and service the former shack sites (Turok, 2015; Hunter and Posel, 2012). The contentious nature of this process of relocation lies in the physical and social dislocation and unpredictable timescale for living in these

areas, where residents are displaced from their communities and work opportunities (Turok, 2015; Hunter and Posel, 2012). Similar to site and service settlements, transit camps may be classified as Category D: Informal, Legal, Planned, Legitimate. However, these controversial spaces are planned to be temporary in nature, thus influencing the type of structures and tenure arrangements as well as the level of legitimacy afforded to the residents.

2.6.6 Hybrid, multi-structured settlements

Hybrid, multi-structured slums have emerged over time, spanning both formal/informal, legal/illegal, planned/unplanned and legitimate/illegitimate dimensions. An example of this settlement type can be found in Kayamandi, Stellenbosch (a town in South Africa). These settlements initially comprised hostel structures and later formal public or RDP housing. However, owing to overcrowding and a lack of maintenance and influx control, the settlement has devolved from a planned, formal, legal settlement (Category A), to one which includes a variety of settlement types and structures. For example, spontaneous informal housing is recognised as occurring outside the framework of formal township planning and development, despite being situated within a formal township (Urban Foundation, 1991).

This type of housing has occurred and persisted over time and may be further categorised in two forms (Urban Foundation, 1991):

- Backyard shacks – informal structures erected on residential properties in formal legal townships; and
- Free-standing informal settlements – clusters of informal structures located on tracts of land within formal townships; in buffer zones between townships; on undeveloped farmland; on tribal land close to urban centres; and on vacant land in formerly white, coloured or Asian areas.

These types of settlements encompassing both formal/informal; legal/illegal; and planned/unplanned aspects may thus be classified as combining Categories A to D, forming a new category E, illustrated in Figure 2.2.

From the discussion above, it may be surmised that the classification of slums in

South Africa is more nuanced, leading to a fifth category of slums, namely, Category E: Hybrid, multi-structured settlements.

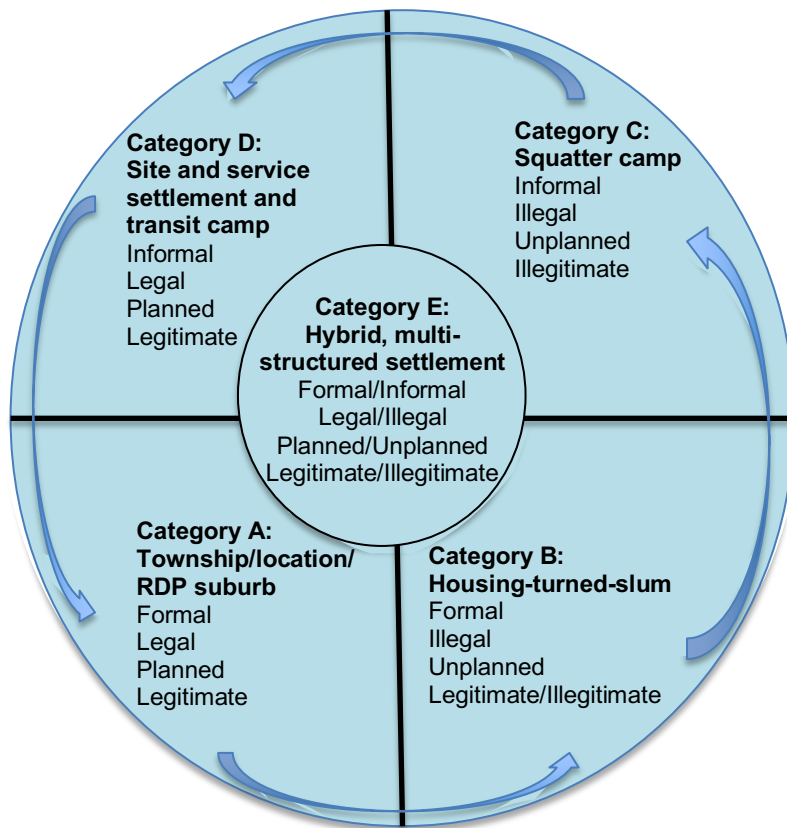


Figure 2.2: South African typology of settlements

The typology of South African slums described in Figure 2.2 extend the conventional understanding of slums, presented earlier in Figure 2.1, to include the dimension of legitimacy and how formal entities may be positioned in terms of their policy approaches. However, for sustainable urban planning, the material realities of urban slums need to be analysed as well.

2.7 Urban approaches to slums

The key challenges facing African cities relate to: (i) urban sprawl; (ii) substantial housing backlogs; (iii) segregation; (iv) slum and informal settlement proliferation; and (v) inadequate infrastructure and service provision (UN-Habitat, 2014a). Added to these are high levels of income inequality, unemployment and poverty –

as in the case of South Africa. Hence, the phenomenon of slums is unlikely to reduce or dissipate any time soon.

Considering the range of deterministic approaches (mainly stemming from the Global North) and limited number of positive cases of improved livelihoods, one may need to be more innovative and contextually relevant than turning to developed nations for answers on sustainable urban planning and development. According to UN-Habitat (2014a), “African cities are often analysed from a perspective that sees urbanism and urban living as progressing towards the example set by Western paradigms”. However, the conditions and circumstances that shaped the cities of the Global North are vastly different from the realities of today, where, for example, the advent of climate change and resource scarcity have had a major effect. Several authors have expressed the need to locate the production of theory and policy in the cities of the developing world owing to the limited relevance of general theory to the contexts of the Global South (see for example Ernston, Lawhorn and Duminy, 2014; McFarlane, 2008; Roy, 2005). Furthermore, when applied to the Global South, approaches following Global North paradigms tend to overlook or ignore informality in analyses and assessments (see for example Smit and Musango, 2015a; 2015b).

The conceptualisation and approach to slums in urban policy and planning are diverse, and often contradictory, in terms of their characterisation, whether slums are a problem and how they and their inhabitants should be treated (Turok, 2015; Nuisl and Heinrichs, 2013; Hunter and Posel, 2012). For example, Weiss (2014) argues that the post-apartheid landscape of South Africa has rendered “urban planning frameworks prone to reinforcing the marginalization of informal stakeholder engagement, ultimately perpetuating a socio-spatial inequality such programs set out to mitigate”. Furthermore, Turok (2015: 13) points to the need for informal settlements to be seen as “integral parts of the city occupied by motivated and resourceful citizens, not isolated squatter camps full of people who are destitute and desperate”.

Needless to say, where there is little or no government support for slum livelihoods, and where slums are not integrated into the broader urban environment, long-term

inequality and intergenerational disadvantage is perpetuated or even created, through lack of planning for or attention to slums in urban planning (Amado et al., 2016; UN-Habitat, 2015b). This study therefore rejects the view of slums as a separate problem to be solved, or as a place of 'hope' where local potential is used as an argument not to intervene while holding that the phenomenon of slums needs merely to be acknowledged in urban planning.

Nuissl and Heinrichs (2013) describe *problem-orientated* approaches to slums as focusing on three dimensions, namely: (i) the material dimension, referring to physical urban structure and infrastructural layout; (ii) the social dimension, related to deprivation and stigmatisation; and (iii) the institutional dimension, associated with the formal and informal rules influencing the life of slum dwellers. Although these dimensions are recognised as important factors affecting urban policy and planning, it is the contention of this study to introduce a further dimension for analysis, involving what may be considered a more *systems-orientated* approach, namely: the metabolic dimension.

2.8 Metabolic dimension of slums

Based on the typology of settlements in South Africa, illustrated in Figure 2.2, a particular settlement type was identified, and the metabolic dimension applied using MuSIASEM. The MuSIASEM approach, developed by Giampietro et al. (2013, 2012), is based on Georgescu-Roegen's flow-fund model (Giampietro and Mayumi, 2000a; 2000b). Unlike other conventional urban metabolism approaches such as an economy-wide material flow analysis (Raupova, Kamahara and Goto, 2014; Kovanda, 2014), an ecological footprint analysis (Wang, Wang and Shao, 2014), and input-output analyses (Huang and Bohne, 2012), the MuSIASEM approach provides a characterisation of informal settlements at different levels and scales in terms of *funds* and *flows* and *across multiple dimensions*. Fund elements include: (i) human activity measured in time (see Figure 2.3); (ii) exosomatic devices in the form of technology and infrastructure; and (iii) land measured in terms of land use. Flows are represented by the elements metabolised in the system, which include: (i) food; (ii) energy; (iii) water; (iv) waste; and (v) money.

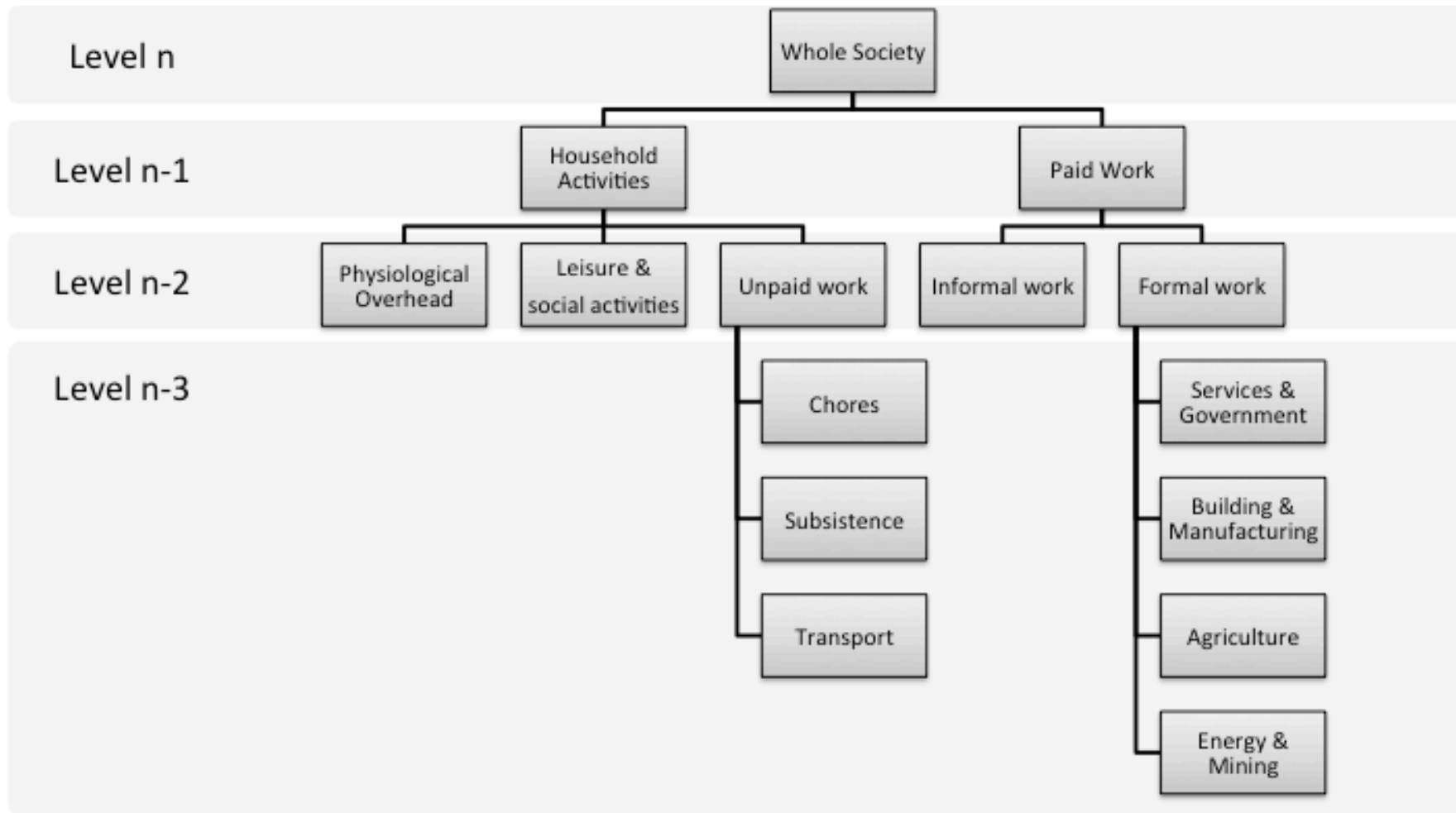


Figure 2.3: Dendrogram of human activity

Essentially, the MuSIASEM approach is an analytical tool for analysing the development of human society in relation to sustainability (Giampietro, Mayumi and Bukkens, 2001). The approach is multidisciplinary, however, in that it is capable of integrating variables related to non-equivalent descriptive domains and equipped to incorporate data from distinct hierarchical levels (Giampietro et al., 2001).

Furthermore, the value of the MuSIASEM approach for analysing both the informal and domestic activities of informal settlements is hailed by Robinson et al. (2013) in their review of several methods related to urban metabolism. The heterogeneity of functions within settlements are illustrated in Figure 2.3, where they are described as human time allocated to different activities measured in hours/year. The analysis may be done at multiple scales, expressed as individual (n-2), household (n-1) and informal settlement or community level (n). Level n is further defined as the number of people in the settlement times the total number of hours available in a single year. At a lower level (n-1), human activity may be divided into: (i) paid work (PW), referring to the number of hours worked per year by the working population; and (ii) household activities (HA), referring to non-working hours of the working population and including hours of the non-working population. At a lower level (n-2), the types of PW and HA are further broken down into categories of physiological overhead, leisure and social activities, unpaid work, informal work, and formal work.

This type of distinction of activities is a key factor in understanding informal economic activities, as well as for identifying leverage points that may improve the productivity and development of the settlement. For example, it may be argued that unpaid work and informal work, which are trademarks of the informal economy, contribute to society. In other words, these activities are productive, though for different reasons. For example, time spent on transport (in terms of journey time and waiting time) should ideally be reduced through improved public transport networks, as this time may be spent more productively, either in the PW sector or on other HA, which improve quality of life. In contrast, unpaid work (in the form of, say, looking after a neighbour's child) might not be considered directly productive in economic terms. However, it may be considered as indirectly productive, as it:

i) contributes to the social economy of the informal settlement; and ii) enables the recipient of the service to be economically active. The recognition of informal work as part of the PW sector is also very helpful. These activities provide for many of the needs of informal settlement dwellers, yet they are by definition excluded from GDP calculations, which consider these activities as non-economically productive. This type of analysis, which recognises the value of informal and unpaid work, may therefore contribute to our understanding of slum economies and how they connect with the broader local formal economies, as well as how these livelihood strategies may be improved or supported.

The MuSIASEM approach is thus relevant for both urban and developmental policy and planning. In addition, it is essential for dealing with different levels of uncertainty that affect the analysis of urban informal settlements and the introduction of sociotechnical solutions. It can also be utilised for understanding the material standard of living of the inhabitants and the dynamics of slum development, as well as how these spaces interact with their wider socioeconomic contexts (Smit et al., forthcoming; Kovacic and Giampietro, 2016; Kovacic, et al., 2016; Miranda et al., 2015).

As part of contributing to the understanding of the societal metabolism of urban informal settlements, this study used Enkanini informal settlement as a case study. The use of time, money and energy in Enkanini was investigated using the MuSIASEM approach.

2.9 Assessing societal metabolism of Enkanini informal settlement

Enkanini is an informal settlement, which was established in 2006 through the illegal occupation of municipal land (CORC, 2012). It is located approximately 4 km from the centre of Stellenbosch town⁴. Based on the aforementioned slum categories (see Figure 2.2), Enkanini may be classified as having started as a

⁴ A more detailed description of Enkanini can be found in Chapters 3 and 4 and Kovacic et al. 2016.

squatter camp (Category C: Informal, Illegal, Unplanned, Illegitimate), which is gradually progressing to a site and service informal settlement (Category D: Informal, Legal, Planned; Legitimate) with limited access to basic services.

Several research studies have been conducted in the Enkanini informal settlement. Examples are studies focusing on waste management (Von der Heyde, 2014), food waste and food production (Mollat, 2014), sustainable energy and in situ upgrading (Keller, 2012) and power transitions (Wessels, 2015). Wessels (2015) characterises the Enkanini informal settlement as an illegal, un-mobilised, underdeveloped local community. Although these characterisations are valuable in understanding the complex nature of the community, they do not position the informal settlement as a socioecological system that is connected to the wider urban system. An alternative approach is thus necessary.

The societal metabolism and biophysical characterisation of the Enkanini informal settlement was therefore examined at different scales, including individual, household and whole settlement level, and for different resources. Primary data was based on a survey (see Appendix C) of 100 households (276 people), which was carried out as part of the Participatory Integrated Assessment of Energy Systems to Promote Energy Access and Efficiency (PARTICIPIA) project. The following sections highlight some key results obtained by applying the MuSIASEM approach, related to the use of time, money and energy in the Enkanini informal settlement.

2.9.1 Human activity in Enkanini informal settlement

In terms of human activity in the Enkanini informal settlement, the initial results indicated that the components of the informal settlement, in this case different household types, were both productive (hypercyclic) and consumptive (dissipative) in nature (Giampietro et al., 2009). The Enkanini informal settlement is a net provider of labour to the town of Stellenbosch, as 69% of the working age population of the sample were found to be employed (see Figure 2.4).

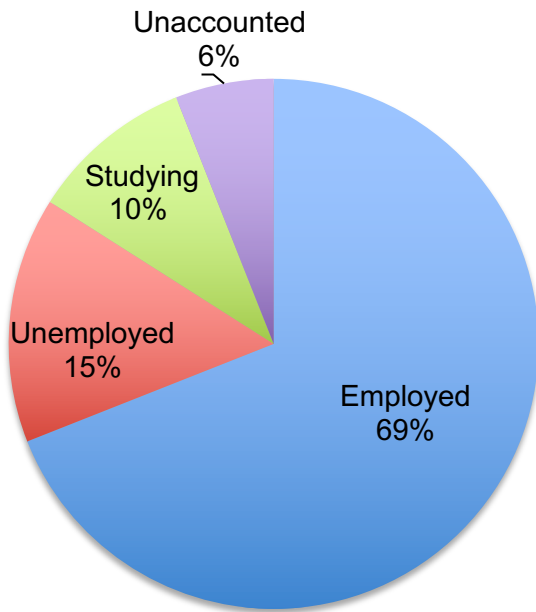


Figure 2.4: Employment status of working-age population

The majority of those who did paid work were observed to be in the services and government sector (82%), followed by 11% in the productive sector (energy, construction and manufacturing) and 5% in the primary sector (agriculture) (see Figure 2.5).

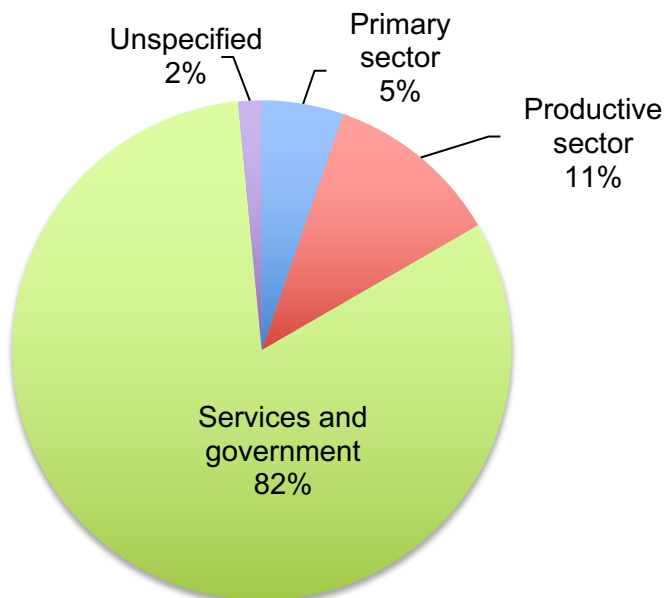


Figure 2.5: Contribution of paid work to sectors of society

The data further yielded insight into how much time workers spent on travelling to and from work, as well as the associated costs, which could be high as many residents rely on informal taxi services in the absence of public transport (see Chapter 3 for more details).

2.9.2 Monetary flows in Enkanini informal settlement

In terms of monetary flows, the Enkanini informal settlement has its own internal economy, which is connected to the wider Stellenbosch Municipality and formal economy. Money flows were traced through the income of residents and their expenditure for goods and services. In particular, Figure 2.6 highlights that food constituted the largest expenditure at 31%, followed by clothing at 12% and the third largest was fuel at 11%. Savings only accounted for 14% of the overall budget. The majority of residents hailed from the Eastern Cape province, where the survey showed that most households still had familial ties and assets and thus expended cash surpluses in these regions. This indicated that the flow of money extended beyond the Stellenbosch Municipality borders to other regions (including outside South Africa).

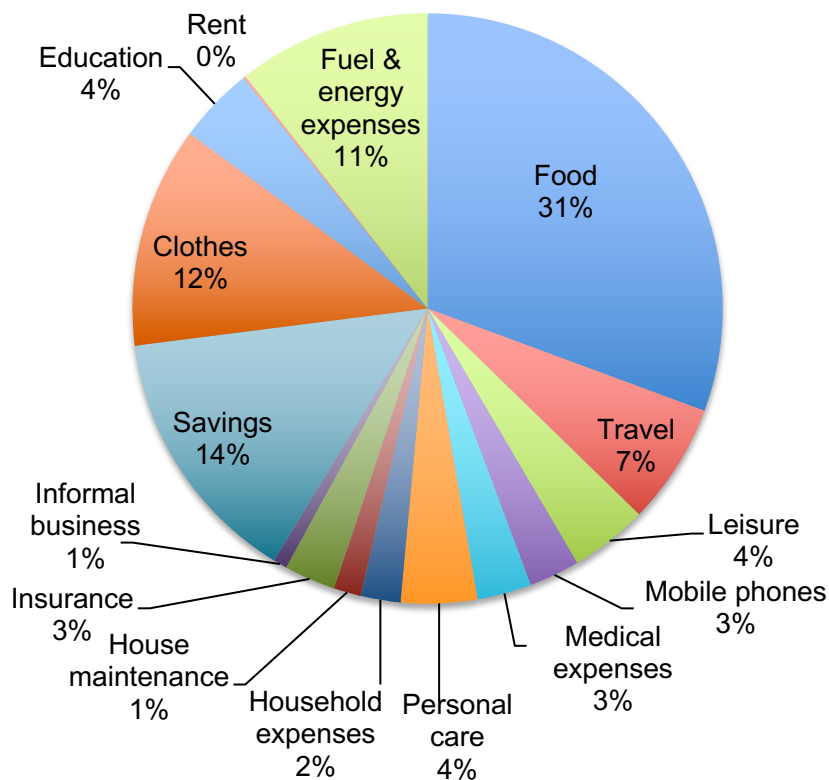


Figure 2.6: Breakdown of household expenses

On comparing the average household expenditure for the Enkanini sample (level n), with the South Africa average household expenditure on basic goods and services (see Figure 2.7), it was observed that Enkanini residents proportionally spent much less on transport (7% compared to 17.1%), and fuel (11% versus 32%), than the average South African household. However, these figures represented the inherent inequalities, as many Enkanini residents chose to walk to work to save costs, and only 7% of the residents had access to grid-connected electricity, thus relying on paraffin and gas for most of their energy needs.

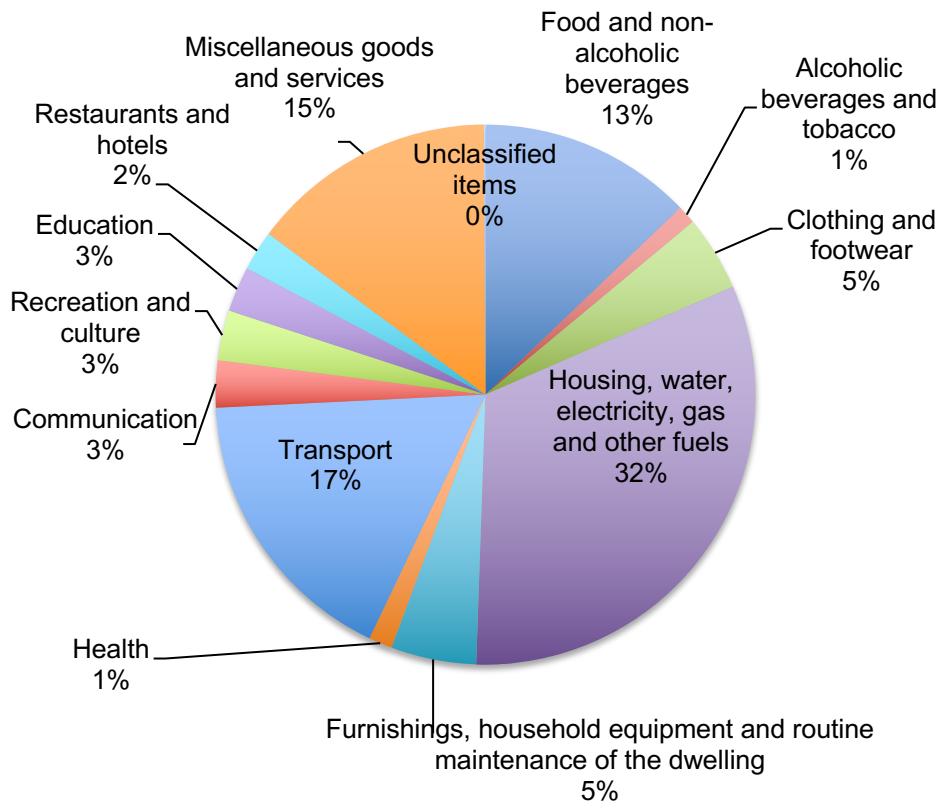


Figure 2.7: Average South African household expenditure

Source: StatsSA, 2012.

Given that the MuSIASEM approach considers different hierarchical levels, it was further possible to examine the economic activity for individuals (level n-2) and different household types (level n-1). This is arguably an important feature of the approach as the composition of the settlement had changed considerably since its inception. In 2012, Enkanini was dominated by single adult households, which were estimated at 53% (CORC, 2012), while the survey carried out in 2015 for this study indicated that the largest number of households were those with three persons and more, at 51%, while the number of single adult households had declined to 24% (Kovacic et al., 2016). The changed proportion of household types had significantly altered spending patterns related to food, education and clothing, while having particular effects on the quantity and type of fuel and energy consumed (Kovacic et al., 2016). Furthermore, at the level of individuals (n-2), it was possible to uncover gender and age-related aspects pertaining to income and employment (see Chapter 3).

2.9.3 Energy flows in Enkanini informal settlement

In terms of energy flows, the Enkanini settlement is a net consumer. The settlement currently has no municipal-supplied access to electricity. However, it was found that 74% of the households sampled had access to electricity, either through indirect connections to the grid (via a neighbour), or through a solar electric system (see Figure 2.8). However, it should be noted that of the 67 households using a solar system, the majority (66%) did not consider themselves as having access to electricity.

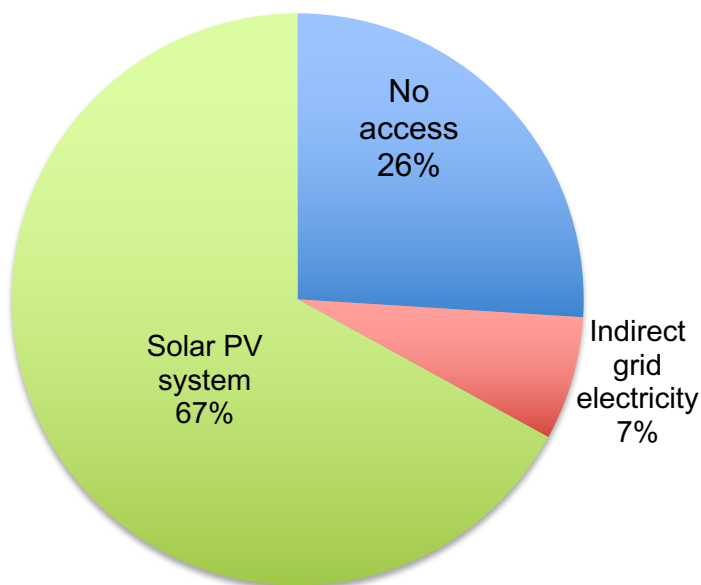


Figure 2.8: Community access to electricity

Having access to electricity (in the form of either solar or indirect grid-connected electricity), had little to no effect on the type of fuel used for cooking, water heating and space heating, as most households still relied on paraffin and/or gas for these activities (see Table 2.3). It is worth noting that, although one might expect those with access to grid electricity to use it for cooking, this was generally not the case. There was only one instance where grid electricity was used for cooking.

Participants with access to electricity in the form of indirect connections indicated that it was generally understood that using electricity for cooking placed too much strain on the supply, causing the connections down the line to trip or fail. These

users therefore substituted electricity with alternative fuels in the form of paraffin or gas. Alternatively, users arranged for communal or shared cooking time within the household at the juncture from which the grid electricity connection stemmed. Similarly, those with access to electricity via solar energy did not rely on solar energy for cooking, water heating or space heating, owing to the limited power capacity and volatility of supply.

Table 2.3: Overall fuel mix per activity

Fuel source	Cooking	Lighting	Water heating	Space heating	Electric goods
Paraffin	47%	39%	43%	88%	
Wood	1%		2%	6%	
Gas	51%		51%	1%	
Candles		19%			
Coal				1%	
Solar PV		37%			89%
Batteries		1%			7%
Indirect electricity	1%	5%	4%	3%	4%
TOTAL	100%	100%	100%	100%	100%

Several factors influenced the type and quantity of fuels used, including cost and availability. Solar users paid a flat rate of R150 per month through a local company operating in the settlement, while those indirectly connected to the electricity grid via a neighbour could pay up to R300 per month, which they paid to the owner of the grid connection. As resident's usage was not metered, social aspects, such as trust, were vital to the transaction, although it may be argued that exploitation was rife. Similarly, because of their locale, informal micro businesses or Spaza shops located within the settlement were the preferred option for purchasing paraffin and candles. However, residents reported that prices tended to vary dramatically, increasing nearly three-fold during shortages.

Other factors affecting fuel consumption related to population dynamics. Kovacic et al. (2016) described the impact of household composition (at level n-1) as having a major impact on the type and quantity of fuels used, explaining that although the Enkanini population had nearly doubled between 2012 and 2015, their consumption of fuel and energy had not. Rather the consumption was determined by the number and instance of certain household types, as well as the combination of fuels used. This phenomenon however, could only be explained by analysing the data at household level. Overall, these issues represented not only consumptive inequality, but, according to Kovacic et al. (2016), it also pointed to issues of energy poverty and distributional inequality⁵.

These results shed new insights on the societal metabolism of informal settlements and how they connect with the wider urban system. It therefore moved beyond an understanding of the slum, based on legal and physical characteristics, and considered the material reality of a slum and its inhabitants based on certain characteristics, and as pertaining to the politics embedded in these flows, which influenced the inhabitants' ability and capacity to metabolise resources.

2.10 Conclusion

Given the imperative for a holistic approach and understanding of the functioning of slums, or informal settlements, and their connection to the wider urban system, there was a need to re-conceptualise these spaces beyond classifications based on deprivation or as poor neighbourhoods with low quality housing, and rather to see them as intricately connected socioecological systems. In this respect, the chapter traced the conceptualisation of slums on a global scale and provided a broad perspective and understanding of slum classifications, as well as the factors that influence and affect the study of slums. A conceptual framework was developed for classifying urban slums based on physical and legal characteristics. This type of classification was considered useful, forming the basis upon which different slum types may be analysed. However, to achieve sustainable urban

⁵ For a detailed description of the effect of household composition on energy consumption, see Kovacic et al., 2016.

planning and development, it was argued that urban informal settlements also need to be analysed from a metabolic perspective. As such, a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach was found to be useful, particularly as related to the following aspects: (i) providing rich data at different hierarchical levels; (ii) allowing for the use of multiple tools and criteria to analyse the informal settlement as socioecological, sociotechnical and socioeconomic systems; (iii) recognising and tracing the connections between the formal and informal city; (iv) providing a deeper understanding of the material reality of slums and their inhabitants; (iv) uncovering the politics embedded in resource flows; (v) highlighting areas for policy intervention; and (vi) being useful as a decision support tool for socially equitable and sustainable urban planning.

The study recognised that several issues affect the conceptualisation of, and approaches to, the planning of slums. These aspects were investigated, and relate to: (i) governance, both internal and external to the slum, in determining the quality of engagement between slum dwellers and the municipality in relation to energy fuel choice and energy access, as described in Chapter 4; and (ii) the different levels of uncertainty that affect the analysis of urban informal settlements and the implications of the implementation of upgrading policies, as explored in Kovacic et al. (2016). In addition, further work, in the form of a Master's study (see Makinde, 2018), was conducted, which considered the metabolic dimension for a different category of slum.

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CHAPTER 3: TOWARDS MEASURING THE INFORMAL CITY: A SOCIETAL METABOLISM APPROACH^{6,7}

3.1 Chapter overview

Chapter three addresses the second research question: How does a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach contribute to the study of informal settlements in the context of sustainable urban development? Certain key results are provided in order to demonstrate how an urban informal settlement is connected to the broader urban environment in terms of the use of time, money and energy. The writing and development of this chapter were principally the responsibility of the writer and resulted in the publishing of a paper in the *Journal of Industrial Ecology*.

Abstract

The rapid growth of urban informal settlements or slums poses a particular challenge for balancing developmental and environmental goals. In South Africa, high levels of inequality, poverty and unemployment contribute to widespread migration. The influx of migrant workers into cities however is rarely matched with adequate housing and infrastructure, resulting in the formation and growth of urban informal settlements. Despite the persistence of the slum phenomenon, very few studies provide an in-depth understanding of the metabolic processes that link these spaces, and informal economies, to the broader urban environment and

⁶ A paper based on this chapter was published in the *Journal of Industrial Ecology*. The reference is: Smit, S., Musango, J.K., Kovacic, Z., and Brent, A.C. 2018. Towards measuring the informal city: A societal metabolism approach. *Journal of Industrial Ecology* (in press).

⁷ Certain outputs were presented at the following: Southern African Sustainable Energy Initiative (SASEI), International Renewable Energy Conference (IREC), 26–28 October 2016, Gaborone, Botswana; PhD colloquium of the Innovation for Sustainable Development Network (inno4sd), Africa-Europe Dialogue Symposium on Innovation for Sustainable Development, 29 November – 1 December 2017; and 24th International Sustainable Development Research Society Conference (ISDRS 2018), 13–15 June 2018, Messina, Italy.

economy. This study therefore utilised a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach to examine human activity and land use in Enkanini, an urban informal settlement in Stellenbosch, South Africa. The results highlight a number of issues to be addressed through spatial, developmental, and local economic policy such as the need for improved transport linkages. The time use results show that Enkanini is a net provider of labour to the surrounding area. Further, geographic mapping indicates Enkanini as a small, but vibrant, informal economy, while being grossly underserved in terms of water, waste and sanitation infrastructure. Key implications are discussed in terms of the theoretical, methodological, societal and policy impact of the study, including the need for city observatories that conduct regular data collection and analysis.

Keywords: urban slum; informal settlement; urban metabolism; societal metabolism; MuSIASEM

3.2 Introduction

Increasing urbanisation, coupled with the proliferation of slums, particularly in developing countries, gives rise to the need for a holistic approach to, and understanding of, the functioning of slums and their connection to the wider urban system (Smit et al., 2017; Guibrunet and Castán Broto, 2015; Guibrunet, Sanzana Calvet and Castán Broto, 2016; Attia and Khalil, 2015). Informal settlements, or slums, are recognised by the United Nations Human Settlement Programme (UN-Habitat, 2010) as households lacking any of the following conditions: (i) access to improved water; (ii) access to improved sanitation facilities; (iii) sufficient living area – not overcrowded; (iv) structural quality/durability of dwellings; and (v) security of tenure. The analysis of slums should not solely be based on their physical, geographical and legal characteristics (Smit et al., 2017) but should also consider their societal metabolism in relation to the overall city. This is because slums are not self-evident units of analysis and are connected to the broader urban metabolism in many different ways.

Urban metabolism provides a conceptual framework for understanding the functioning of cities with regard to the technical, socioeconomic and socioecological processes that result in growth, production and consumption of material flows, and the elimination of waste; thereby influencing sustainable urban planning and design (Kennedy, Cuddihy and Enege-yan, 2007; Kennedy, Pincetl and Bunje, 2011; Pincetl, Bunje and Holmes, 2012; Currie and Musango, 2016). While urban metabolism is useful for shaping urban sustainability (Kennedy and Hoornweg, 2012), existing studies have not effectively engaged with the institutional and political contexts, which shape and influence urban material flows (Pincetl et al., 2012; Guibrunet et al., 2016; Currie and Musango, 2016).

This has led several authors to call for a 'politicisation' of urban metabolism (Newell and Cousins, 2015; Smit et al., 2017) and the inclusion of urban informal settlements or slums in the study of urban metabolism (Smit et al., 2017; Guibrunet et al., 2016; 2015; Attia and Khalil, 2015; Currie and Musango, 2016). Furthermore, effective policy and infrastructure planning requires understanding the variations of resource consumption within the city (Horta and Keirstead, 2016). This implies that urban metabolism studies should explicitly incorporate urban informality to uncover the environmental, social and economic aspects of resource distribution, and to unpack the politics embedded in material flows (Guibrunet and Castán Broto, 2015; Musango, Currie and Robinson, 2017).

Conventional urban metabolism methods⁸ tend to incorporate accounting methods that rely on secondary data (Beloin-Saint-Pierre et al., 2016), or statistical methods for downscaling aggregate data (Horta and Keirstead, 2016; Currie and Musango, 2016), rather than utilising primary data based on bottom-up approaches. These studies therefore tend to ignore informal flows and processes of informal settlements, which are deemed 'data scarce' areas (Currie and Musango, 2016).

⁸ Conventional urban metabolism methods include economy-wide material flow analyses; ecological footprint analyses; input-output analyses; energy assessments; life cycle assessments; network analyses; and combinations of these methods (Beloin-Saint-Pierre et al., 2016; Musango et al., 2017).

Therefore, in cities where informal settlements represent the largest population, the urban metabolism results may not be a complete representation of metabolic flows.

In this regard, using a bottom-up approach to urban metabolism that accounts for human activity measured in time and which is derived from the broader field of societal metabolism can be useful. Societal metabolism measures the metabolism of human society through characterisation of the processes that a society employs to transform energy and materials to ensure its continued existence (Kovacic and Giampietro, 2016; Giampietro, Mayumi and Ramos-Martin, 2009; Fischer-Kowalski and Hüttler, 1999; Fischer-Kowalski, 1998). Societal metabolism was first introduced by Marx's *Capital* (Castán Broto, Allen and Rapoport, 2012; Martinez-Alier, 2009; Foster, 1999) and later taken up by ecological economists (most notably Martinez Alier, 2009) and combined with political ecology (Martinez-Alier et al., 2010). Main attempts to quantify and operationalise societal metabolism relate to the work of Fischer-Kowalski (1998), Fischer-Kowalski and Hüttler (1999), Giampietro et al. (2009) and Giampietro and Mayumi (2000a; 2000b). The potential here is to utilise the societal metabolism approach to identify both the formal and informal processes that drive urban metabolism.

While the societal metabolism approach has been applied to urban metabolism studies (see for example Ramos-Martín et al., 2009), its application to urban informal settlements is limited (see Attia and Khalil, 2015; Royden-Turner, 2012). Existing studies that have applied societal metabolism to informal settlements or slums have utilised a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach (see for example Smit et al., 2017; Kovacic and Giampietro, 2016; Kovacic et al., 2016; and Miranda, Santos and Giampietro, 2015). The MuSIASEM approach was developed by Giampietro, Mayumi and Sorman (2013, 2012), and is based on Georgescu-Roegen's flow-fund model (Giampietro and Mayumi, 2000a; 2000b).

To the researcher's knowledge, theoretical and empirical studies on the metabolism of the informal city are limited, although a small body of work in this field is emerging. For example, Guibrunet et al. (2016) analyse system boundaries and waste flows as a means to politicise urban metabolism research; Demaria and Schindler (2016) concentrate on waste-to-energy as a means of highlighting contestations over the (re)configuration of urban metabolisms; Attia and Khalil (2015) analyse water flows and quality of life to understand the role of informal areas in achieving sustainable cities; and Kovacic et al. (2016) investigate energy flows and energy policies to address misconceptions of slum communities, and to illuminate inequality and marginalisation. In terms of philosophical underpinnings, Guibrunet et al. (2016) confront ontological assumptions about the concept of 'city', whereas Kovacic et al. (2016) deal with the methodological, technical and epistemological uncertainties that characterise energy interventions in urban informal settlements.

This chapter therefore makes a methodological and empirical contribution to the societal metabolism assessment of the informal city. It investigates the second research question of this study, based on the following two sub-questions: (i) How can the informal city be measured in terms of metabolic funds and flows? (ii) What are the policy implications of adopting a societal metabolism approach applied to urban informal settlement? The chapter is organised into the following sections: firstly, the concept of the informal city is described, then the methods utilised and the case study are discussed; secondly, the case study findings regarding the societal metabolism of an urban informal settlement are discussed; and finally, the theoretical, methodological, societal and policy implications of applying the societal metabolism approach to an informal settlement are highlighted.

3.3 What is an informal city? From qualification to quantification

An 'informal city' refers to an active city that supports multiple basic livelihoods of urban residents but remains mostly invisible to urban authorities (Guibrunet and Castán Broto, 2015) and urban metabolism studies. There are numerous conceptions of urban informality and its emergence (for example see Haid, 2016;

and Roy, 2005). The informal city results from informality⁹, which encompasses patterns of spatial organisation, social relations and economic exchanges, and as the bottom-up provision of urban goods and services, including housing, employment and infrastructure, where government has failed to deliver (Guibrunet and Castán Broto, 2015). Within this chapter, the informal city is represented through an urban informal settlement, which encompasses a particular spatial organisation, with its own informal economy and responses to poor infrastructure and service delivery. We thus recognise informal settlements as having their own patterns of consumption and production, and informal processes.

3.4 Methods to quantify informal city societal metabolism

The MuSIASEM approach consists of five steps, described in Miranda et al. (2015). However, this study was limited to the first two steps, which entail defining the system, in this case an informal settlement, in terms of funds and the system activities in terms of flows. Fund elements in MuSIASEM include: (i) human activity – measured in time; (ii) exosomatic devices in the form of technology and infrastructure; and (iii) land use, while flows are represented by the elements metabolised in the system, which include: (i) food; (ii) energy; (iii) water; (iv) waste; and (v) money. MuSIASEM was thus utilised as an exploratory study of Enkanini informal settlement, incorporating mixed quantitative and qualitative methods, in order to understand the use of time, money and energy within the settlement.

Information regarding population dynamics, the flow of money and energy consumption are found elsewhere (see Smit et al., 2017; Kovacic et al., 2016; Kovacic and Giampietro, 2016), while the analysis of food and waste flows was beyond the scope of the study. In short, the focus of this article is on the fund elements of Enkanini informal settlement, and is thus limited to human activity, exosomatic devices and land use.

⁹ Informality is recognised as including unofficial (i.e. neither prescribed nor formally measured or sanctioned) actions or processes that may fall outside the scope of law but are not necessarily illegal.

3.5 Description of the Enkanini informal settlement

Enkanini, which means to ‘take by force’, is located about four kilometres (approximately 2.5 miles) from the centre of Stellenbosch, an affluent town with high levels of inequality, in South Africa (Western Cape Government, 2015). Enkanini informal settlement was established around 2006 through illegal occupation, when a small number of backyard shack dwellers were evicted from the neighbouring and officially recognised Kayamandi settlement (CORC, 2012; CST, 2016; Zibagwe, 2016). The number of households illegally occupying municipal land (zoned as agricultural, non-residential land) soon grew to 225 households, leading the municipality to resort to litigation in February 2007. After a period of six months, the courts granted the municipality the right to evict the 225 households provided that the order be enforced by December 2007. During this time however, the number of households had increased to nearly 1000 households (Zibagwe, 2016). Furthermore, enforcement of the eviction order required that the municipality hold a full council meeting to discuss and vote on the decision; as to avoid the eviction being deemed unprocedural. According to Zibagwe (2016), this meeting never took place and it was only in 2013 that a full council meeting was held to formally reflect on and consider the court order.

In 2011, Stellenbosch municipality partnered with the South African Slum/shack Dwellers International (SDI) Alliance to enumerate the settlement, and provided a limited number of toilets and taps. By 2013 the Stellenbosch municipality was unable to implement the eviction order previously granted as i) the court deadline for eviction had passed in December 2007; ii) the number of households in Enkanini now far exceeded 225 households and iii) the eviction order was never ratified by a full council meeting. Instead, Stellenbosch municipality began to investigate the possibility of rezoning the land for residential use, stating that the process of re-zoning would take a long time (Zibagwe, 2016).

In 2016 the Stellenbosch municipality had not identified Enkanini for social or

formal housing but had allocated one million rand¹⁰ (around sixty-eight thousand dollars), in terms of planning and services related to the Enkanini informal settlement (Stellenbosch Municipality, 2016). In 2017, Enkanini was scheduled to receive 1300 enhanced services over the next 3 to 5 years (Stellenbosch Municipality, 2017).

According to Swilling (2014) however, it could take a further eight years before the community is connected to the water and electricity grids, despite bordering a formalised township with direct electricity access, to its north, and an industrial area with factories, to its south. This suggests that the legality of the informal settlement or residents' rights to tenure is in transition. As per the classification by Smit et al. (2017), Enkanini is transitioning from Category C type: Informal, Illegal, Unplanned, Illegitimate towards Category D: Informal, Legal, Planned and Legitimate.

Furthermore, the Enkanini informal settlement is fast changing and dynamic: it's population nearly doubling from 4 500 (in 2011) to 8 000 people (in 2015), while the type of households have drastically changed from mostly single adult households (53% of the population in 2011) to mainly households with two or more people (76% in 2015). Other than the enumeration conducted in 2011, very little is known about the settlement in terms of human activity, land use and infrastructural requirements, thus indicating the need for this type of study to effect planning to meet the service delivery and resource requirements of the settlement.

¹⁰ Average exchange rate in 2016 was R14.71 to \$1 (From: https://www.nedbank.co.za/content/dam/nedbank/site-assets/AboutUs/Economics_Unit/Forecast_and_data/Daily_Rates/Annual_Average_Exchange_Rates.pdf)

3.6 Data collection process and tools

To collect the required data on human activity, household income and energy consumption¹¹, fieldwork was conducted in collaboration with the Enkanini Research Centre Association, through which five experienced community-based field researchers administered questionnaires to 100 households¹². Land use and infrastructure data were captured using GIS; while interviews with six community-based field researchers informed qualitative observations, thus verifying context and providing validation of the quantitative data collected.

3.6.1 Human activity measured in time

The MuSIASEM approach allocates hours of human activity across several different compartments operating at different hierarchical levels. These different compartments express the key functions performed by society in order to operate and reproduce a socioeconomic system (Giampietro et al., 2012). Figure 1 represents the sizes of the various compartments in hours allocated per year, where, at the level of the whole (level n), the total available hours for all sampled households for one year was calculated by multiplying 8 760 hours in a year by the number of individuals in the sampled households.

¹¹ It should be noted that energy consumption data was limited to quantities of traditional fuels, such as paraffin and gas, used per household per month; and changes in energy mix over time (see Kovacic et al. 2016 in Appendix A). This is due to the fact that indirect electricity and solar PV electricity use is not metred. The survey originally did not account for this (see Appendix C). This limitation prompted a follow-up study, currently underway, which is calculating electric and solar PV energy consumption.

¹² The sample size was comparatively small for a population of 2 800 households. However, the objective of the study was to identify patterns or trends in consumption among different household types.

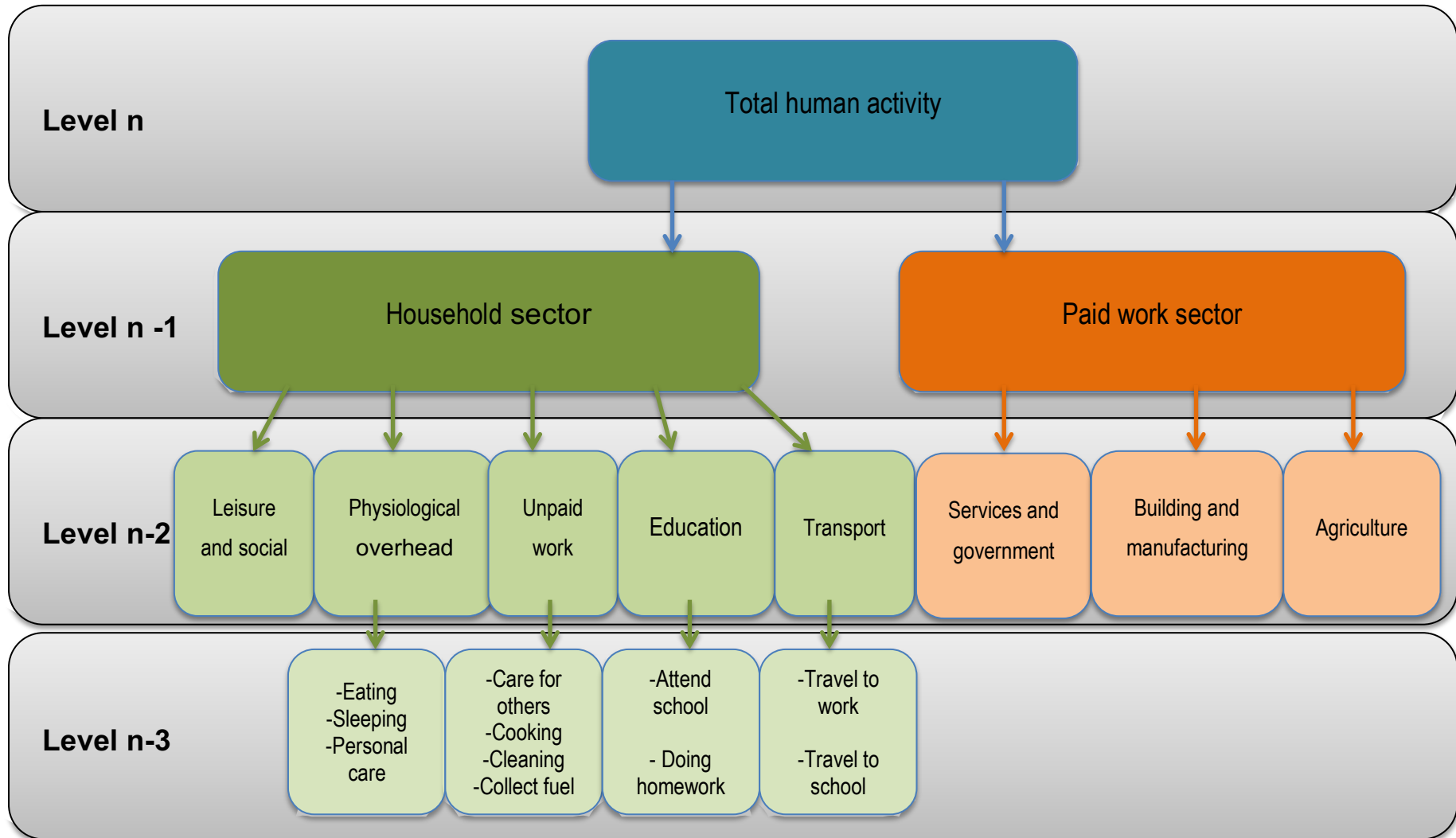


Figure 3.1: Categories of human activity at different hierarchical levels

Total human activity, as indicated in Figure 3.1, can also be calculated as the sum of the total number of hours spent in the household sector and paid work sector at level n-1. The household sector includes all the activities carried out outside the paid work sector. The pattern of activities in the household sector can be categorised further at level n-3. Whereas the paid work sector, which includes the hours of human activity invested as formal or informal paid work in the economic process, may be assigned to different economic sectors.

3.6.2 Participatory mapping and livelihood mapping using GIS

Participatory mapping was undertaken in collaboration with five community-based researchers that live in the settlement, using coloured markers to identify major roads, infrastructure, social organisations and leisure areas, informal businesses and sectional divisions on an enlarged 2015 Google Earth map of the settlement.

This was followed with mapping by means of a GPS device to capture the geographic data pertaining to land use and infrastructure. The process of mapping involved recording the GPS position of each structure or shack (informally built structures using mainly corrugated iron) within the informal settlement. The structures were then classified as belonging to energy access, land use or water, waste and sanitation infrastructure categories (see Table 3.1).

Table 3.1: Human activity and land use classification matrix

1. Energy access classification	1.1 Shack with electricity connected to grid	1.2 Shack with indirect electricity (informal connection via a neighbour)	1.3 Shack with solar electricity (Solar PV system)	1.4 Shack with NEITHER solar NOR indirect electricity	1.5 Shack with BOTH solar AND indirect electricity	
2. Land use classification	2.1 Residential only	2.2 Business only	2.3 Combination of residential and business	2.4 Religious organisations/churches	2.5 Educational facilities	2.6 Agriculture and farming
		2.2.1 Retail	2.3.1 Residential and retail	2.4.1 Church (Christian)	2.5.1 Day care service	2.6.1 Commercial
		2.2.2 Food and beverage service activities	2.3.2 Residential and food and beverage service activities	2.4.2 Mosque (Islam)	2.5.2 Basic education up to Grade 12	2.6.2 Subsistence
		2.2.3 Accommodation and rentals		2.4.3 Mandir (Hinduism)	2.5.3 Vocational training	
		2.2.4 Construction		2.4.4 Temple (Buddhism)	2.5.4 Research Centre	
				2.4.5 Folk religion	2.5.5 Other	
				2.4.6 Other		
3. Water, waste and sanitation infrastructure classification	3.1 Taps	3.2 Toilets	3.3 Waste disposal sites			
	3.1.1 Direct, municipal supplied taps	3.2.1 Formal municipal supplied toilets	3.3.1 Municipal supplied waste disposal site			
	3.1.2 Indirect community supplied taps	3.2.2 Informal community supplied toilets	3.3.2 Unauthorised/informal dumping site			

A total of 5 866 data points was captured, of which 2 786 related to energy access, 2 859 to land use, and 221 to water, waste and sanitation infrastructure. An example of a completed observation sheet, illustrating attributes of two data points is represented in Table 2.

Table 3.2: Example of completed observation sheet

GPS points	Code	Attribute
¹³ xx xx xxx S xx xx xxx W	1.1; 2.2.2; 3.1.1	<ul style="list-style-type: none"> ○ Shack with electricity connected to a grid ○ Shebeen business¹⁴ ○ Direct tap water connection from the municipality
xx xx xxx S xx xx xxx W	3.3.2	<ul style="list-style-type: none"> ○ Unauthorised waste disposal site

Energy access classifications were employed to demonstrate the range of energy carriers used and point to developmental aspects for policy and planning purposes, such as improving overall access to modern and safe energy. Secondly, Land use classifications provided the range of informal economy activities, number of social organisations and service providers and also point to livelihood strategies, through a dual-purpose application of residential and business activities within a structure. Water, waste and sanitation infrastructure classifications were used to inform what is needed in terms of formal service delivery.

3.7 Societal metabolism of the Enkanini informal settlement

The societal metabolism of Enkanini informal settlement in terms of human activity, land use, and infrastructure and service provision are presented first. This addresses the first question of this chapter on how the informal city can be measured from a societal metabolism perspective.

¹³ Actual GPS tracking data has been omitted to protect the privacy of the residents.

¹⁴ The word 'shebeen' describes premises offering both food and alcohol.

3.7.1 Human activity based on time use in Enkanini informal settlement

The total available hours for all sampled households in Enkanini for one year was 2 137 440 hours. This was calculated by multiplying 8 760 hours in a year by 244, the number of individuals in the sampled 100 households. Of the 244 participants in the sample, 48% were male and 52% were female. Figure 3.2 shows that most of the total human activities for the sampled households were spent in the household sector (88.3%), while 11.7% of time was spent in the paid work sector. The time use for each of these sectors is elaborated upon below.

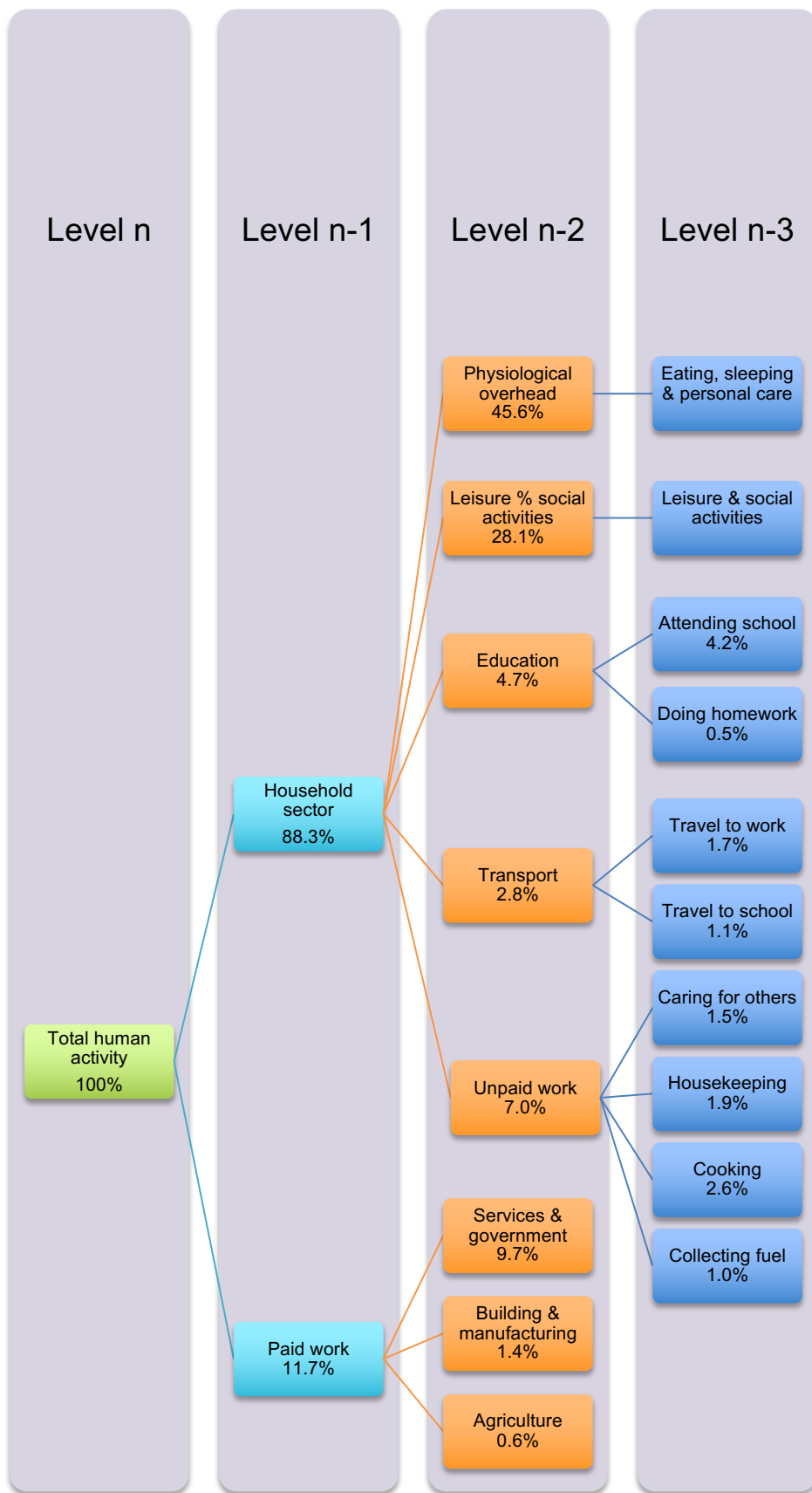


Figure 3.2: Breakdown of human activities as a percentage of total human activity

3.7.1.1 Household sector activities in the Enkanini informal settlement

Time spent in the household sector consisted of all the hours spent by all persons of working age and non-working age outside of work, including children and unemployed adults. Most of the time spent in the household sector for the sampled households related to 45.6% in physiological overhead, which included eating, sleeping and personal care, and 28.1% in leisure and social activities. Men and women of all ages spent a median of three hours per day on leisure and social activities, 11 hours per day on eating, sleeping and personal care, and two hours per day doing unpaid work. Unpaid work constituted 7% of total human activity and included activities such as cooking, housekeeping, collecting fuel, and caring for others. This proportion was relatively high, considering the paid work sector constituted 11.7 %, while at national level, paid work is estimated to be 6.45% of total human activity¹⁵.

Generally, men and women spent the same amount of time cooking and collecting fuel, while females spent twice as much time on housekeeping than men in the sample. In terms of participation rates, Figure 3.3 indicates that female participation far outweighed male participation for unpaid work activities related to caring for others (86%), housekeeping (72%) and cooking (70%), whereas the activity of collecting fuel was more balanced between male and female participants (45% and 55%, respectively). Therefore, despite the amount of time spent per gender on each unpaid work activity, overall female participation in these activities was far greater than male participation.

¹⁵ Paid work data was estimated by the authors based on the 2015 national labour force survey (StatsSA, 2015), which relates to the period that data collection took place.

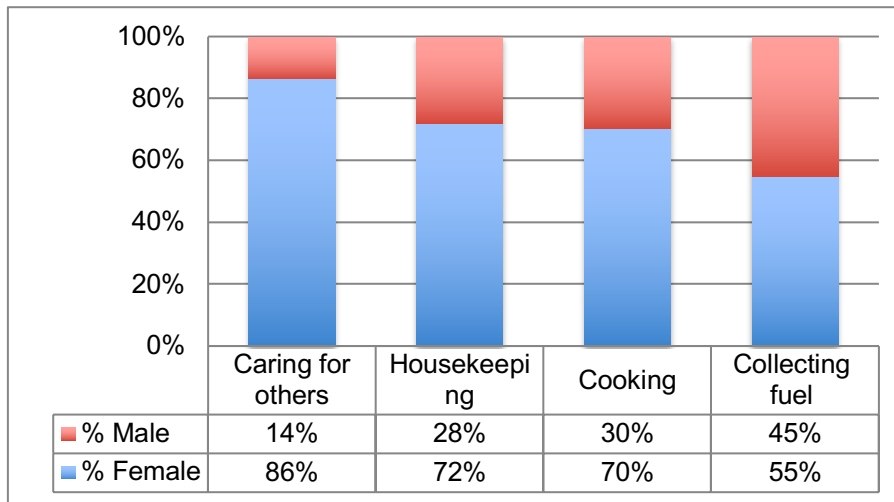


Figure 3.3: Division of unpaid work activities by gender

Although the time spent travelling to and from work contributes to the economic activity, long waiting times and irregular services have an impact on workers' available time and could be used more productively. Transport constitutes 2.8% of total human activity, while travelling to work constitutes 1.7% and travelling to school constitutes 1.1% (refer to Figure 3.2). The median time spent on travelling to work on a daily basis is approximately 45 minutes per person, with little difference between men and women (43 and 40 minutes, respectively). This compares well to the national average of 87 minutes per person per day (StatsSA, 2013). There are an equal number of male and female workers (63 per gender) and the most common mode of transport for both genders is walking (61%), followed by taking an informally operated mini-bus taxi (17%) or train (13%).

The high number of walkers (61%) combined with cyclists (4%), indicate that the majority of workers live close to their places of work. The median walking time is approximately 21 minutes per single or one-way journey, suggesting that the jobs are mostly local to Stellenbosch, thereby indicating that Enkanini residents are economically connected to the wider town. Some individuals in the sampled households indicated frustration with informally operated mini-bus taxi services as being both costly and unreliable, hence the reason for walking to work. On the other hand, those that rely on mini-bus taxis do so because of longer travelling distances (too far to walk), and lack of public transport that connects different work

centres. In terms of travel to school, the national average stands at 58 minutes per day (StatsSA, 2013), whereas the children of Enkanini spend on average 106 minutes (1 hour 45 minutes) travelling to school, while half the children travel more than two hours per day. These long travel times may point to a lack of affordable or no-fee schools in the area and/or lack of school buses, thus leaving children either to walk very long distances or having to travel to surrounding towns to gain access to education. Overall, the travel times may indicate the need for affordable, reliable public transport which is well connected between Stellenbosch and neighbouring towns, as well as the need for more no-fee schools in the area.

3.7.1.2 Paid work sector in the Enkanini informal settlement

The paid work sector constituted 11.7% of total human activity for the Enkanini sample, and included the hours of all individuals who were working either part time or full time. Of the 244 individuals sampled, 64% were of working age (aged 15 to 64, but not going to school); 11% were unemployed, and 2% were studying, bringing the total number of employed persons to 52% of the sample population. In comparison, the paid work sector for South Africa in 2015 was estimated at 6.45% of total time available to society, the working age population was similarly around 66%, while unemployment was notably higher, averaging at 25% (compared to 11% in Enkanini) (StatsSA, 2015). Furthermore, 80% of the working age population were in employment, whereas at national level, the labour absorption rate was only 43% (StatsSA, 2015). This signified that Enkanini was a net provider of labour to the wider community, indicating that it provided more hours of paid work than it required in terms of schooling, health care and public services in general.

However, taking a closer look into the working conditions for the Enkanini sample by gender and type of work, that is full-time (considered long-term, regular work, more than four days a week) and part-time (considered as temporary, irregular, seasonal work, or less than three days a week), a different picture in terms of job security and gender emerged (see Figure 3.4).

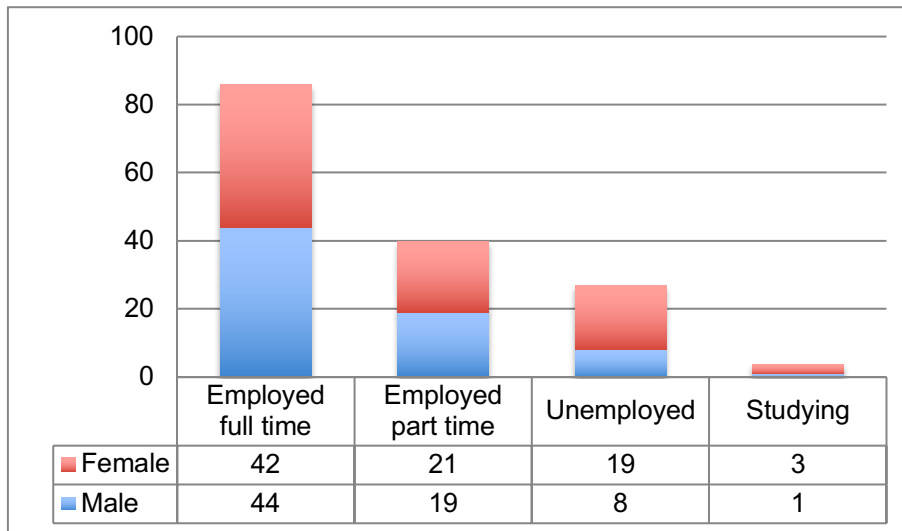


Figure 3.4: Working age population status by gender

Figure 3.4 indicates that 32% of working individuals sampled were in temporary or part-time jobs, thus influencing job security and the ability to generate income. A further noticeable trend related to the gender disparity in unemployed persons, where females constituted 70% and males 30% of unemployed persons of the sampled individuals. The term unemployed here referred to a person of working age (15 to 64 years) that was not in an education programme and not in any form of employment.

3.7.1.3 Employment by sector in the Enkanini informal settlement

The majority of paid work occurred in the services and government sector (83%), followed by the building and manufacturing sector (11%), and the agricultural sector (6%). The services and government sector provided the most full-time work opportunities overall (63%), thus offering the most job security and income-generating opportunity. In terms of the gender breakdown per sector, Figure 3.5 indicates that while the agricultural sector and services and government sector jobs were equally distributed between men and women, the energy, building and manufacturing sector jobs were mainly retained by men. Although a wide range of jobs fell within the services and government sector, the majority of service work related to domestic work (24%) and security work (25%), with 92% of domestic work done by women and 92% of security work done by men. These types of jobs were also indicative of the reliance of higher-income groups in the formal parts of the city on the cheap labour provided by informal settlement residents.

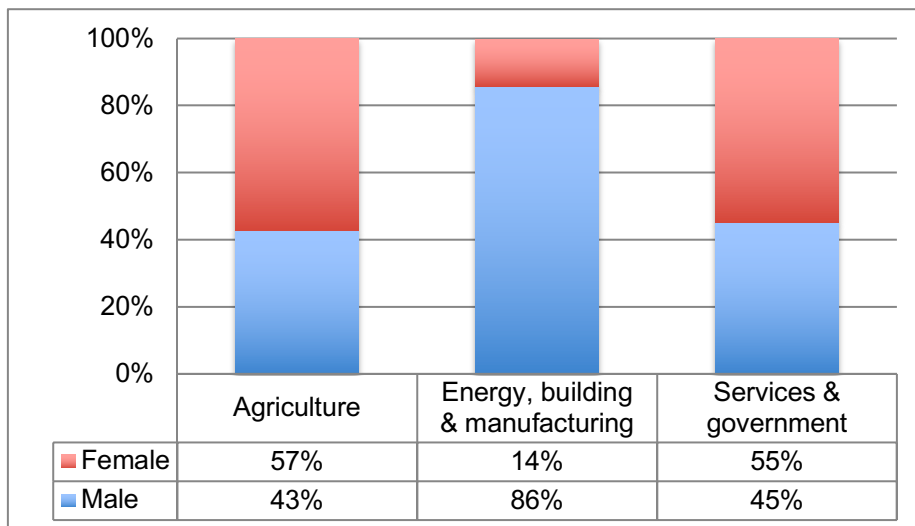


Figure 3.5: Gender breakdown by sector

3.7.2 Community representation of land use and infrastructure in the Enkanini informal settlement

Photograph 3.1 represents the Enkanini map, which was produced in participation with community-based field researchers. The map indicates the location of churches, shebeens (informal restaurant establishments), educational facilities, spaza shops (micro businesses), and municipal toilet blocks, while the white lines represent flood-prone areas.



Photograph 3.1: Community map of land use and infrastructure in Enkanini

3.7.3 Land use and infrastructure mapping results in the Enkanini informal settlement

The results of the GPS mapping are organised per classification category related to: (i) energy access; (ii) land use; and (iii) water, waste and sanitation infrastructure.

3.7.3.1 Energy access in Enkanini informal settlement

Currently, 86% of South Africans have access to electricity. While the South African national government aims to achieve universal energy access by 2025, it recognises issues related to electrifying informal settlements (Department of Energy, 2017). The Enkanini informal settlement is still classified as an illegal informal settlement, therefore currently no direct grid-connected electricity access is available (see Figure 3.6). Consequently, the majority (63%) of shacks have no

access to either solar electricity or indirect grid electricity¹⁶. These spaces mainly rely on traditional energy carriers, such as paraffin and gas, to supply their energy needs. Structures relying mainly on solar electricity, generated through solar photovoltaic (PV) systems¹⁷, constitute 24% of the settlement.

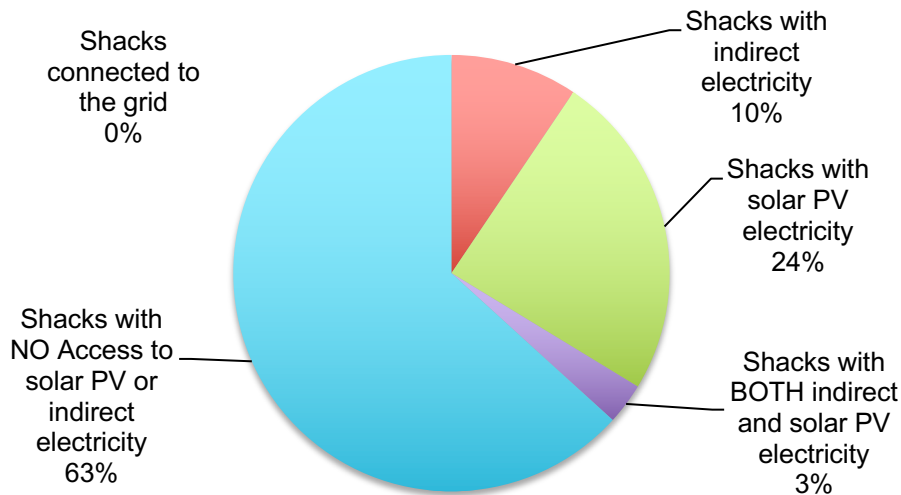


Figure 3.6: Shacks classified by energy access

Although a seemingly positive development in terms of the adoption of renewable energy is emerging, the study established that 66% of solar users did not consider themselves as having access to electricity. Moreover, the solar PV systems did not fulfil the energy requirements of households, leaving them to supplement their supplies with traditional fuels. A similar scenario existed for the 10% of residents who relied on indirect electricity that also supplemented their energy sources, particularly as related to cooking, because of the low capacity of the respective systems. Therefore, any gains made from using modern and safe energy sources

¹⁶ Indirect electricity users obtained electricity through informal connections via neighbours from the Kayamandi settlement (situated to the north of Enkanini) who were formally and directly connected to the electricity grid. Indirect electricity users purchased prepaid electricity vouchers that were passed on to the owner of the formal connection. As there was no record kept of actual electricity use by the indirect user, this arrangement relied heavily on trust.

¹⁷ For more information see <http://www.ishackproject.co.za/>.

such as solar and electricity were lost, as traditional fuels were still the staple, while indirect electricity connections were prone to causing fires.

3.7.3.2 Land use in Enkanini informal settlement

Although 98% of the structures in Enkanini were residential only, there was a small but vibrant informal economy offering a range of products and services (see Figure 3.7). Excluding agriculture and forestry, 65% of economic activities revolved around the sale of food and beverages, followed by service offerings (25%), including hair and beauty salons, and childcare facilities. Sixty per cent of economic activities took place within residences, whereas activities such as hawking required no structures other than a small table situated at a busy intersection. In terms of agriculture, 2.5% of residents grew their own food, selling or giving the remainder to other households, while commercial animal farms (two relatively large spaces designated for pig and chicken farming) sold directly to residents and local businesses.

Further to economic activity, participants in the participatory mapping exercise indicated that the municipality previously attempted to relocate residents living in the flood-prone areas (found in the centre of the map where the rivers converge) to higher ground. However, as the settlement grew, these spaces were reoccupied, mainly by single mothers, which indicates that different vulnerable groups within the settlement lived in more precarious areas (Smit, 2015). Considering the social dynamics of the settlements, this suggests that a permanent solution need to be sought in consultation with the residents of the informal settlement.

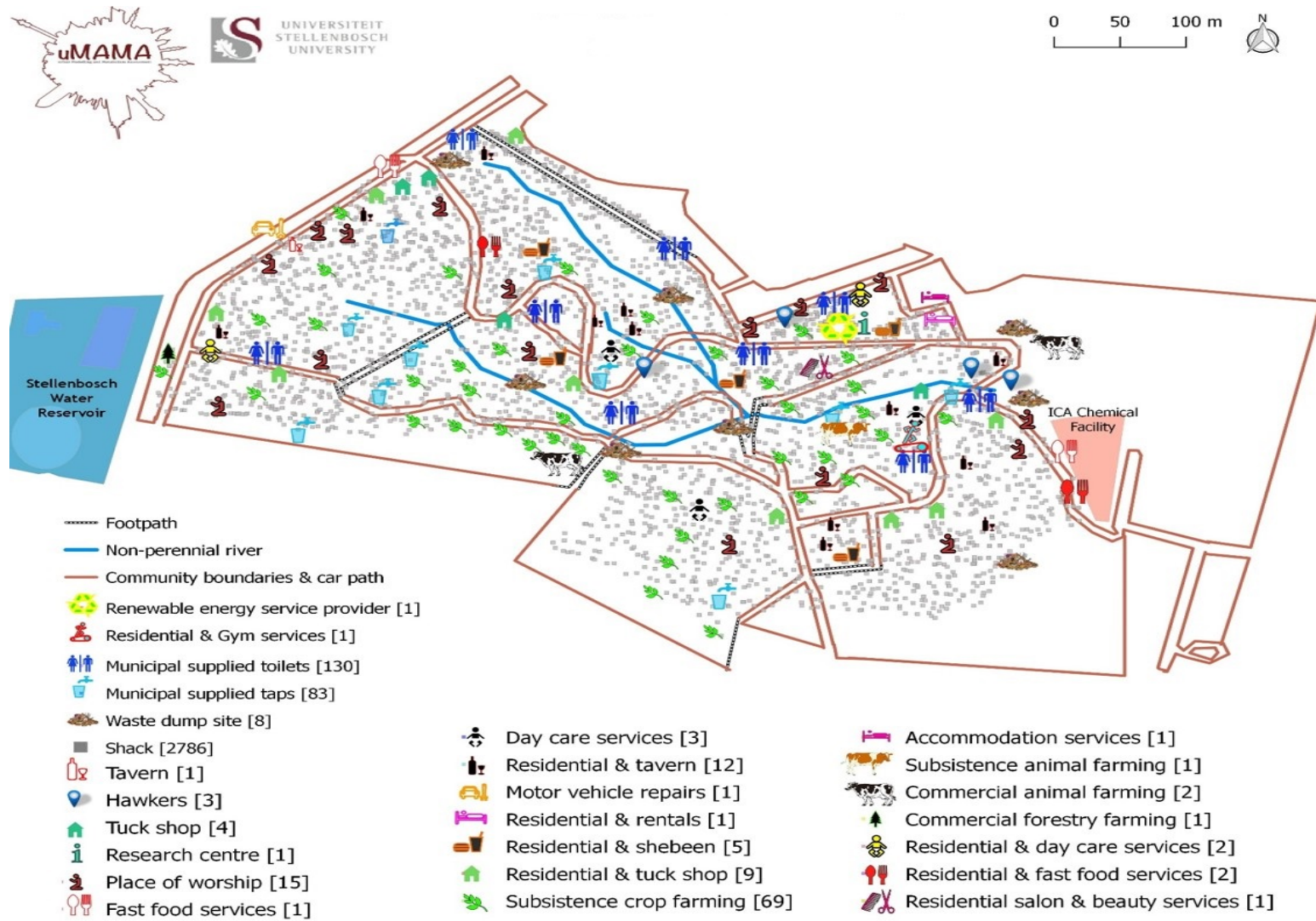


Figure 3.7: Land use map of Enkanini settlement

The transport infrastructure of Enkanini settlement were also highly problematic as roads, carved out of the clay soil, were narrow, steep, uneven and slippery, with barely enough space for one car to manoeuvre. The poor road network had also exacerbated the waste and sanitation problems in the settlement, as waste collection by municipal truck was not possible. Similarly, the footpaths within the settlement required attention as these were frequently filled with sewerage off-flow. While the building of new road networks and footpaths would improve the health and safety of the daily commuters, it would require much consultation with residents, as some dwellings would have to be demolished to make room for new serviceable roads.

3.7.3.3 *Water, waste and sanitation infrastructure in Enkanini informal settlement*

The water and sanitation infrastructure provided by the municipality, illustrated in Figure 3.8, has become vastly inadequate with the growth of the settlement. This prompted some residents to devise their own solutions in the form of informal connections, including piped tap extensions and toilet facilities in residences¹⁸. The ratio of households, taken as the number of residential only and dual-purpose shacks, to municipal supplied toilets currently stands at 21.2 households per toilet, or 2 753 shacks to 130 toilets, while the number of households to municipal supplied taps stands at 33.2 households per tap. This means that there are approximately 61.5 people per toilet, which is in excess of the national target of 50 users per communal toilet seat (Department of Water and Sanitation, 2017). A further distressing trend is the lack of functional municipality-supplied and serviced refuse removal services, leading to the emergence of eight dumping sites within the settlement. The lack of refuse removal has visibly contributed to the deterioration of the overall environment and led to an increase in unsafe and unhealthy conditions.

In view of the sensitive nature of this information, the informal connections that were observed are not indicated on the map for the sake of confidentiality.

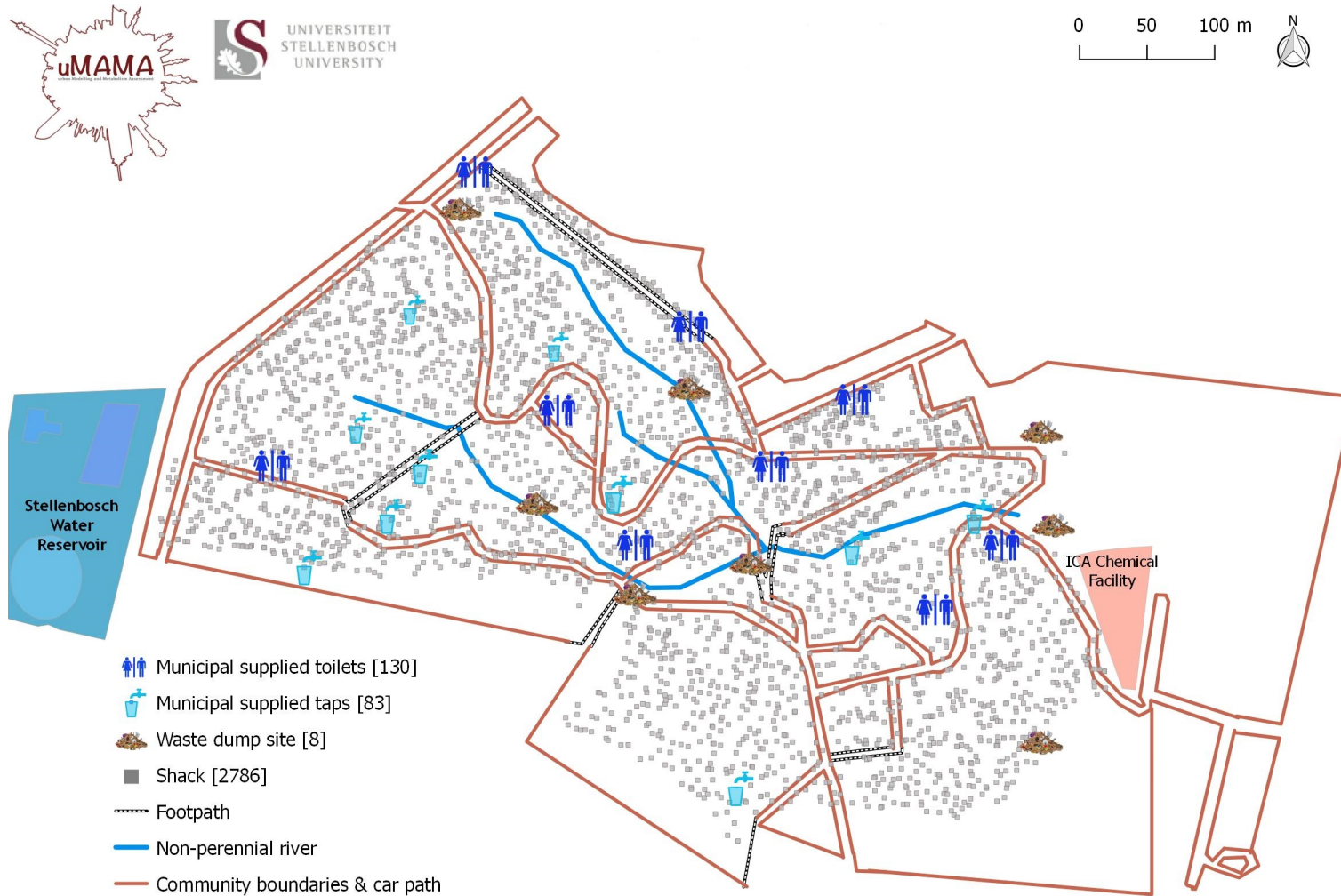


Figure 3.8: Water, waste and sanitation infrastructure in Enkanini settlement

3.8 Implications of adopting the societal metabolism approach to urban informal settlements

This section addresses the second sub-question posed in the chapter and therefore considers the implications for theory, methodology, society and policy.

3.8.1 Theoretical implications

This study has argued that urban informal settlements should be included in urban metabolism analysis, particularly in the developing world where large portions of the urban population live and work in slums. This inclusion would contribute to the realisation of urban metabolism that takes a holistic perspective and seeks to recognise and address resource inequality, while providing a more robust analysis of cities based on differentiated urban metabolism.

Further to this, the Enkanini case study forms part of a newly proposed master's programme on Participatory Integrated Assessment of Energy Systems to Promote Energy Access and Energy Efficiency in Southern Africa (PARTICIPIA)¹⁹; a transdisciplinary approach for supporting energy and development policies (see Kiravu et al., 2018).

3.8.2 Methodological implications

The MuSIASEM approach was applied in part, as an exploratory study to uncover the societal metabolism of a particular urban informal settlement type. This approach was taken in recognition of the fact that there are different settlement types, which may display different metabolic rates owing to their available infrastructure, building types, level of legality or legitimacy, and socioeconomic circumstances. The Enkanini case was therefore the first step in analysing these different types of settlements in terms of their societal metabolism. Although the

19 For more information on PARTICIPIA visit: <http://www.participia.net/>.

full results of the Enkanini case are not published here, the combination of MuSIASEM with mixed methods, enabled verification and validation of the data produced for analysing human activity, monetary flows, land use and infrastructure.

Further, the MuSIASEM questionnaire has been replicated in Kayamandi, a hybrid, multi-structured settlement type, in Stellenbosch, South Africa (Makinde, 2018). This formed the basis for customising the MuSIASEM questionnaire for a cross-country comparative analysis currently underway with Mathare in Nairobi, Kenya and Kasubi Kawala in Kampala, Uganda, which aims to co-design energy communities with poor urban women²⁰.

In all the informal settlement case studies, a sample size was standardised and limited to 100 households. Although the sample size might seem small for larger informal settlements, great care was taken to ensure that the sample was representative of household types, building types and geographical sections. Furthermore, the objective of the study was to identify patterns or trends in consumption among different household types. Once these patterns are identified, energy consumption for the community can be extrapolated by multiplying the median energy usage for each household type with the number of instances of the different household types. This data will be available from national census data; however, as demonstrated in the Enkanini case, these spaces are fast changing and require enumeration more frequently than the 10-yearly census. In this regard, establishing city observatories that conduct data surveys on a regular basis and which allow for regular analysis of informal settlements may be useful. The Gauteng City-Region Observatory²¹ in South Africa, for example, conducts surveys every three years to stay abreast of changes in the province of Gauteng and neighbouring regions.

²⁰ <http://codec.livinglab.co.ke/>.

²¹ <http://www.gcro.ac.za/>.

3.8.3 Societal implications

The societal impact of this type of work lies in its ability to give visibility, voice and validity to marginalised communities while providing policy makers and local authorities with the tools for dealing with the complexity and uncertainty that define urban informal settlements and slums. While the results presented here may not be comprehensive, it is arguably a positive step towards urban and developmental planning that is integrated and inclusive.

3.8.4 Policy implications: Contributions to urban agenda policies

This study contributes to the international urban policy agenda in several ways: firstly, by providing societal metabolism data for informal settlements described as data scarce areas; thus, contributing to the development of standardised metrics such as ISO 37120:2014 developed by the World Council for City Data (WCCD, 2017); secondly, by enhancing the relevance of the concept of urban metabolism and its application to the developing world context through cross-country studies in Africa; and, thirdly, by providing methodological rigour through empirical evidence, using mixed and unconventional approaches to urban metabolism assessments – a need recently highlighted in the Sustainable Development Goals report (UN, 2017a). Finally, the study contributes to the international urban policy agenda by informing standards and principles for planning sustainable and equitable urban areas promoted through the five pillars of the New Urban Agenda (UN, 2017b).

3.9 Conclusion

This chapter considers how the informal city may be quantified in terms of societal metabolism and what the implications of such an application is to theory, methodology, society and policy. A Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach, in combination with mixed quantitative and qualitative methods, is promoted as an appropriate methodology for quantifying the informal city in terms of funds and flows, although only fund data are presented here. The MuSIASEM approach enabled the analysis of informal economic activities through time use surveys; while capturing

developmental and infrastructural requirements through participatory and GIS mapping.

The analysis of human activity suggested that Enkanini residents were a net provider of labour to wealthier parts of Stellenbosch. Furthermore, Enkanini residents were far more economically active than the national average. Land use results pointed to a number of informal economy and livelihood activities, in the form of dual-purpose structures for residential and business activities, while water, waste and sanitation infrastructure was found to be grossly inadequate. Furthermore, energy access remained constrained owing to the lack of direct electricity connections and satisfactory substitutes. The key findings at local policy level therefore related to the need for i) improved roads and foot paths in the community; ii) affordable public transport connecting workers to different work centres, and children to schools; iii) increased education and day care facilities; iv) access to direct electricity or improved alternatives that fulfil households' energy requirements; v) improved water, waste and sanitation services to enhance the health and safety of residents; vi) support for small and micro enterprises to improve economic activity and livelihood strategies either through legal advice, financial support, or advice bureaus.

The implications of applying societal metabolism to an urban informal settlement relate to theoretical contributions to the field of urban metabolism; methodological contributions through the replication of the study in other African cities; societal impact of representing marginalised communities, previously neglected in urban metabolism; and as informing international urban policy, standards and metrics.

The Enkanini case does not deliver a comprehensive set of metabolism results; however, as an exploratory study into the societal metabolism of slums, it has led to and informed several subsequent studies. Additionally, the lessons learnt from the application of MuSIASEM to a particular informal settlement type contributes to the development and improvement of the method for future cases.

Data collection from a bottom-up perspective may be time consuming and costly; however the data scarcity and persistence of these spaces warrant in-depth analysis for sustainable and equitable urban planning. Going forward, the intention is to continue with the expanded roll-out and improvement of MuSIASEM for analysing different slums types in the urban African context.

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CHAPTER 4: UNDERSTANDING ELECTRICITY LEGITIMACY DYNAMICS IN AN URBAN INFORMAL SETTLEMENT IN SOUTH AFRICA: A COMMUNITY BASED SYSTEM DYNAMICS APPROACH^{22,23}

4.1 Chapter overview

Chapter 4 addresses research question 3: What are the electricity legitimacy dynamics of Enkanini informal settlement? Research question 3 emerged from the results of applying MuSIASEM to Enkanini informal settlement, which indicated a need for a deeper understanding of the issues that affect energy fuel choice and energy access. The writing and development of this chapter, as well as the submission of the resulting paper to the journal *Energy for Sustainable Development*, were principally the responsibility of the writer.

Abstract

The aim of providing affordable, reliable, sustainable and modern energy for all requires an in-depth understanding of the issues that affect energy access and energy choice, particularly as related to urban informal settlements or slums. Within unequal societies, such as those in South Africa, a reliance on technical solutions to address access and inequality is inadequate, leading to resistance and protest. This chapter therefore investigates the issues that affect energy fuel choice and energy access as related to the introduction of a renewable energy solution in an

²² A paper based on this chapter has been submitted to the journal *Energy for Sustainable Development*. The reference is: Smit, S., Musango, J.K. and Brent, A.C. (forthcoming). Understanding electricity legitimacy dynamics in an urban informal settlement in South Africa: A Community Based System Dynamics approach. Paper submitted to *Energy for Sustainable Development*, manuscript number: ESD_2018_838.

²³ Certain aspects of this chapter were presented at the PhD colloquium of the 34th International Conference of the System Dynamics Society (ICSDS), 16–21 July 2016, Delft, The Netherlands.

urban informal settlement. The case of Enkanini demonstrates that the introduction of a technical solution – such as solar PV electricity – to address energy access is not a simple process and requires a systems perspective. Using Community Based System Dynamics modelling, factors that affect energy access and energy fuel choice, as well as the relationship between these factors in order to improve future interventions, were examined. These included economic and market-related factors such as affordability, availability, and land ownership. Different energy user groups were engaged in the development of causal loop diagrams to visualise the key feedback loops based on the identified factors that affect energy access and energy fuel choice in an illegitimate urban informal settlement in South Africa. Seventeen feedback loops emerged, of which 13 were reinforcing loops, and four were balancing loops. The key feedback loops related to community empowerment and representation, while participation in the political process and the quest for legitimacy through direct electricity connections were recognised as broader issues to be addressed.

Keywords: informal settlement; slum; energy access; electrification; community based system dynamics; solar photovoltaic

4.2 Introduction

The adoption of the sustainable development goals (SDGs) in 2015 (UN, 2016) cemented the global impetus for developmental progress that is both sustainable and equitable. Of particular interest in this chapter are SDG 7, which aims to provide universal access to affordable, reliable, sustainable and modern energy; and SDG 11 on sustainable cities and communities, which addresses slums²⁴ or informal settlements. Despite energy being integral to development and the achievement of several other SDGs, including those related to gender equality, poverty reduction, health improvement, and climate change (IEA, 2017), much still

²⁴ The term slum or informal settlement is defined by the UN (UN-Habitat, 2010) as relating to households that lack access to either water, sanitation, durable structures, secure tenure and/or that are over-crowded.

needs to be done to improve universal access to affordable, reliable and sustainable energy services (UN, 2017), particularly in the Global South. According to the UN (2017), this would include increasing access to electricity, clean cooking fuels and technologies, and the use of renewable energy, while requiring countries to embrace new technologies, such as solar photovoltaic (PV) or solar home systems, on an ambitious scale.

Electricity access in South Africa has improved significantly since 1994, increasing from 66% of the population in 2000, to 86% in 2016 (IEA, 2017). At the same time, the proportion of the urban population living in slums in South Africa has reduced from 39.7% in 1995 to 23% in 2014 (The World Bank, 2014). Although this reduction may be considered positive, the percentage of urban population living in slums has remained constant at 23% since 2007 (The World Bank, 2014). Since 1994, the South African government has followed a variety of approaches toward informal settlements, ranging from the provision of formal housing (in the form of RDP²⁵ houses), to the eradication of slums and finally to an acceptance of the need for in situ upgrading strategies (Smit et al., 2017; Swilling, 2014). The process of in situ upgrading has however been associated with a “wait for the grid” approach, with negative political consequences (Swilling, 2014). While the onus of service delivery falls to local government, with financial assistance from national government, the provision of electricity, water, sanitation, roads and waste removal can only occur if a settlement has been legally recognised and zoned as residential (Swilling, 2014).

South Africa, however, has several types of settlements, fluctuating between legal and illegal, formal and informal, planned and unplanned, legitimate and illegitimate (see Smit et al., 2017). Furthermore, Swilling (2014) indicates that on average it typically takes eight years after legalisation or rezoning for communities to be

²⁵ Refers to a government housing scheme, the Reconstruction and Development Programme (RDP) aimed at redressing socioeconomic inequalities.

connected to water and electricity grids and, even then, electrification may be limited to street lighting only. More recently, the South African government has acknowledged that issues related to electrifying informal settlements may affect their aim of achieving universal access to electricity by 2025 (DoE, 2017).

The long waiting times and untenable conditions faced by the population living in unrecognised informal settlements prompted researchers from Stellenbosch University to co-design an incremental shack²⁶ upgrade that includes solar PV in its design (Swilling, 2014; Keller, 2012), dubbed 'Improved Shack' or iShack. The iShack project was tested in Enkanini, an urban informal settlement on the outskirts of Stellenbosch, South Africa. Enkanini had not received legal recognition yet, suggesting that the community would in all likelihood wait more than eight years for grid connections, despite bordering on a formal neighbourhood to the north and an industrial area to the south. The project received financial support from the Bill and Melinda Gates Foundation and the South African Green Fund, as well as policy support from the local municipality, which changed its indigent policy to provide for the transfer of the free basic electricity subsidy to non-grid connected shack dwellers that were installing the iShack PV system (Glasser, 2017; Swilling, 2016; 2014; Keller, 2012). The project has since been heavily promoted in terms of its potential for addressing energy service provision in informal settlements or settlements that are ineligible for grid electrification (Runsten, Nerini and Tait, 2018; Glasser, 2017; Swilling, 2016; 2014). This indicates that a mass roll-out of the iShack project may be pursued in other informal settlements in South Africa in the future.

The potential of this type of project for addressing energy poverty and access to modern, clean energy is undeniable. However, recent studies on the metabolic dimension of the Enkanini settlement (see Smit et al., 2017; Kovacic et al., 2016;

²⁶ A shack refers to an informal dwelling, generally built from scrap materials including corrugated metal sheets.

Kovacic and Giampietro, 2016) indicate that a general roll-out may be problematic within the South African context. While the adoption of solar PV electricity may indicate an acceptance of the technology as an alternative or substitute for grid-connected electricity, the solar PV users in Enkanini did not consider themselves as having access to electricity, implying that solar PV is not perceived as a substitute for electricity (Smit et al., 2017). As a result, a portion of the Enkanini population is resistant to the introduction of solar PV. This development has had a negative impact on the further distribution of solar PV systems and has led to negative political consequences for the municipality, as “electricity has become the protest theme among residents” (CORC, 2012). This seeming resistance to solar PV therefore signified the need for further investigation into the issues surrounding energy access and energy fuel choice in the Enkanini settlement.

Numerous studies consider a range of issues around energy access for the urban poor or slums in the developing country context (see for example Rahut, Behera and Ali, 2016; Puzzolo et al., 2016; Butera et al., 2016; Coelho and Goldember, 2013; Bravo, Kozulj and Landaveri, 2008; Karekezi, Kimani and Onguru, 2008; Shrestha et al., 2008). Some studies focus on policies for transitioning from traditional energy sources to cleaner energy sources such as liquefied petroleum gas (Coelho and Goldember, 2013; Bravo et al., 2008); and others highlight political and legal issues related to, for example, land tenure, household income and legal status as major obstacles to energy access (Jimenez, 2017; Dhingra et al., 2008; Bravo et al., 2008). In the South African context, social, political, economic and methodological issues are highlighted. For example, Visagie (2008) assessed policy options for providing more sustainable energy options to the urban poor; while Tait (2017) problematised the standardised metrics used for defining energy access; instead arguing for metrics that are both multidimensional and contextually relevant. Runsten et al. (2018) developed a multicriteria sustainability analysis for assessing electricity alternatives, while considering a host of technical, economic, environmental and health, social and institutional indicators.

Although these studies cover a range of factors and issues, they fail to examine the causal relationships between the factors that influence energy fuel choice and energy access for those living in slum conditions. This chapter therefore uses the case study of Enkanini informal settlement to address research question 3 of this study, based on the following three sub-questions: (i) What factors influence energy fuel choice, energy bias and energy switching in Enkanini informal settlement? (ii) What are the issues that characterise energy access in Enkanini informal settlement? and (iii) How are these factors related?

4.3 Methodology

In order to address the questions posed in Chapter 4, a Community Based System Dynamics (CBSD) approach was adopted. Community Based System Dynamics is a subset of System Dynamics and Group Model Building and originates from the work of Hovmand (2014) and the Brown School Social System Design Lab. System Dynamics stems from the work of Forrester (1961), with major contributions by Meadows (1972), Sterman (2000), and Vennix (1996) to the field. System Dynamics is recognised as a systems thinking tool to visualise and understand complex problems (Maani and Cavana, 2012).

Initially System Dynamics was utilised for corporate modelling, but this was later extended to the modelling of broader social systems and applied widely to, for example, business management, education, energy systems, politics, sustainable development and health care (Forrester, 2007). Forrester's work *Urban Dynamics* (Forrester, 1969) is particularly relevant for highlighting the counterintuitive nature of certain system feedbacks and the need to address flawed mental models²⁷ (Forrester, 2007).

²⁷ In the field of System Dynamics, "a mental model of a dynamic system is a cognitive representation of the real system" (Doyle and Ford, 1998, in Hovmand, 2014).

In his review of the development of System Dynamics, however, Forrester (2007) relates how the practice of system dynamics relied on a 'consultant' mode whereby the system dynamics practitioner would study an organisation and independently formulate a model with recommendations; in other words, without further inputs from the stakeholders. Accordingly, this practice would not encourage organisational buy-in; thus, hindering long-term behavioural change. In response to this limitation, the field of Group Model Building emerged (see for example Vennix, 1996; Richard and Anderson, 1995). Group Model Building is considered to be a participatory approach, which involves a greater number of stakeholders in the modelling process with the aim of creating more buy-in and behavioural change within the organisational setting (Hovmand, 2014; Forrester, 2007).

Group Model Building has been mainly applied in the context of private organisations and government, with participants ranging from middle to senior management, and with very few cases occurring at community level (Hovmand, 2014). Group Model Building thus fulfilled the need to include more stakeholders in the model building process (see for example Allender et al., 2015; Brennan et al., 2015), but has been less successful in making the method more accessible to a wider lay audience. For example, Hager et al. (2015) point out that community based systems thinking interventions are contextually very different from group model building exercises. Firstly, Group Model Building primarily includes stakeholders with institutional affiliations rather than marginalised groups with generally low levels of education; and secondly there is a vast difference with regard to the technology and infrastructure available for quantitative modelling and simulation.

This led Hovmand (2014) to develop Community Based System Dynamics as a method to involve community members, or stakeholders who are embedded in a particular system, in the modelling process.

According to Hovmand (2014), Community Based System Dynamics is about:

engaging communities, helping communities cocreate the models that lead to system insights and recommendations, empowerment, and mobilizing communities to advocate for and implement changes based on these insights.

Community Based System Dynamics has been applied to a variety of issues including alcohol abuse among college students in the United States (Apostolopoulos et al., 2018); mental health service uptake in a conflict setting in Afghanistan (Trani et al., 2016); sustained adoption of clean cooking systems in impoverished communities in India (Kumar, Chalise and Yadama, 2016); and knowledge change among smallholder farmers in Zambia (Hager, Kopainsky and Nyanga, 2015); while variants of the method are used in natural resources management, such as water and forestry planning (Rosenthal et al., 2017).

Community Based System Dynamics, however, is not the only participatory approach for engaging communities. Community-based Participatory Research is also recognised for its collaborative approach to engage effectively with communities by including community members as full participants (Frerichs et al., 2016; BeLue et al., 2012). However, Minkler (2010) proposes that Community-based Participatory Research is not a research method in itself, but rather an orientation to research; whereas BeLue et al. (2012) and Frerichs et al. (2016) argue that Community-based Participatory Research could be much enhanced through integration with system science, including System Dynamics.

Considering that Community Based System Dynamics stems from System Dynamics and Group Model Building, while directly engaging community members as participants, Hovmand's work therefore bridges Community-based Participatory Research and system science. Community Based System Dynamics is also useful for uncovering mental models and gaining insights that would not be achieved through Community-based Participatory Research alone and was therefore the

preferred method in this study. Furthermore, Trani et al. (2016) promote the use of Community Based System Dynamics as giving a voice to stakeholders, allowing them to share their views of a problem, while generating robust, sophisticated results with actionable policy recommendations, which are built on the knowledge and expertise of people embedded in the system. Community Based System Dynamics focuses on outcomes that address the needs of the community and is “particularly valuable for messy and neglected problems” (Rosenthal et al., 2017; Trani et al., 2016).

4.4 Setting, study design and participants

A Community Based System Dynamics workshop focusing on energy was held over three days in the Enkanini Research Centre in Enkanini informal settlement²⁸. A variety of energy options are available to Enkanini residents, ranging from energy sources such as paraffin, candles, wood and gas to renewable energy in the form of mini solar PV systems, as well as fossil fuel intensive energy in the form of indirect connected electricity. The participants were divided into three groups of 10 people each, representing a particular energy user profile, namely: i) solar PV users; ii) indirect electricity users; and iii) divergent energy users – those who do not use solar PV or indirect electricity, but rely mainly on paraffin, candles and gas. For each group, females constituted 60% and males 40% of participants. This was unintended as the aim had been to achieve a 50/50 split. Most participants (27 out of 30) had achieved secondary level education, two had primary education and 1 had tertiary education, while none of the participants had taken part in a research study before. The sessions incorporated a series of scripts adapted from an online manual²⁹ for conducting structured group model-building activities and included the Hopes and Fears (see Appendix E) and Variable Elicitation (see Appendix F) scripts.

²⁸ The daily workshop schedule can be found in Appendix D.

²⁹ Available from: <https://en.wikibooks.org/wiki/Scriptapedia>.

In order to identify and address the issues influencing energy access in Enkanini, the factors influencing energy fuel choice in Enkanini first had to be understood. This led to the need for a deeper understanding of i) the types of energy fuel sources used by households; ii) the perceived benefits and disadvantages of these energy fuel sources; and iii) the bias for or against particular energy fuel sources. Therefore, each energy user group was asked to indicate why it used a particular energy fuel source and what the participants felt the benefits and disadvantages of that particular source were. The next step in the workshop was to capture the participants' thoughts about the different energy fuel sources in order to identify the energy biases of each group towards the other energy fuel sources and how these biases may influence their ability or willingness to switch to an alternative energy fuel source (see Appendix G). This was followed by a number of breakaway sessions focusing on issues that characterise energy access. The proceedings and targeted question sessions were the same for each workshop day and resulted in data that could be compared across the different energy user groups and were finally combined to produce an integrated causal loop diagram.

4.5 Modelling process and outputs

Model building requires a team and the following roles were therefore adopted: two community liaison officers; one process facilitator; one modeller; one translator/co-researcher; two recorders; and one photographer.

The outputs of the Community Based System Dynamics workshops were a series of causal loop diagrams that illustrate community members' perceptions, based on actual and hypothetical behaviours, regarding the issues around energy access and energy fuel choice in the Enkanini informal settlement. Causal loop diagrams are visual representations or maps used for problem structuring, system conceptualisation and capacity building (Brennan et al., 2015). Causal loop diagrams, in contrast to formal computer models, provide more transparency and are more easily understood by lay audiences (Brennan et al., 2015). Causal loop diagrams constitute several elements (see Table 4.1). For example, arrows or links

indicate a causal relationship between two variables, which are considered to be “a condition, situation, action or decision that can influence, and can be influenced by other variables” (Musango, Brent and Bassi, 2015).

Table 4.1: Constituents of causal loop diagrams

Term/Symbol	Description
Variables or words	Quantitative or qualitative factors that can increase and/or decrease
Arrow or line	Indicate causal relationships of influence
Polarity (+)	Variables change in the same direction (both increase, both decrease)
Polarity (-)	Variables change in the opposite direction (one increases and the other decreases, or vice versa)
Feedback loop	<p>Two or more variables in a causal sequence that “feeds back” to the original variable, completing a loop.</p> <p>There are two types of feedback loops:</p> <p>Reinforcing loop or positive feedback In a reinforcing loop, the effect of an increase or decrease (growing or declining action) in a variable continues through the casual pathway and reinforces the increase or decrease in the initial variable, thus amplifying change.</p> <p>Balancing loop or negative feedback Balancing loops seek stability or return to a specific target. In a balancing loop, the effect of changes in variables within the loop is to counteract or balance the direction of change. Rather than accelerating the direction of change (reinforcing loops), balancing loops tend to slow down the rate of change so that, in addition to counteracting the initial change, they also tend to push a system toward some stable goal.</p>

Source: Adapted from Brennan et al., 2015.

In each session, a series of variables related to factors that affect energy access and/or fuel choice in Enkanini were discussed and compiled. Participants were then asked to identify if and how any of the variables were related. After each workshop, the identified connections were visualised in a causal loop diagram by the modeller for each user group and, finally, with inputs from the whole modelling team, the final combined model from the three groups was produced.

4.6 Results

The results section discusses the factors that influenced energy fuel choice, energy bias and energy switching in Enkanini and the issues that characterised energy access in Enkanini; and examines the causal relationships to identify the key feedback loops and how they dynamically influenced each other and affected energy fuel choice and energy access.

4.6.1 Factors influencing energy fuel choice in Enkanini informal settlement

The factors that influenced energy fuel choice for the different energy fuel user groups are presented in Table 4.2. Solar users were mainly influenced by access barriers to direct and indirect electricity and health and safety benefits of the solar systems relative to other fuel sources. Direct electricity connection, which means being connected to the grid by the electricity utility in South Africa, Eskom, was not an option for Enkanini residents because the settlement was not serviced. In order to obtain an indirect connection, the Enkanini household had to establish an affiliation or relationship with a household from the neighbouring, formalised settlement, Kayamandi, that has formal direct electricity connections. Initiating such a relationship can be difficult and takes time to build, which acted as a barrier to access. Furthermore, solar users were prohibited through their service agreement from having an indirect electricity connection. In terms of perceived health benefits, solar PV systems did not produce smoke and were less likely to cause electrocution in contrast to indirect connections. Indirect connections tended to cause fires, while paraffin and gas produced toxic fumes and constituted a fire risk.

Table 4.2: Factors influencing choice of energy fuel source

Energy user group	Reasons for using this energy source	Benefits	Disadvantages
Solar electricity users	<ul style="list-style-type: none"> No other electricity access Charging cell phones Lighting Unable to establish relationship to access indirect electricity 	<ul style="list-style-type: none"> Safe 	<ul style="list-style-type: none"> Sometimes trips High charges Poor service Sometimes not available Delays and long wait before faults are fixed "Sometimes not strong enough"
Indirect electricity users	<ul style="list-style-type: none"> Some can use it for cooking Lighting Charging cell phones Some can use it for refrigeration "Solar is not powerful, candles don't last, paraffin has smoke" 	<ul style="list-style-type: none"> Healthier, no smoke Cleaner 	<ul style="list-style-type: none"> Not easy to get connected, you must know someone Power trips often Risky – can cause fatality "Don't know how much electricity (many units) really used" Fire hazard/electrocution "It's temporary"
Divergent energy users	Paraffin – Lighting and cooking	<ul style="list-style-type: none"> Easy to light Easy to obtain Heats house well Cheap 	<ul style="list-style-type: none"> Gives bad taste to food Causes fires Prices vary a lot Causes fever Not always available "Makes chest burn"
	Candles – Lighting	<ul style="list-style-type: none"> Cheap Gives good light 	<ul style="list-style-type: none"> Causes fire
	Gas – Cooking	<ul style="list-style-type: none"> Quick lighting Less smell Lasts longer No bad taste on food Good value for money 	<ul style="list-style-type: none"> Highly flammable – causes fire "Difficult to monitor (don't know how much in cylinder)" "Danger of carbon monoxide poisoning if leaks" Not easy to obtain (have to go far)

Indirect electricity users suggested that their preference lay in the capacity of the energy fuel source (however limited it was) to fulfil their cell phone charging and refrigeration needs and in its superiority to solar systems. The irony was that, in practice, the solar system users and indirect electricity users tended to have similar limitations in terms of their energy fuel source usage. Further, both groups still relied on paraffin, candles and gas to fulfil their energy service requirements, such as for cooking, lighting and heating.

Divergent energy users mainly relied on paraffin, gas and candles to provide their needs because of the affordability, accessibility and availability of these sources. However, they also recognised the disadvantages and risks of these fuels for their health and well-being.

The energy bias and switching requirements for each of the three energy user groups are depicted in Table 4.3. All participants, across the three user groups, acknowledged the health and safety benefits of solar in relation to indirect connections and paraffin and gas fuel options. However, divergent and indirect electricity users were generally put off by the low quality or capacity of the solar systems in delivering their energy requirements as well as the variability of supply due to poor weather conditions.

Table 4.3: Energy bias and switching requirements

User group	Thoughts on solar PV	Thoughts on indirect electricity connections	Thoughts on paraffin and gas	What would you change in your energy mix?
Solar electricity users	<ul style="list-style-type: none"> • Generally satisfied with solar, however it sometimes doesn't last throughout the month; • Need to top up with candles and pay others to charge phones; still use gas and paraffin to supplement cooking and lighting • It is affordable, depending on the package • Not considered good value for money 	<ul style="list-style-type: none"> • Also limited in terms of what you can use it for • Unsafe – fire and electrocution risk • Can't cook with it • You need to have social connections to get the indirect line • Solar cheaper than indirect 	<ul style="list-style-type: none"> • Expensive • Need special lamp • Price varies a lot during winter • All use gas for cooking 	<ul style="list-style-type: none"> • Solar capacity needs to be improved • Need to be able to cook and refrigerate with it
Indirect electricity users	<ul style="list-style-type: none"> • Not strong – can't do much with it • Weather affects it – when it rains, gadgets don't work well • Not reliable 	<ul style="list-style-type: none"> • Would prefer to have electricity metered or direct – in order to be able to monitor and control use 	<ul style="list-style-type: none"> • Gas is good for cooking, quick, cheap and lasts more than a month • Paraffin smokes and burns eyes 	<ul style="list-style-type: none"> • If solar capacity improves, then would consider having both sources, as a backup and to reduce costs
Divergent energy users	<p>Positives:</p> <ul style="list-style-type: none"> • Solar is good for lighting and television, cell phone charging and running some small appliances • It has health benefits – does not cause fire • Gives better and brighter light than candles • Inexpensive; is not subject to load shedding <p>Negatives:</p> <ul style="list-style-type: none"> • Can't cook with it • Unreliable (weather) • Limited in use, which can affect business • Access barrier – must be four households together to apply for solar • Can't run a business with it 	<ul style="list-style-type: none"> • It's not right (neither legal nor safe) • Dangerous – causes fire and electrocution • Expensive • Does not last throughout the month • Prone to load shedding and power failures 	<ul style="list-style-type: none"> • Paraffin – cheap, warms up house but health risks • Gas – good value for money and for cooking; fewer health risks but is still a fire risk 	<ul style="list-style-type: none"> • Would include solar into energy mix if entry barriers were removed • Prefer solar to indirect electricity • Would use solar mainly for lighting

Both divergent and indirect electricity users indicated that one of the major drawbacks to a community-wide roll-out or acceptance of the solar systems related to substitution and legitimacy. These two groups were mainly concerned that the presence of solar systems in Enkanini meant that the municipality would be less likely to approve of investment in direct electricity connections. The divergent and indirect electricity users therefore considered solar systems to be a barrier to accessing direct electricity, whereas the solar users did not share this fear. However, across all three groups, there was a strong belief that solar was not a substitute for grid-connected electricity, and that acquiring a direct connection would be akin to the legitimisation of the settlement.

4.6.2 Issues that characterise energy access in the Enkanini informal settlement

The various factors and issues that contributed to the lack of direct electricity provision to the Enkanini settlement are presented in Table 4.4.

Table 4.4: Factors contributing to the lack of electricity access in Enkanini

User group	What issues/factors contribute to the lack of electricity in Enkanini?	Variables
Solar electricity users	<ul style="list-style-type: none"> • Households moved in without permission from municipality • “Think Municipality thinks it’s a waste of money to invest” • Shacks too close to each other to put in electricity poles • Councillor – policy maker issue • Political issues between parties • Social issues – unrest • Lack of communication • Lack of trust in community representatives and municipality • No feedback from municipality on community issues • Slope/steep • High cost • Non-participatory processes • Lack of community space for meetings • Lack of accountability • Lack of choice 	<ul style="list-style-type: none"> • Land ownership • Cost recovery • Density/layout • Representation • Party politics • Social issues/violence • Communication • Trust/ubuntu • Communication • Layout/geography • Cost • Representation • Organisation • Accountability • Legitimacy
Indirect electricity users	<ul style="list-style-type: none"> • Non-performance by councillors • Enkanini not on map, not recognised • Lack of leadership from Enkanini • No organisation in Enkanini that is not politically motivated • Lack of feedback from councillors • Land is illegally occupied • Lack of leadership due to misrepresentation • Misrepresentation leads to corruption and competition for resources • Councillors afraid of us – violence • Councillors powerless at municipality level • Councillors lives threatened • Can't talk directly to municipality 	<ul style="list-style-type: none"> • Accountability/politics • Recognition/legitimacy • Organisation • Politics • Communication • Land ownership/legitimacy • Representation • Corruption/competition for resources • Social issues/violence • Party politics • Violence • Representation
Divergent energy users	<ul style="list-style-type: none"> • Solar causes delay from municipality • Lack of leadership; lack of effective street committee • No feedback from councillors • Poor organisation • Disconnect between communities (Kayamandi and Enkanini) No Ubuntu • Lack of support • Not enough power (people do not stand together) • Lack of services (infrastructure) • Competition for resources (with Kayamandi) 	<ul style="list-style-type: none"> • Substitution • Leadership • Communication/feedback • Organisation • Representation/ubuntu • Ubuntu/legitimacy • Organisation/community cohesion • Infrastructure/service delivery • Competition for resources

The factors identified in Table 4.4 were converted into a word cloud to indicate the most used words or phrases that represent the issues characterising energy access in Enkanini (see Figure 4.1).



Figure 4.1: Main factors affecting energy access in Enkanini

As shown in Figure 4.1, the main factors contributing to the lack of electricity in Enkanini relate to: (i) representation; (ii) organisation; (iii) communication; (iv) legitimacy; and (v) ubuntu³⁰.

Representation is recognised as the most important factor affecting electricity provision in Enkanini. It relates to representative leadership and the effect of politics within the community, that hinder the community's ability to organise itself

³⁰ The term ubuntu means humanity and relates to a sense of community and shared compassion.

effectively. The ability of Enkanini residents to mobilise and thereby seek better representation is, however, influenced by several factors, including active leadership, organisation and ubuntu. The lack of communication between current leadership structures, such as local councillors and appointed community representatives, and the wider community has led to a sense of distrust and disillusionment with the political process. While land ownership and participation in the political process usually denotes a community's legitimacy and validity, Enkanini residents went a step further and indicated that access to direct electricity is an interrelated factor which confers a sense of legitimacy and validation on the community.

Participants described a lack of ubuntu or disconnect within the community but also with the neighbouring settlement. This was partly due to the fact that the neighbouring settlement, Kayamandi, was an established and more formalised settlement, which according to Enkanini residents received greater developmental and infrastructural support from the local municipality, for example, in the form of direct electricity connections provided. Furthermore, Enkanini residents were frustrated that Kayamandi residents tended to be less involved when Enkanini residents protested against their current conditions, resulting in a social disconnect between the two communities. At the same time, Enkanini residents were becoming indifferent to the political process, feeling disempowered by years of unfulfilled promises by various political parties. However, as time passed, the lack of direct electricity connections had become a greater point of contention, leading to a greater need for community mobilisation.

4.6.3 Key feedback loops influencing energy fuel choice in Enkanini informal settlement

Based on the identified factors in Table 4.2 and Table 4.3, the following sections discuss the various feedback loops related to energy fuel choice.

4.6.3.1 Direct access (R1) and indirect access feedback loops (B1)

Enkanini residents' energy fuel choices were influenced by the amount of total electricity provided. The direct access and indirect access loops are shown in Figure 4.2 and the variables are described in Table 4.5.

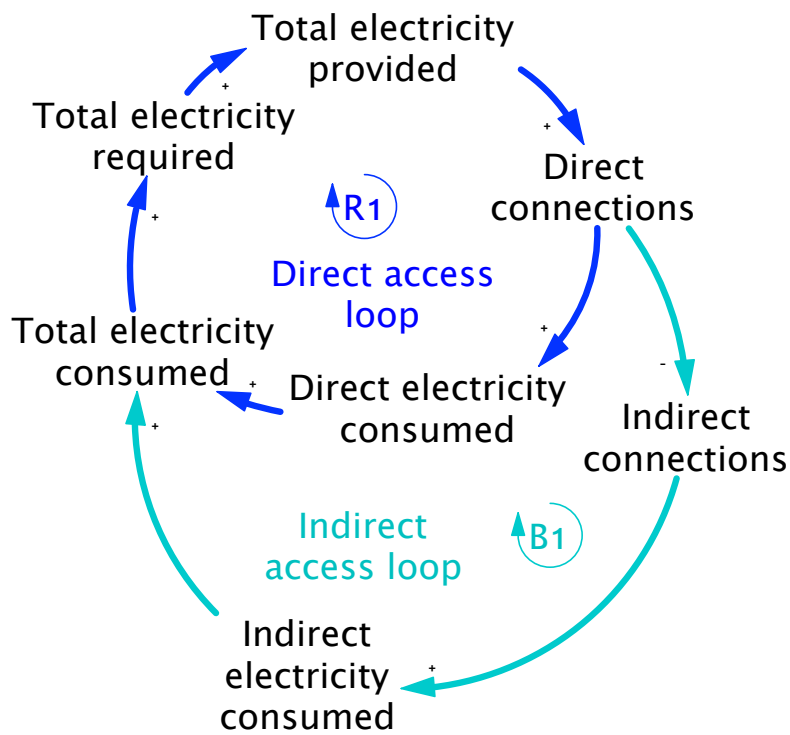


Figure 4.2: Direct (R1) and indirect (B1) access loops

Table 4.5: Variable description for direct access (R1) and indirect access (B1) loops

Variable	Description
Total electricity provided	Refers to the total amount of electricity provided for both direct and indirect connections
Direct connection	Electricity provided through formal, legal connections sanctioned by the municipality. The amount of electricity used is metered and charged on a per-unit basis
Indirect connection	An electricity connection that is informally attached to a formal connection. Although the indirect connection is sanctioned by the formal homeowner who has a direct connection, these connections are not formally or legally sanctioned by the municipality and tend to be dangerous or hazardous. The amount of electricity used is not metered and charges are therefore not based on actual consumption. The ability of users to fulfil their energy requirements is limited by the number of indirect connections stemming from one formal connection
Total electricity consumed	The total amount of electricity consumed, either through direct or indirect connections
Total electricity required	The total electricity that is required to service the whole settlement regardless of their current energy fuel source

Total electricity provision is limited by the capacity of the national electricity provider, Eskom, which faces a constrained power system due to insufficient supply during peak periods and the continued growth of electricity users (Eskom, 2017). In recent years, South Africa has experienced controlled power outages, referred to as 'load shedding', to safeguard the electricity power system from a total nationwide blackout. Therefore, an increase in total electricity provided leads to an increase in the number of direct connections, which in turn reduces the number of indirect connections as users gain access to direct connections. If the number of direct connections does not increase, the number of indirect connections increases in line with the growth of informal settlements. However, an increase in both direct and indirect connections effectively increases the total electricity consumed, further constraining total electricity supply.

As per Figure 4.2, the more total electricity provided by the municipality, the greater the number of households that would opt for a direct connection, which in turn

would lead to more direct electricity to be consumed which increases the total electricity consumed. The more the total electricity consumed, the more the total electricity required, which means the municipality needs to increase the total electricity provided. The direct access loop therefore represents a reinforcing loop.

Furthermore, the more direct connections there are, the fewer indirect connections there would be, and the number of indirect connections would thus reduce, decreasing the amount of indirect electricity consumed. This further leads to less total electricity consumed. A decrease in total electricity consumed decreases the amount of total electricity required, which, in turn, means that the municipality needs to provide less total electricity. Providing less total electricity, however, would reduce the number of direct connections and increase the number of indirect connections, therefore the indirect access (B1) loop represents a balancing loop.

4.6.3.2 Cost attractiveness (R2) loop

Electricity consumption is also affected by the cost of electricity and its impact on disposable income as represented in the cost attractiveness loop (R2) (see Figure 4.3). The variables for Figure 4.3 are defined in Table 4.6.

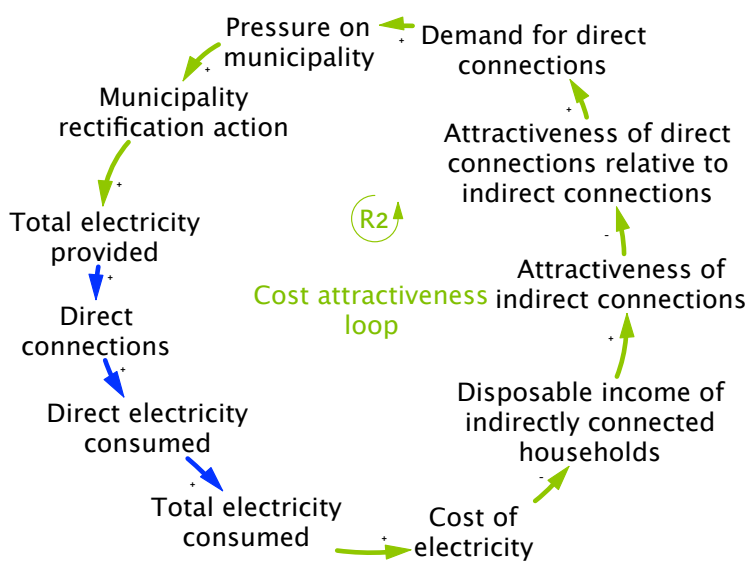


Figure 4.3: Cost attractiveness loop

Table 4.6: Variable description for cost attractiveness (R2) loop

Variable	Description
Cost of electricity	Indirect electricity costs are determined by the formal homeowner who provides the connection and is therefore not related to actual, measured use
Disposable income of indirectly connected households	The amount of money households have available after tax to spend or save
Attractiveness of indirect connections	The appeal of having or getting an indirect connection
Attractiveness of direct connections relative to indirect connections	The appeal of direct connections over indirect connections
Demand for direct connections	The continued desire and request for direct connections
Pressure on municipality	Social and political pressure
Municipality rectification action	Actions taken by the municipality to improve conditions, either through policy or some type of intervention

Generally, the electricity provider determines the cost of electricity. In the case of informal connections, it is the directly connected homeowner that decides how much an indirect user must pay, whereas the directly connected user's electricity cost is subject to metered usage from Eskom or the municipality. Any increase in the cost of electricity reduces the amount of disposable income a household has available to spend on its indirect connection. The greater the amount of disposable income available to indirectly connected households, the more attractive an indirect connection becomes, and the less attractive direct connections become relative to the indirect connection.

However, the inverse also holds true: the less disposable income is available, the less attractive indirect connections become as the owners of the direct connection may disconnect their indirect connection. This uncertainty and lack of control over usage of indirect connections increases the attractiveness of direct connections relative to indirect connections, as directly connected households would have greater control over their costs and usage. This in turn drives an increased demand for direct connections, which places more pressure on the municipality, leading to

a greater likelihood that the municipality would take a rectification action such as providing electricity infrastructure.

An increase in electricity infrastructure would lead to an increase in the total electricity provided, thereby increasing the number of direct connections and the amount of direct and total electricity consumed. At the same time, the more electricity is consumed, the higher the cost of electricity becomes per unit for formally connected users. Stellenbosch Municipality (2015) may in turn increase the cost of electricity supplied to indirectly connected users or unplug or remove the indirect connection. The cost attractiveness loop therefore represents a reinforcing loop.

4.6.3.3 Energy fuel source attractiveness

The attractiveness of a particular energy source is relative to the attractiveness of other energy fuel sources when comparing aspects such as cost, access and availability. The refined variables or factors influencing the attractiveness of a particular energy source in relation to others include: i) capacity adequacy; ii) ability to meet energy service requirements; iii) safety; iv) availability; v) social status access; and vi) access barriers to direct connections.

4.6.3.3.1 Capacity adequacy (R3) feedback loop

Figure 4.4 illustrates the effect of inadequate capacity and connects to the direct access (R1) and indirect access (B1) loops as described in Figure 4.2. The variables related to capacity adequacy are described in Table 4.7.

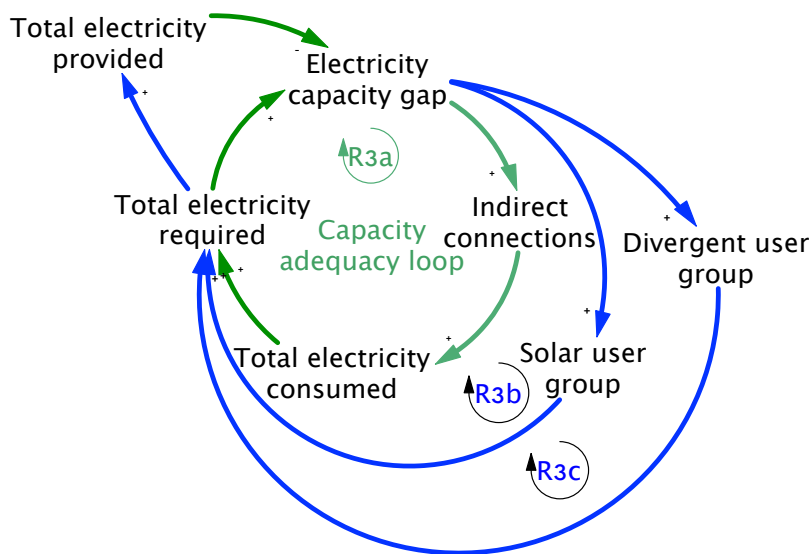


Figure 4.4: Capacity adequacy (R3) loop

Table 4.7: Variables describing capacity adequacy (R3) loop

Variable	Description
Electricity capacity gap	The difference between total electricity provided and total electricity required

The current electricity gap in Enkanini drives residents to opt for alternative energy fuel sources leading to three distinct energy user groups in the form of solar users, indirectly connected users and divergent users who rely on paraffin and gas energy mixes. At the same time, the inability of these sources to fulfil the energy requirements of residents increases the total electricity required, which in turn also increases the electricity gap if the total electricity required is greater than the total electricity provided. However, the more electricity is provided, the smaller the electricity gap becomes, while driving up total electricity consumption.

The total electricity provided is, however, contingent on factors such as willingness of the municipality to invest in electricity infrastructure (represented as municipality rectification action). Electricity provision is also limited by cost and the capacity of the national grid, which has been described in the direct and indirect access loops

(see Figure 4.2) as being limited and under strain. This would suggest that even if the municipality were willing to build the infrastructure to provide direct electricity access, the limited supply by the national grid may still be insufficient to fulfil the energy needs of Enkanini.

Therefore, in terms of providing sufficient electricity supply in the future, it is necessary that the total electricity required by Enkanini residents is factored into overall electricity demand. At present, the municipality has not endeavoured to measure or understand the energy requirements of the settlement and are therefore not informed on the actual amount of electricity that they may need to provide in future. This situation is highly problematic, and common among municipalities in South Africa. This leaves municipalities ill-prepared to improve energy access in urban informal settlements. The capacity adequacy (R3) loop forms a reinforcing feedback loop.

4.6.3.3.2 Ability to meet energy service requirements (R4) loop

The attractiveness of a particular fuel source in relation to a direct connection is influenced by its ability to meet the energy service requirements of a household (see Figure 4.5). Table 4.8 describes the variables for loop R4.

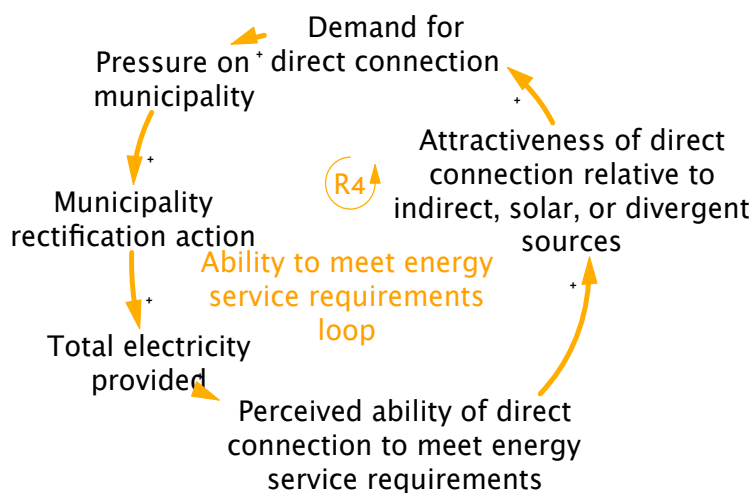


Figure 4.5: Ability to meet energy service requirements (R4) loop

Table 4.8: Variable description for ability to meet energy service requirements (R4) loop

Variable	Description
Perceived ability of direct connections to meet energy service requirements	The belief that energy users have that direct connections are best able to meet their energy service requirements
Attractiveness of direct connections relative to indirect, solar or divergent sources	The appeal of a direct connection compared to indirect, solar or divergent energy fuel sources

Overall, the participants indicated that their preference for direct connections was influenced by their ability to meet their energy service requirements. Hence, the greater the perception that direct connections would fulfil their energy needs, the more attractive direct connections became in relation to either indirect, solar or divergent energy sources. This would lead to an increased demand for direct connections, placing more pressure on the municipality to take rectification action and increase the total electricity provided. At the same time, the more households were connected to the grid, the more their energy service requirements would be met, which, in turn, would drive the perception that direct electricity connections were able to meet energy service requirements, making this a reinforcing feedback loop.

4.6.3.3.3 *Safety of direct connections (R5) and safety of indirect and divergent (R6) loops*

The safety of direct connections (R5) and safety of indirect connections and divergent (R6) loops are illustrated in Figure 4.6 and the variables are described in Table 4.9.

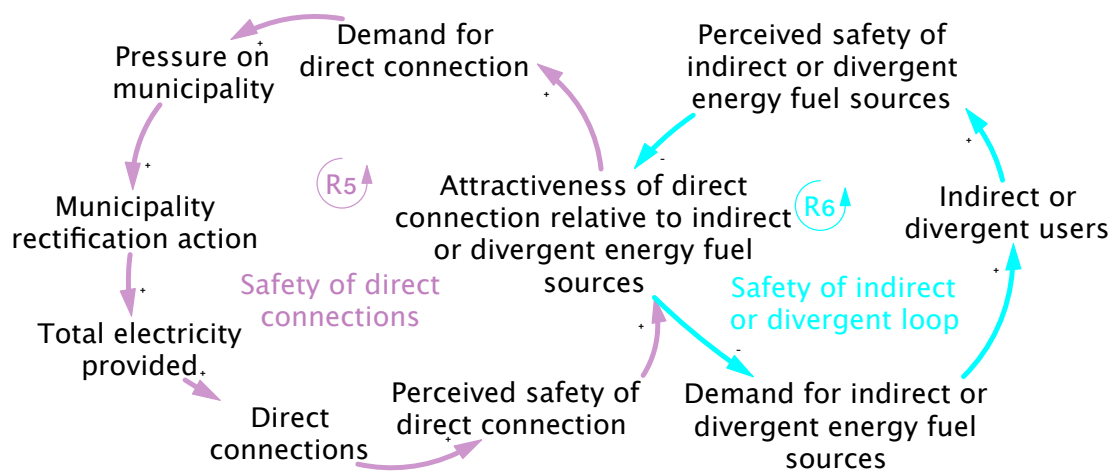


Figure 4.6: Safety of direct connections (R5) and safety of indirect and divergent (R6) loops

Table 4.9: Variable description of safety of direct connections (R5) and safety of indirect and divergent (R6) loops

Variable	Description
Demand for indirect or divergent energy fuel sources	Households using or wanting to opt for indirect connections or divergent energy in the form of paraffin or gas
Perceived safety of indirect or divergent energy fuel sources	Households' beliefs about the benefits of indirect connections or divergent energy fuel sources that reduce the chances of health and safety risks including fire, electrocution and air pollution

Although all user groups recognised the need for energy fuel sources that were safe, divergent energy users still chose paraffin and gas over indirect electricity connections, as they viewed indirect connections as more hazardous to their health. In contrast, indirect connection users considered their choice safer than relying on paraffin or gas. In all cases, participants had the perception that direct connections were safest, which made direct connections more attractive than indirect or divergent energy sources. This in turn fed the demand for direct connections, forming a reinforcing feedback loop. On the other hand, the more attractive direct connections became relative to indirect or divergent fuel sources, the less attractive indirect or divergent energy sources would become, thus

reducing demand and reducing the number of indirect and divergent user groups. The smaller the indirect and divergent user groups became, the less these sources would be perceived as being safe, thus increasing the attractiveness of direct connections relative to other sources.

4.6.3.3.4 Availability of divergent fuels (B2) and cost of divergent fuels (B3) loops

Divergent fuel users described their fuel choices as being driven by the access barrier to direct connections and the cost of divergent fuels (see Figure 4.7). The variables for B2 and B3 are described in Table 4.10.

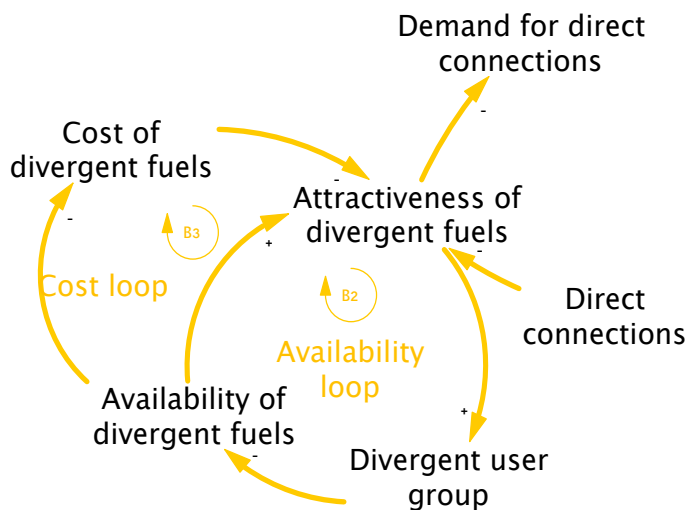


Figure 4.7: Availability of divergent fuels (B2) and cost of divergent fuel (B3) loops

Table 4.10: Variable description of availability of divergent fuels (B2) and cost of divergent fuel (B3) loops

Variable	Description
Availability of divergent fuels	Relates to the quantity of divergent fuels on offer and a household's ability to source these fuels with relative ease
Cost of divergent fuels	The price paid by households per litre of paraffin or kilogramme of gas

The fewer direct connections are available, the more attractive divergent fuels become to households, which increases the divergent user group. However, the more people use divergent fuel sources, the sooner this leads to a reduction in the amount of fuel available to the settlement, as paraffin and gas supplies can run low during winter months. This, in turn, reduces the attractiveness of divergent fuels. Participants indicated that when divergent fuels became scarce, the cost of paraffin and gas escalated. In the case of paraffin, the cost could increase up to fourfold, which ultimately would reduce the attractiveness of divergent fuels and in turn could lead to a greater demand for direct electricity. Both the availability (B2) and cost (B3) of divergent fuels loops are balancing loops.

4.6.3.3.5 *Social status (R7) loop*

Participants attached a level of importance and position to different energy fuel sources, which also influenced their fuel choice. This perceived status was linked to the ability of the energy fuel source to fulfil energy requirements, but in particular it related to a household's ability to have cell phone charging facilities and the use of an electric oven and refrigerator. However, none of the current energy fuel sources met these criteria fully. For example, in the case of the solar users, running an oven or refrigerator was not possible, whereas with indirectly connected users (depending on their location) some were able to run a small fridge and charge cell phones, but ovens took too much power. Divergent energy users could not operate any of the mentioned appliances. All user groups indicated that direct connections offered the highest status of all energy sources. The higher the perceived status of direct connections was, the more attractive direct connections became relative to the other energy fuel sources, thereby leading to an increased demand for direct connections (see Figure 4.8). The social status (R7) loop is reinforcing, indicating that it would become stronger over time.

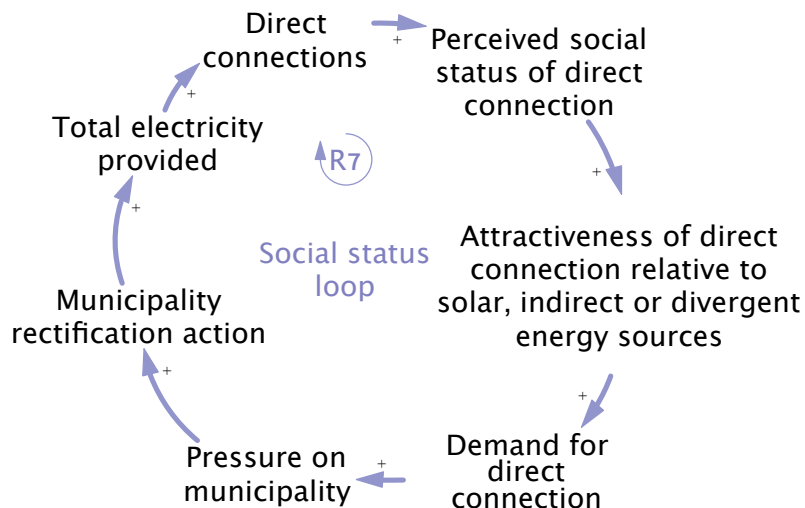


Figure 4.8: Social status (R7) loop

4.6.3.3.6 Access barrier to direct connections (R8) and solar threat (R9) loops

Solar users indicated that their preference for solar electricity stemmed from the lack of access to direct connections in Enkanini, while indirect and divergent users were concerned that the use of solar power might obstruct the future roll-out of direct connections. This is illustrated in Figure 4.9, while the variables are described in Table 4.11.

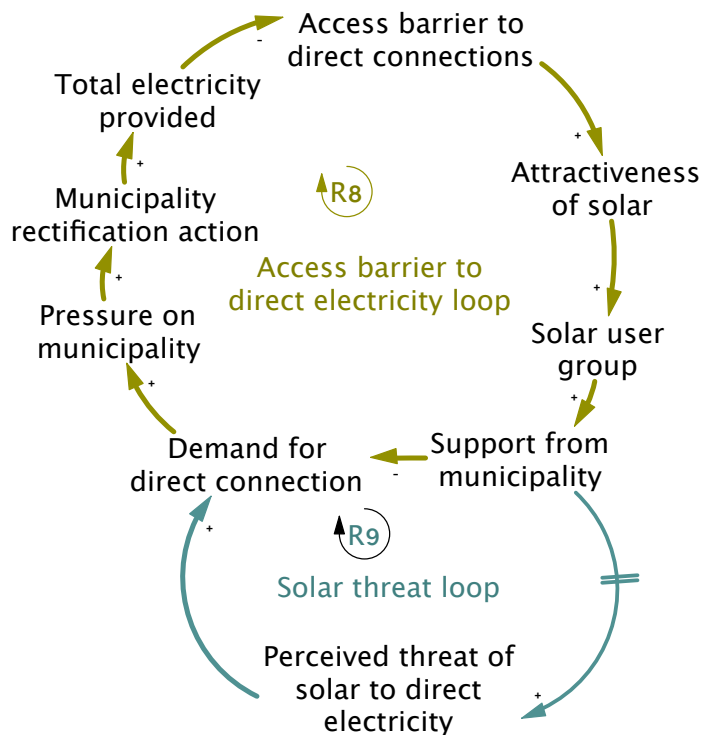


Figure 4.9: Access barrier to direct connections (R7) and solar threat (R9) loops

Table 4.11: Variable description for access barrier to direct connections (R7) and solar threat (R9) loops

Variable	Description
Access barrier to direct connections	Lack of direct connections
Support from municipality	Policy support in the form of subsidies
Perceived threat of solar to direct electricity	Residents' belief that the acceptance and roll-out of solar PV systems will deter the municipality from actively pursuing direct electricity provision in Enkanini

As per Figure 4.9, the less total electricity is provided by the municipality, the greater the access barrier to direct connections. Solar power therefore becomes more attractive and leads to an increase in solar users. The increase in the number of solar users led the municipality to give policy support to the initiative through a transfer of the electricity subsidy to solar users, which in turn could decrease the demand for direct connections. However, after some time, the increased support

from the municipality for solar led the indirect and divergent users to believe that the solar systems were actually becoming a barrier or threat to obtaining direct connections. This fear and frustration thus tends to lead to a greater demand for direct connections, as witnessed through violent protest, thereby placing more pressure on the municipality to take rectification action and provide more total electricity and to remove the access barrier to direct connections. Both the access barrier to direct connections (R8) and solar threat (R9) loops are reinforcing, thereby competing with each other and leading to conflict within Enkanini. If the municipality wanted to reduce the conflict with and between Enkanini residents, it could clarify its position on solar power as having an impact on the future roll-out of direct connections and increase transparency around the solar subsidy. This may lead to more indirect and divergent users switching to solar power, if they do not perceive it as a threat to direct connections.

4.6.4 Key energy access feedbacks

Based on the identified factors in section 4.6.2, the following sections consider the feedback loops for issues that characterise energy access in Enkanini, including: i) representation; ii) legitimacy and favourable zoning; and iii) community empowerment and ubuntu.

4.6.4.1 Representation feedback loop (R10)

The representation feedback loop is shown in Figure 4.10 and the variables are described in Table 4.12.

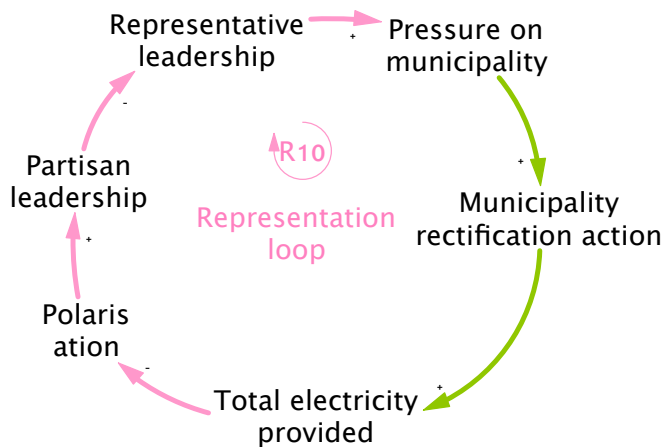


Figure 4.10: Representation feedback loop (R10)

Table 4.12: Variable description for representation loop (R10)

Variable	Description
Representative leadership	Organised leadership that is representative of the Enkanini community
Polarisation	Social division within the community brought about by contrasting political agendas
Partisan leadership	Leadership that is biased towards the agenda of a particular political agenda

The participants indicated that although they voted for the ward councillor, their interests were not fully represented, as the councillor was not from Enkanini and therefore did not have their interests at heart. The councillor hailed from the adjacent formalised and recognised settlement of Kayamandi, with whom the Enkanini residents had an uneasy alliance as they had to compete for resources. The lack of representative leadership was also partly due to the fact that Enkanini residents were generally unwilling to take up a political role themselves because they felt disillusioned with the political process, which, according to participants, had resulted in years of empty promises by political parties.

These views are captured in Figure 4.10, which indicates that the greater the level of representative leadership, the more political pressure the residents are able to apply on the municipality. This may in turn lead the municipality to introduce

favourable policies or interventions on their behalf in order to improve energy access or choice in Enkanini. However, over the years various political parties used the current lack of electricity provision as a ploy to gain votes, thereby polarising the community and leading to partisan leadership based on broader political agendas and diminishing true representative leadership. Therefore, an increase in the total electricity provided could reduce the polarisation within the community and at the same time reduce partisan leadership. A reduction in partisan leadership would increase representative leadership and increase residents' ability to apply pressure on the municipality.

4.6.4.2 Legitimacy (R11) and zoning feedback loop (R12)

The variables related to the legitimacy and residential zoning loops are described in Table 4.13 and illustrated in Figure 4.11.

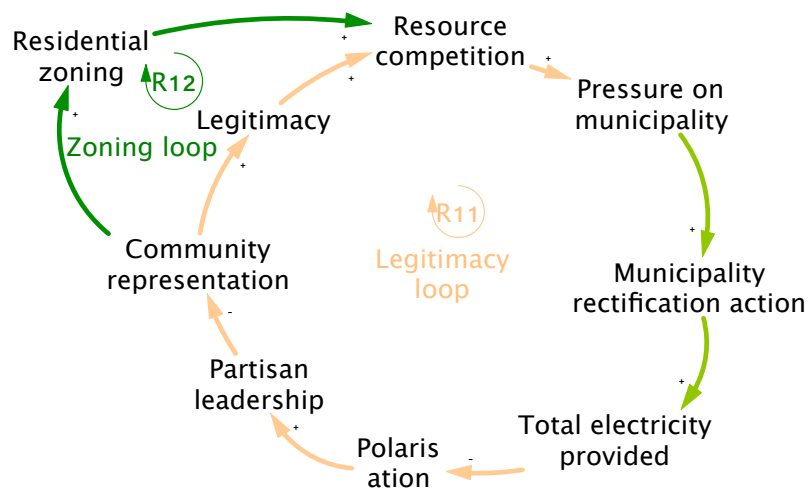


Figure 4.11: Legitimacy (R11) and zoning (R12) loops

Table 4.13: Variable description of legitimacy (R11) and zoning (R12) loops

Variable	Description
Community representation	Where representation is closely aligned with community goals and/or includes Enkanini residents
Legitimacy	A sense of validity and formal recognition by the local municipality
Resource competition	Ability to vie for developmental and infrastructural investment by the municipality
Community mobilisation	Active citizenship – including organisation
Residential zoning	Zoning that regulates the development of land and land use to include residential accommodation

As per the legitimacy loop (R11), the better the community is represented, the more likely the settlement will gain legitimacy, which in turn improves the residents' ability to compete for resources. The more the community can compete for resources, the more pressure it can apply on the municipality and the more likely the municipality will take rectification action, which could lead to an increase in the total electricity provided. However, the less total electricity is provided, the more polarised the community becomes, which leads to an increase in partisan leadership. This in turn reduces community representation. At the same time, poor community representation may have a negative impact on residential zoning, which would see the settlement become recognised for residential development and improved infrastructure. However, if Enkanini is re-zoned, its representatives would be in a better position to compete for resources. Both these scenarios however depend on the ability of the community to organise itself and set up representative leadership that is non-partisan, while the total electricity provided can either increase or decrease polarisation within the community.

4.6.4.3 Community empowerment (B4) and ubuntu (R13) feedback loops

Figure 4.12 illustrates the community empowerment and ubuntu feedback loops and the variables are discussed in Table 4.14.

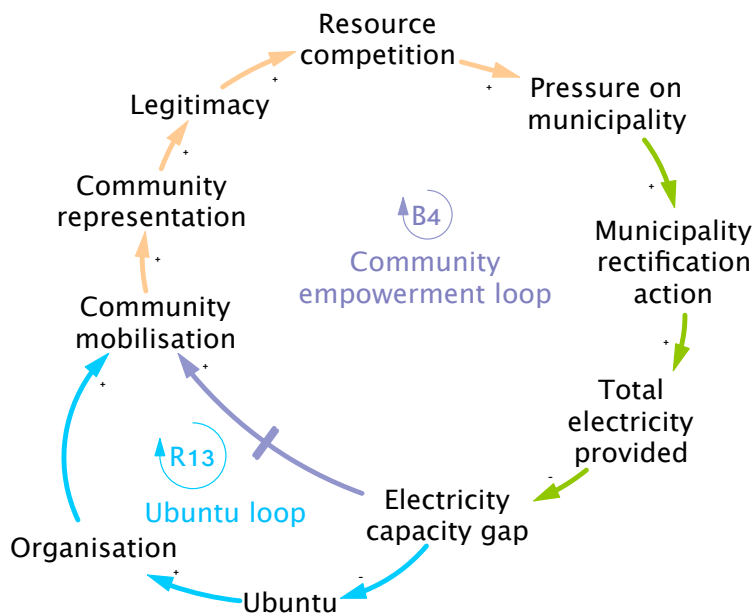


Figure 4.12: Community empowerment (B4) and ubuntu (R13) feedback loops

Table 4.14: Variable description for community empowerment (B4) and ubuntu (R13) loops

Variable	Description
Community mobilisation	Active citizenship – including organisation and actively participating in democratic processes and discussions with the municipality.
Organisation	A community-led process for bringing residents together to rally around a specific issue.
Ubuntu	A feeling of social connection and loyalty to fellow residents and neighbours.
Electricity capacity gap	The difference between the amount of electricity provided and electricity required

According to the participants, the lack of electricity provision by the municipality led to an increased electricity capacity gap which reduced the sense of community or ubuntu in Enkanini. This lack of ubuntu was one of the factors that impeded their ability to organise themselves effectively, while the lack of organisation impeded or reduced the likelihood of community mobilisation. If the community were not mobilised, then it would be less likely to achieve proper community representation, which would reduce the community’s chance of gaining legitimacy and competing for resources effectively.

Thus, according to Enkanini residents, the greater the electricity capacity gap, the greater the need for ubuntu. However, the continued lack of electricity provision meant that the electricity gap did not decrease and, over time, as frustrations grew, the lack of electricity would become a point of contention, leading to community mobilisation in the form of violent protests. This increase in community mobilisation might lead to improved community representation, thereby increasing the community's chances of gaining legitimacy and improving its ability to compete for resources and place pressure on the municipality.

Community mobilisation and representation therefore become key components in bringing about change in the community. On the one hand, from a bottom-up perspective, it may be deduced that Enkanini residents need to mobilise themselves effectively through organisation and by electing active leaders that represent their views. On the other hand, the municipality can assist in improving community representation and participation by recognising community structures and strengthening its support for and interaction with these structures.

4.6.5 Combined causal loop diagram of the factors influencing energy fuel choice and energy access in Enkanini

Figure 4.13 illustrates the overall causal loop diagram relating to the factors influencing energy fuel choice and energy access in Enkanini.

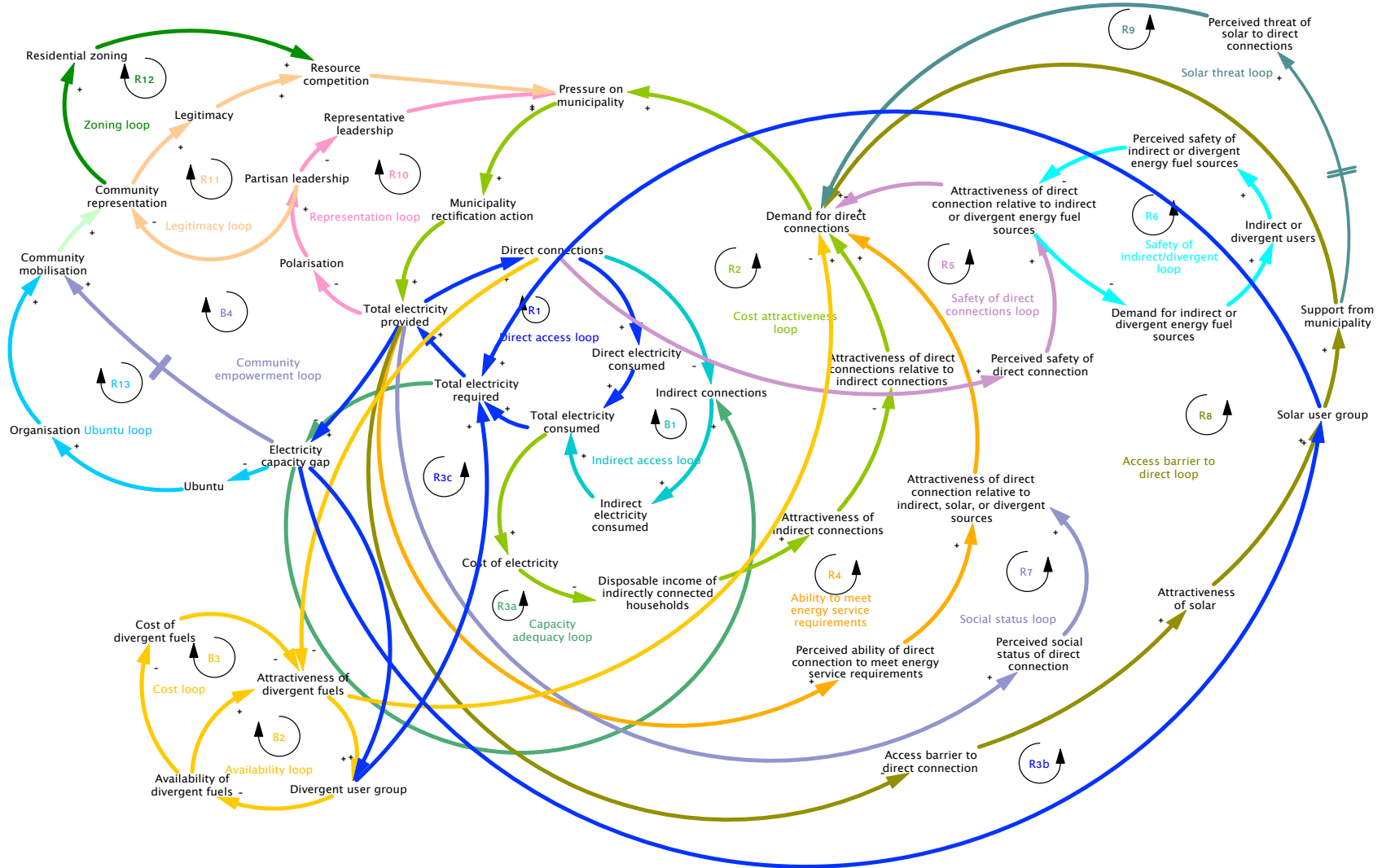


Figure 4.13: Overall causal loop diagram of the factors influencing energy fuel choice and energy access

A number of factors overlap, indicating the interconnected nature of issues that limit choice and perpetuate the lack of energy access. At the same time, the overall causal loop diagram indicates leverage points, which may contribute to improving either energy access or energy fuel choice. For example, while the electricity capacity gap drives residents to opt for lower quality or more hazardous energy fuel sources, over time it may also become a driver for community mobilisation, which may improve community representation, and ultimately the community's ability to compete for resources. Similarly, the municipality may be pressured to take some kind of rectification action (such as providing infrastructure for direct electricity connections) through i) engaging with representative leaders of the community; ii) recognising the legitimacy of the community to compete for resources; or iii) as a result of increasing fire and health hazards. Certainly, the first two scenarios are proactive and therefore preferred to a passive approach that would see the municipality react only after a major disaster and possible loss of life.

A further possible leverage point relates to improving the total electricity provided. Currently, the municipality supports the roll-out of solar, but as previously mentioned (and documented in Kovacic et al., 2016), participants do not consider solar as a substitute for grid connected electricity, despite recognising several benefits associated with this type of energy source. Therefore, if the municipality is constrained to increase the number of direct electricity connections (owing to, for example, limited supply capacity or cost) it may consider improving the capacity of the solar power systems to fulfil residents' energy requirements. This may go a long way to improving energy access in Enkanini, while reducing fire and health risks. However, the municipality would also need to address the status of or social perceptions regarding solar power systems within the community. This may require further engagement with community leaders to address these perceptions and to pave the way for acceptance and implementation. Such a participatory process may also improve the sense of legitimacy that the residents of Enkanini desire.

4.7 Conclusion

This chapter set out to identify the issues that influence energy fuel choice, energy bias and energy switching, as well as the factors that characterise the issues related to energy access within Enkanini, an unrecognised, illegitimate informal settlement. Furthermore, the aim was to understand if and how these factors are causally related. Using Community Based System Dynamics modelling, various causal relationships were identified and visualised, resulting in 13 reinforcing and four balancing feedback loops. Through this process, the Enkanini case has demonstrated that the aim to achieve universal access to affordable, reliable, sustainable and modern energy within an unequal society is a complex problem. While lacking financial infrastructure and political will, the problem of improving energy access requires more than technical solutions in the form of solar PV systems, despite being affordable, renewable and sustainable. It requires a deeper understanding of the contextual realities and interconnected nature of the factors that influence energy fuel choice and access in urban informal settlements, particularly in those regarded as unrecognised or illegitimate.

The use of Community Based System Dynamics modelling, not only highlighted the usual economic and technical factors such as affordability, availability and capacity that influence energy fuel choice or access, but also identified the root cause of the resistance to solar PV power as threatening residents' struggle for legitimacy. Furthermore, during the workshops that underpinned this research, participants gained a level of system insight based on several key feedback loops which were identified as influencing active citizenry in the form of community organisation or mobilisation and representation; while the importance of participating in the political process was recognised as being fundamental to gaining electricity access or improving energy fuel choice. This suggests that future interventions may benefit from deeper engagement and transparent communication with the residents of informal settlements and recognition of the non-technical and aspirational factors that drive their behaviours relating to energy.

Going forward, the researcher will engage with the local municipality in order to present the views and perceptions of the Enkanini residents on energy access and energy fuel choice. The aim of the engagement will be to gain insights on potential leverage intervention points that the municipality can consider in enhancing the agenda of SDG 7 to achieve “energy access for all” (UN. 2016).

4.8 References: Chapter 4

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CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter reviews the main contributions of the study, the key research findings and the limitations of the study. This is followed by the theoretical and practical implications of the study. Finally, a variety of topics for future research are suggested.

This study argues that increasing urbanisation coupled with the persistence of the slum phenomenon has prompted the requirement of new methods to understand what informal settlements are, how they function and how they contribute to the metabolism of the city. Urban metabolism was posited as a useful theoretical framework for assessing the resource use of cities. However, literature has indicated that conventional methods generally used in urban metabolism studies are inadequate for measuring informal metabolic processes and do not consider the politics embedded in resource flows. This study therefore addressed the following research questions:

- What are urban informal settlements and how do they connect to the broader urban context?
- How does a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach contribute to the study of informal settlements in the context of sustainable urban development?
- What are the electricity legitimacy dynamics of Enkanini informal settlement?

5.2 Contributions of the study

The following is a summary of the contributions of the study.

5.2.1 Theoretical contribution

This study contributes to the limited literature on the urban metabolism of informal settlements, which are particularly dominant in the Global South. The study led to the development of a general typology of slums, presented in Figure 5.1. This typology provides a conceptual framework for recognising different slum types for the assessment of their metabolic dimension. Within the context of sustainable development, the typology assists in the definition and recognition of what a slum is, thereby contributing to Sustainable Development Goal 11, in which the upgrading of slums is mentioned, but the term slum is neither defined nor developed.

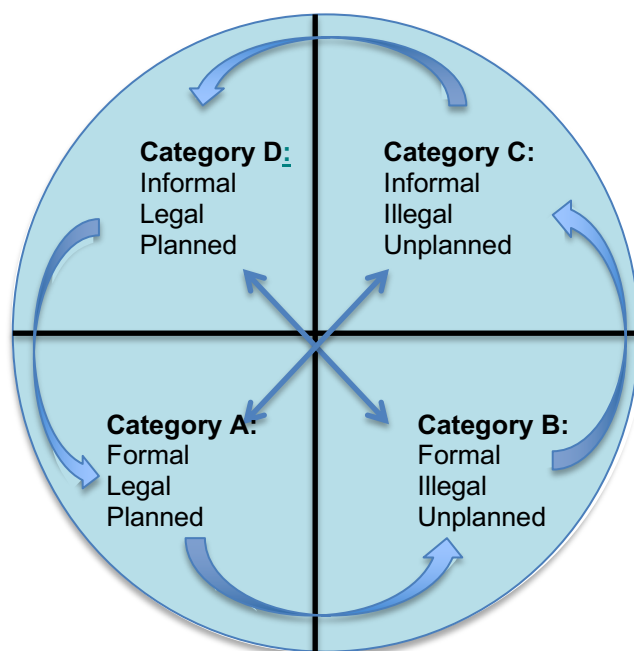


Figure 5.1: General typology of slums

5.2.2 Methodological contribution

This study established and demonstrated the potential of MuSIASEM when applied in a context which differs from that for which it was originally developed. This study also contributed to the methodology through the development of the tool that captures the necessary disaggregated data at different hierarchical levels. Previous applications of MuSIASEM have relied on secondary, highly aggregated data. The application of MuSIASEM in urban informal settlements is in itself novel and depicts how the metabolic dimension of slums can be assessed, thus contributing to the field of urban metabolism. Although MuSIASEM was previously applied in informal settlements (in Brazil), the method was not fully demonstrated (focusing on waste flows only), nor was it applied on the African continent. For the South African context, a more nuanced classification of settlement types was made, as presented in Figure 5.2.

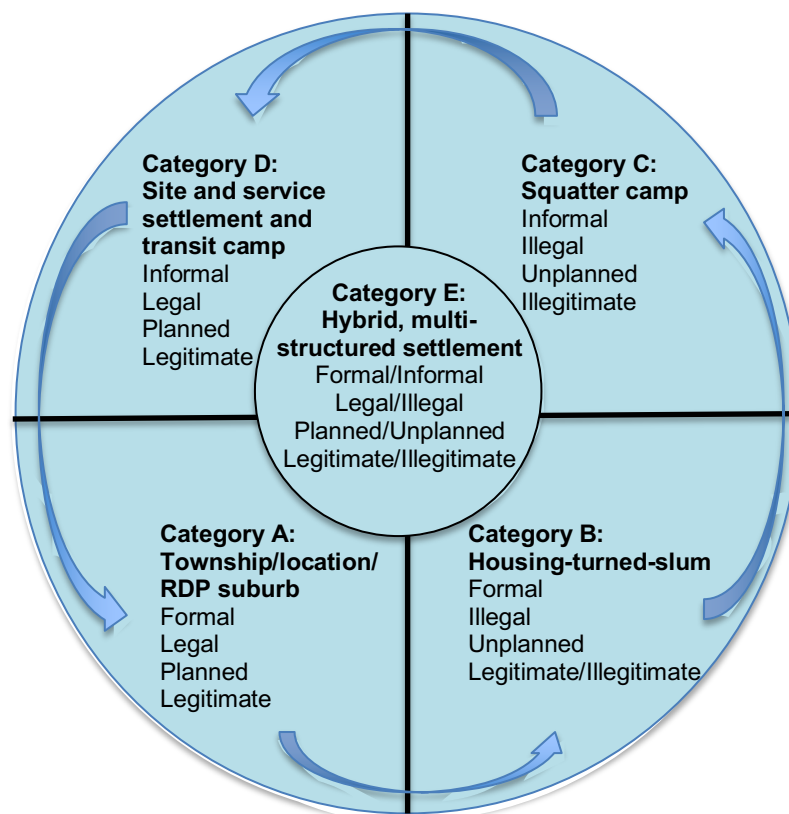


Figure 5.2: South African typology of slums

The combination of parts of MuSIASEM with mixed quantitative and qualitative methods, along with the development of an accompanying survey tool has contributed to the development of the method for use in the context of urban informal settlements in Africa.

As such, the MuSIASEM approach was found to be useful, particularly as related to the following aspects: (i) providing rich data at different hierarchical levels; (ii) allowing for the use of multiple tools and criteria to analyse informal settlements as socioecological, sociotechnical and socioeconomic systems; (iii) recognising and tracing the connections between the formal and informal city; (iv) providing a deeper understanding of the material reality of slums and their inhabitants; (iv) uncovering the politics embedded in resource flows; and (v) highlighting areas for policy intervention; and (vi) being useful as a decision support tool for socially equitable and sustainable urban planning.

This study developed a questionnaire that formed the basis of its utilisation as a template tool for data collection in other informal settlements in Africa. The replicability of the method is evidenced through the application of MuSIASEM in the Kayamandi, Kasubi Kawala and Mathare slums.

The combination of insights gained from MuSIASEM with Community Based System Dynamics is novel in terms of methodological approaches. This unique combination of methods encapsulated the sociopolitical dynamics of energy fuel choice and energy access in Enkanini settlement and assisted in identifying the root causes that influence the settlement's metabolic dimension.

5.3 Key research findings

The first paper reviewed the notion of a slum and identified conventional methods for analysing slums, leading to a general typology of slums. By considering the political context in South Africa, a further category of slum or settlement type emerged. The typology therefore indicated that slums are not

homogenous. The paper argued that sustainable and equitable urban planning requires the analysis of slums to include their metabolic dimension. However, the literature indicated that, although urban metabolism is useful as a conceptual framework for analysing the metabolic dimension of slums, conventional urban metabolism methods are not suitable for capturing informal flows. It was suggested that a Multi-scale Integrated Assessment of the Societal and Ecosystem Metabolism (MuSIASEM) approach would be useful in this regard.

The second paper applied the first two steps of MuSIASEM, in combination with mixed quantitative and qualitative methods, to an urban informal settlement in South Africa and demonstrated the suitability of MuSIASEM for analysing the societal metabolism of slums in terms of the use of time, money and energy. The results revealed that the MuSIASEM approach enables the analysis of informal economic activities through time use surveys, while capturing developmental and infrastructural requirements through participatory and GIS mapping. Key results indicated the connections between the Enkanini informal settlement and the wider adjoining town in terms of employment, monetary flows and resource requirements. The study further highlighted issues around energy fuel choice and energy access in the settlement, particularly as related to the introduction of renewable energy in the form of solar PV systems.

The third paper investigated the issues affecting energy fuel choice and energy access in Enkanini and applied Community Based System Dynamics to identify and visualise the causal relationships between factors that represent the electricity legitimacy dynamics in the settlement. Several key feedback loops were identified as either reinforcing or balancing certain system behaviours. The paper argued that addressing energy access requires more than technical solutions; it requires a deeper understanding of the contextual realities and interconnected nature of the factors that influence energy fuel choice and energy access in urban informal settlements.

Overall, the study found that slums are dynamic and fast-changing. Being connected in a myriad of ways, slums operate as complex subsystems of the wider urban system. This supported the main argument that slums should be included in urban metabolism analyses of cities. Furthermore, the study demonstrated the application of MuSIASEM, in combination with mixed methods, as being useful in the metabolic analysis of slums, while the energy legitimacy dynamics of Enkanini were identified and visually demonstrated.

Based on the aforementioned findings, it is proposed that the study has addressed the research questions adequately. However, it is recognised that the study can be improved by addressing certain limitations which are discussed in the next section.

5.4 Limitations and assumptions of the study

The following limitations are recognised:

- The case study was limited to one category of informal settlement, namely *squatter camp* (see Figure 5.2), using the case of Enkanini informal settlement, situated in Stellenbosch, South Africa.
- The sample size of 100 households may be inadequate for representative generalisation, as the settlement is dynamic and fast-changing. However, the aim of the study was to identify resource consumption trends among household types.
- The sample represents only Xhosa-speaking residents, found to be the largest population group in Enkanini, despite other groupings being present.
- The sample represents all but one zone within Enkanini owing to limited access.
- It is recognised that data obtained via the questionnaire may have been affected by the respondents' individual misunderstanding and misinterpretation of questions, as well as their unwillingness to impart sensitive information related to income.

- The time use component of the questionnaire did not allow for the capturing of multitasking or concurrent human activities, which may skew gender-based results regarding certain activities such as caring for others.
- Energy flow data were not quantified, as the initial survey instrument (see Appendix C) did not account for unmetered and solar PV electricity consumption.

5.5 Theoretical and practical implications of the study

5.5.1 Theoretical implications

The application of MuSIASEM revealed what a holistic or broader, more inclusive approach to urban metabolism involves, thus contributing to the body of knowledge on urban metabolism as well as contributing to the achievement of Sustainable Development Goal 7 and 11. The study contributes to goal 7 by tracing energy usage, and available infrastructure and technology, as well as increasing our knowledge and understanding of the socio-political and economic issues that affect energy choices and energy access in an informal settlement in South Africa. Furthermore, it demonstrates that the energy metabolism of an informal settlement can be quantified. The contribution to the field of sustainable development in general and sustainable development goal 11 in particular, lies in the categorisation of slums based on a general typology as well as going some way to address the issue of methods that produce disaggregated data for analysis, while bringing scientific rigour to methods that deal with complexity and uncertainty. Moreover, the Enkanini case was used as a practical example in teaching the Participatory Integrated Assessment of Energy Systems to Promote Energy Access and Energy Efficiency in Southern Africa (PARTICIPIA). The case is currently available on-line via the MOOC: *Sustainability of Social-Ecological Systems: The Nexus between Water, Energy and Food*³¹.

³¹ For more information see: www.coursera.org.

5.5.2 Societal implications

The study utilised a bottom-up approach in terms of data collection and analysis. It therefore represents not only the household and individual levels, but the community as a whole. This type of disaggregated data is vital to informing local integrated and economic development plans based on differentiated urban metabolism. By considering the local context, the study demonstrates the implications for local policy makers and planners while affording representation to marginalised communities.

The Community Based System Dynamics workshops contributed to the participants' knowledge and understanding of the factors that affect energy fuel choice and energy access in Enkanini, while the causal loop diagrams visually express their thoughts and perceptions around these issues.

Furthermore, the study employed participatory processes, by involving local community members in designing the survey tool, conducting field work and data collection, and assisting with mapping the settlement. This approach produced rich data, based on lived experiences. The study thus demonstrates the value of local knowledge and community participation as vital to addressing real-world problems.

5.5.3 Policy implications

Beyond its implications for local policy, the study will have an impact on international policy related to sustainable urban development – in particular by addressing methodological gaps and by providing evidence-based policy recommendations for local, national, regional or continental situations.

5.6 Recommendations for future research

The following recommendations for future research are drawn from this study, which was designed to be exploratory in nature:

This study focused on one type of informal settlement or slum. Future studies should consider expanding the application of MuSIASEM to all the different settlement types, based on the developed typology of slums conceptual framework presented in Chapter 2. It is recognised that each slum type displays a unique metabolism based on a series of factors including building type, population dynamics, and cultural, economic and sociopolitical contexts. The MuSIASEM approach has been applied to two different settlement types across three countries. More case studies are required to assist in identifying resource use trends in the various settlement types.

Further development and improvement of the MuSIASEM method and accompanying survey tool are required. In particular, more work needs to be done in order to increase the efficiency of data collection and to improve the time use survey for capturing activities that are multitasked. Presently, the survey tool does not support this.

The application of MuSIASEM should be expanded to different neighbourhood types as part of a differentiated urban metabolism approach. This would involve conducting an urban metabolism study for a whole city which represents different socioeconomic groups or resource users. This type of study would demonstrate the value of investigating differentiated urban metabolism by highlighting resource inequalities and identifying key areas for intervention.

The development and dissemination of a MuSIASEM practitioner's guide would be useful. To facilitate wider utilisation and application of MuSIASEM, it is essential to have a step-by-step guide on how to apply the process to various habitats. This will require putting together a practitioner's booklet which would be useful to academics interested in replicating the approach and urban practitioners who may use the method in their urban metabolism assessments.

Local municipalities' approaches to informal settlements are impacted by, and limited in, their responses through current legislation and policies pertaining to informal settlements. A clearer understanding of these dynamics is required that may benefit from mapping the policy landscape surrounding informal settlements, as well as tracing the systems of governance that impact these dynamics.

CHAPTER 6: LIST OF APPENDICES

6.1 Appendix A: Published articles

Each of the following papers were published in international, accredited, and peer-reviewed journals.

6.1.1 Publication 1

The writing and development of the published paper in the journal, *Cities*³² were principally the responsibility of the writer.

Cities 62 (2017) 107–119



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Conceptualising slum in an urban African context 

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<p>ARTICLE INFO</p> <p>Article history: Received 13 June 2016 Received in revised form 12 October 2016 Accepted 28 December 2016 Available online xxxxx</p> <p>Keywords: Informal settlement Urban metabolism Multi-scale analysis Urban slums Urban Africa South Africa</p>	<p>ABSTRACT</p> <p>Increasing urbanisation and the proliferation of slums require a holistic understanding of the urban metabolism of cities. However, existing urban metabolic analyses exclude a detailed understanding of how urban slums function and contribute to biophysical, including energy, flows. This paper aims at filling this gap by critically investigating the notion of the urban slum in general, the extent to which it differs in the African context, specifically in South Africa, and broadening the understanding of urban slum based on the concept of urban metabolism, using the multi-scale integrated analysis of societal and ecosystem metabolism (MUSIASEM) a approach, which was applied to the Enkanini informal settlement in Stellenbosch, South Africa. The analysis shows that South Africa has a more nuanced typology of the notion of urban slums categorised as: (i) townships; (ii) housing-turned-slum; (iii) squatter camps; (iv) site and service settlements; (v) transit camps; and (vi) hybrid multi-structured settlements. Beyond these definitions, the case study illustrates that urban slums, however defined, are complex systems with their own internal flows and processes that are connected in a myriad of ways to the larger urban system. The investigation into the use of Time, Money and Energy in the Enkanini case further revealed the productive (hypercyclic) and consumptive (dissipative) nature of the components of the urban informal settlement. This type of analysis reveals new insights into the linkages between urban informal settlements and the city.</p> <p style="text-align: right;">© 2016 Elsevier Ltd. All rights reserved.</p>
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1. Introduction

The urban age is unfolding, with more than half of the world population now living in cities and urbanisation set to increase by a further 2.5 billion people by the year 2050 (UN-DESA, 2014; UN-Habitat, 2015a). This increase is mainly expected to be dominant in Asia and Africa (UN-DESA, 2014; UN-Habitat, 2014a, 2014b). The Africa-wide urbanisation level is projected to reach 58% by 2050, thereby increasing the number of urban dwellers from 400 million in 2010 to 1.26 billion by 2050 (UN-Habitat, 2014b).

This situation places excessive strain on cities to plan for and manage the increase in urbanites and their demand for housing, employment and access to basic infrastructure and services; a situation that is becoming vastly untenable for many cities, particularly those in the developing world. Most urban economies in developing countries are unable to meet these basic needs. Beyond the pressures of population growth, several factors including economic growth, housing market dynamics and urban planning that actively creates spaces of exclusion and segregation (Roy, Lees, Palavali, Pfeffer, & Peter Slood, 2014; Amado, Ramalheite, Amado, & Freitas, 2016) leave the informal economy to provide most of the new employment and housing in these environments,

commonly referred to in various terms such as *informal settlement, slum, shantytown, squatter camp, favela, ghetto, bidonvilles, Katchi Abadis, and campamentos*, (Guibrune & Castán Broto, 2015; UN-Habitat, 2010).

A quarter of the world's population lives in slums (UN-Habitat, 2014b), with the majority of slum dwellers stemming from the developing world (UN-Habitat, 2010, 2014b, 2015a). More than 880 million people in developing countries are currently living and working in slums (UN-DESA, 2015a). Despite a slight decline in the global urban slum population, sub-Saharan Africa continues to have the highest prevalence of slum conditions, whilst the majority of additional population in cities are expected to end up being slum population (UN-DESA, 2015a).

At the same time, sustainable urban development has been identified as one of the most pressing global challenges of the twenty-first century (UN-Habitat, 2015b), whilst the concepts of societal metabolism (Martinez-Alier, 1987; Fischer-Kowalski, 1998; Giampietro, Mayumi, & Ramos-Martin, 2009) and urban metabolism has become fundamental to the development of sustainable cities and communities. The notion of societal metabolism is described as analysing the 'metabolism of human society' through a characterisation of the processes that a society employs to transform energy and material to ensure its continued existence (Giampietro et al., 2009; Fischer-Kowalski, 1998; Fischer-Kowalski & Hüttler, 1999; Kovacic & Giampietro, 2016) and has been applied to urban metabolism studies (see for example

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³² The reference is: Smit, S., Musango, J.K., Kovacic, Z., and Brent, A.C. 2017. Conceptualising slum in an urban African context. *Cities*, 62: 107 – 109.

6.1.2 Publication 2

The writing and development of the paper accepted for publication in the *Journal of Industrial Ecology*³³ were principally the responsibility of the writer. The paper is currently in press.

RESEARCH AND ANALYSIS

Towards Measuring the Informal City A Societal Metabolism Approach

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South Africa
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urban slum

Summary

The rapid growth of urban informal settlements, or slums, poses a particular challenge for balancing developmental and environmental goals. In South Africa, high levels of inequality, poverty, and unemployment contribute to widespread migration. The influx of migrant workers to cities, however, is rarely matched with adequate housing and infrastructure, resulting in the formation and growth of urban informal settlements. Despite the persistence of the slum phenomenon, very few studies provide an in-depth understanding of the metabolic processes that link these spaces, and informal economies, to the broader urban environment and economy. This article therefore utilized a multiscale integrated assessment of the societal and ecosystem metabolism approach to examine human activity and land use in Enkanini, an urban informal settlement in Stellenbosch, South Africa. The results highlight a number of issues to be addressed through spatial, developmental, and local economic policy, such as the need for improved transport linkages. The time-use results show that Enkanini is a net provider of labor to the surrounding area. Further, geographical mapping indicates Enkanini as a small, but vibrant, informal economy, while being grossly underserved in terms of water, waste, and sanitation infrastructure. Key implications are discussed in terms of the theoretical, methodological, societal, and policy impact of the study, including the need for city observatories that conduct regular data collection and analysis.

Introduction

Increasing urbanization, coupled with the proliferation of slums, particularly in developing countries, give rise to the need for a holistic approach and understanding of the functioning of slums, and their connection to the wider urban system (Smit et al. 2017; Guibrunet and Castán Broto 2015; Guibrunet et al. 2016; Attia and Khalil 2015). Informal settlements, or slums, are recognized by the United Nations (UN) Human Settlement program (UN-Habitat 2010) as households lacking any of the

following conditions: (1) access to improved water; (2) access to improved sanitation facilities; (3) sufficient living area—not overcrowded; (4) structural quality/durability of dwellings; and (5) security of tenure. The analysis of slums or informal settlements should not solely be based on their physical, geographical, and legal characteristics (Smit et al. 2017), but should also consider their societal metabolism in relation to the overall city. This is because slums are not self-evident units of analysis and are connected to the broader urban metabolism (UM) in many different ways.

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Abstract

The aim of providing affordable, reliable, sustainable, and modern energy for all requires an in-depth understanding of the issues that affect energy access and energy fuel choice, particularly as related to urban informal settlements or slums. Within unequal societies, such as South Africa, a reliance on technical solutions to address access and inequality is inadequate, leading to resistance and protest. This paper therefore investigates the issues that affect energy fuel choice and energy access as related to the introduction of a renewable energy solution in an urban informal settlement. The case of Enkanini demonstrates that the introduction of a technical solution – such as solar PV – to address energy access, is not a simple process, and requires a systems thinking perspective. Using Community Based System Dynamics modelling, factors that affect energy access and energy fuel choice, as well as the relationships between these factors in order to improve future interventions, were examined. These included economic and market related factors such as affordability, availability, and land ownership. Different energy user groups were engaged in the development of causal loop diagrams to visualise the key feedback loops based on the identified factors that affect energy access and energy fuel choice in an illegitimate urban informal settlement in South Africa. 17 feedback loops emerged, of which 13 are reinforcing loops, and 4 are balancing loops. The key feedback loops relate to community empowerment and representation, whilst participation in the political process and the quest for legitimacy through direct electricity connections were recognised as broader issues to be addressed.


Keywords	informal settlement; slum; energy access; electrification; community based system dynamics; solar photovoltaic
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6.1.4 Publication 4

The lead author for this article is Dr Kovacic, and writer's contributions relate to the data collection, analysis and write-up of the results pertaining to the Enkanini case study³⁵.

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Probing uncertainty levels of electrification in informal urban settlements: A case from South Africa


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ABSTRACT

This paper assesses the different levels of uncertainty that affect the analysis of informal urban settlements and the implementation of upgrading policies, with a specific focus on electrification. The rapid growth of informal settlements in the cities of the Global South poses serious challenges to the management of energy systems, particularly when it comes to the electricity grid. Informal urban settlements are characterized by the lack of urban planning and low or absent provision of public services. Exponential population growth increases the complexity of urban planning. An inadequate understanding of uncertainty can undermine the effectiveness of informal settlement upgrading and deepen social inequalities. Based on the case study of the Enkanini settlement in Stellenbosch, South Africa, this paper probes three levels of uncertainty: (i) methodological uncertainty associated with the challenge of estimating energy demand and demographic changes, (ii) technical uncertainty associated with the expansion of the electric grid and securing revenues, and (iii) epistemological uncertainty associated with the definition of the relevant problems and pertinent solutions for informal settlements. The paper highlights how the focus of technical uncertainty displaces the debate on the socio-political challenges of informal settlement upgrading.

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1. Introduction

The challenge of electrification (Cities Alliance, 2013; Department of Energy, 2011; UNHABITAT, 2014) and upgrading (Abbott, 2002; Bradlow, Bolnick, & Shearing, 2011; Tipple, 2015) of informal urban settlements is attracting increasing attention in the African context. The upgrading hype is occurring despite the long standing criticism of upgrading policies for their narrow focus on physical infrastructure and space (Hardoy & Satterthwaite, 1986; Roy, 2005), and the failure of upgrading programmes in eradicating poverty and controlling the growth of informal settlements

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both in the Global North and in the Global South (Hardoy & Satterthwaite, 1986; Pamuk & Cavallieri, 1998). Informal settlements upgrading focuses on the infrastructural deficits, spatial characteristics and physical living conditions of dwellers, which assume that informal settlements migrants fail to adapt to the city (Abrams, 1964). More complex views of informal settlements recognise them as suppliers of labour to the city (Tipple, 2015), integrated into the socio-economic organisation of cities (Hardoy & Satterthwaite, 1986), where informality is employed as an instrument of social control, economic exploitation, political repression, social stigmatisation and exclusion (AlSayyad, 2004; Roy, 2005).

The most commonly cited problems concerning the electrification of informal urban settlements are: (i) technical issues associated with grid expansion and service provision in low density areas (Department of Energy, 2011; Sustainable Energy Africa, 2014a), (ii) the impact on the load profile and difficulty in estimating energy

³⁵ This paper was published in Habitat International. The reference is: Kovacic, Z., Smit, S., Musango, J.K., Brent, A.C., & Giampietro, M. 2016. Probing uncertainty levels of electrification in informal urban settlements: A case from South Africa. *Habitat International*, 56: 212-221.

6.2 Appendix B: International conference submissions

Certain outputs of the study were accepted and presented at the following international conferences between 2016 and 2018:

- 22nd Annual International Sustainable Development Research Society Conference (ISDRS 2016), 13-15 July 2016, Lisbon, Portugal.
- PhD colloquium of the 34th International Conference of the System Dynamics Society (ICSDS), 16-21 July 2016, Delft, Netherlands.
- Southern African Sustainable Energy Initiative (SASEI), International Renewable Energy Conference (IREC), 26-28 October 2016, Gaborone, Botswana.
- PhD colloquium of the Innovation for Sustainable Development Network (inno4sd); Africa-Europe Dialogue Symposium on Innovation for Sustainable Development, 29 November – 1 December 2017, Pretoria, South Africa.
- 24th International Sustainable Development Research Society Conference (ISDRS 2018), 13-15 June 2018, Messina, Italy.

6.3 Appendix C: MuSIASEM questionnaire

The following questionnaire was used to collect data on the use of time, money and energy in Enkanini settlement and relates to research questions 1 and 2.

Prepared by: Suzanne Smit

Date _____ Time _____

Interviewer _____ Location (General area) _____

Gender of Interviewee (Please circle) M / F

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

English

--

IsiXhosa

--

Other (please specify) _____

2. How old are you? _____

3. Are you the head of the household? Y / N

4. How many people live in the household?

(Indicate number, age and sex)

Age	M	F
0 to 4		
5 to 9		
10 to 14		
15 to 19		
20 to 24		
25 to 29		
30 to 34		
35 to 39		
40 to 44		
45 to 49		
50 to 54		
55 to 59		
60 and above		

5. 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?

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?

D	W	M
---	---	---

How much do you get paid? _____

How do you get to work?

- Taxi
- Walking
- Train
- Bicycle

Other (specify) _____

How long does it take you to get to work? _____

Person 2 (M / F)

What type of work do you do? _____

Is the work full time or part time?

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?

D	W	M
---	---	---

How much do you get paid? _____

How do you get to work?

- Taxi
- Walking
- Train
- Bicycle

Other (specify) _____

How long does it take you to get to work? _____

Person 3 (M / F)

What type of work do you do? _____

Is the work full time or part time?

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?

D	W	M
---	---	---

How much do you get paid? _____

How do you get to work?

- Taxi
- Walking
- Train
- Bicycle

Other (specify) _____

How long does it take you to get to work? _____

Person 4 (M / F)

What type of work do you do? _____

Is the work full time or part time?

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?

D	W	M
---	---	---

How much do you get paid? _____

How do you get to work?

- Taxi
- Walking
- Train
- Bicycle

Other (specify) _____

How long does it take you to get to work? _____

6. How many people in the household are unemployed? _____

7. How many people in the household are retired? _____

8. How many people in the household are in full-time education? _____
 (Complete for each relevant person)

8a) 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			

9. 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	Housekeeping	Cooking
P1			
P2			
P3			
P4			
P5			

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

Person type (A, C, S and M/F)	Collecting fuel, wood, water or gardening	Leisure and social activities (incl. going to church, watching TV, Radio, sports)	Sleeping, eating, personal care
P1			
P2			
P3			
P4			
P5			

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

_____ R _____

Government grants	
Donations	
Interest on savings	
Other (please specify)	

12. What is the total household income per week? _____

13. How much does the household spend in total per week on: (Indicate in Rand)

Where expenses are monthly, please indicate with (M).

- Food _____
- Travel _____
- Leisure _____
- Mobile phones (Calls and data) _____
- Medical expenses _____
- Personal care (Hair, nails etc) _____
- Household expenses (Toiletries, Cleaning products, appliances) _____
- House maintenance _____
- Insurance (Life, Car etc) _____
- Informal/small Business _____
- Savings _____
- Clothes _____
- Education _____
- Water _____
- Loan repayment _____
- Rent _____
- Other (please specify) _____

14. Does the household receive any government grants? Y / N
(If No, continue to Q 15)

14a) How much does the household receive in total from the following grants?
(Indicate in Rand)

- Disability _____
- Childcare _____
- Pension _____
- Social relief _____
- Other (Please specify) _____

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

Loans from friends	<input type="text"/>
Loans from family	<input type="text"/>
Loans from bank	<input type="text"/>
Savings	<input type="text"/>
Stokvel	<input type="text"/>
Other (please specify)	<input type="text"/>

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

Invest in own business	<input type="text"/>
Spend on leisure activities	<input type="text"/>
Spend on personal care	<input type="text"/>
Save	<input type="text"/>
Repay loans	<input type="text"/>
Lend to family or friends	<input type="text"/>
Other (please specify)	<input type="text"/>

17. Does the household have access to electricity? Y / N
(If No, continue to Q 18)

17a. How is the electricity supplied?

Direct via municipality	<input type="text"/>
Indirect through neighbour	<input type="text"/>
Other (please specify)	<input type="text"/>

17b. How much does the electricity cost per week? _____

18. Please indicate which fuels you use for the following activities: (Please tick)

	Cooking	Lighting	Water heating	Space heating	Electric goods	Other (Specify)
Paraffin	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Wood	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Gas	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Candles	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Coal	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Solar	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Biogas	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Batteries	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Car Batteries	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Generator (petrol/diesel)	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Eskom electricity	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Other (please specify)	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

19. Please indicate the proportion of fuels you use for the following activities:
(Indicate %)

	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)						

20. Where do you get the fuels from? (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)					

21. 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)			

22. What is the unit cost per fuel type?

R/kg R/unit R/litre

Paraffin		
Wood		
Gas		
Candles		
Coal		
Solar		
Biogas		
Batteries		
Car batteries		
Generator (petrol/diesel)		
Eskom electricity		
Other (please specify)		

23. How much does the household spend per week on each fuel type? (Indicate in Rand)

	R
Paraffin	
Wood	
Gas	
Candles	
Coal	
Solar	
Biogas	
Batteries	
Car Batteries	
Generator (petrol/diesel)	
Eskom electricity	
Other (please specify)	

24. Any other comments related to time, money or energy use:

6.4 Appendix D: Community Based System Dynamics workshop schedule

The following daily schedule was adhered to for each day of the Community Based System Dynamics workshop on energy in Enkanini.

Daily programme			
Duration	Time	Activity	Participants
30m	9.00 - 9.30	Set up: Prep venue layout	
30m	9.30 - 10.00	Participant registration:	ALL
		Sign ethical consent forms	
		Create name labels	
		Complete participant survey	
		Coffee/tea available during this time	
15m	10.15 - 10.30	Welcome / ice breaker	ALL
15m	10.30 - 10.45	Introduce team and each other	ALL
15m	10.45 - 11.00	Hopes and Fears	ALL
15m	11.00 - 11.15	Introduce purpose of workshop and problem focus area	ALL
1h	11.15 - 12.15	Energy use/perception questions	ALL
30m	12.15 - 12.45	Basic causal loop diagramming	ALL
1h	12.45 - 1.45	LUNCH	
45m	1.45 - 2.30	Break-away:	Small groups
		Is energy access a problem?	Small groups
		If so, why do you think the problem exists? What factors influence it?	Small groups
30m	2.30 - 3.00	Wall builder: Prioritise variables	ALL
45m	3.00 - 3.45	How are these factors related? Build CLD	ALL
15m	3.45 - 4.00	Final remarks and feedback	ALL
30m	4.00 - 4.30	Modelling team feedback and close	

6.5 Appendix E: Hopes and Fears script

The following script was used to assist in building trust with participants and to address any concerns and expectations they had of the workshop.

Hopes and Fears

This script is used to elicit and establish group expectations for a GMB session or project and is performed at the start of a GMB project.

Status

Best practices

Primary nature of group task

Divergent

Time

Preparation time: 0 minutes

Time required during session: 30 minutes

Follow-up time: 0 minutes

Materials

1. Two different colors of office paper (8.5 x 11) for each participant
2. Thick tipped markers
3. Blue "painters" masking tape

Inputs

None

Outputs

List of participants' hopes and fears

Roles

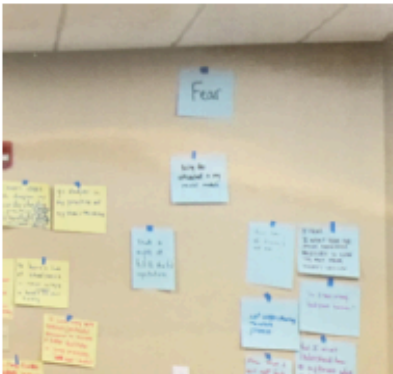
- Facilitator with good group facilitation skills and knowledge of the local language and topic
- Wall-builder to categorize hopes and fears
- Recorder to document the session
- Runner (optional) to transfer hopes and fears from facilitator to wall-builder

Steps

1. Participants are given several sheets of paper in each color. The facilitator explains that they will be writing their hopes and fears for the project and then sharing them with the group.
2. The facilitator states which color represents hopes and which represents fears, and participants write their hopes and fears on the corresponding piece of paper.
3. In a round-robin fashion, each participant then reads one fear and one hope. The facilitator takes each hope and fear that the participant has read and posts it on the wall. After each participant has had a chance to share once, the facilitator may open the floor to participants to offer hopes and fears or may go around the room until everyone has shared all of their hopes and fears.
4. The facilitator then tries to identify some of the themes of the hopes and fears.
5. Recorders write down the hopes and fears in the session notes.

Evaluation Criteria

- Participants have shared both their hopes and fears for the upcoming project
- Participants understand the overall themes of the hopes and fears



Example 1

Authors

George P. Richardson and David F. Andersen

History

First described in Luna-Reyes et al (2006).

Revisions

None

References

Luna-Reyes, L. F., Martinez-Moyano, I. J., Pardo, T. A., Cresswell, A. M., Andersen, D. F., & Richardson, G. P. (2006). Anatomy of a group model-building intervention: Building dynamic theory from case study research. *System Dynamics Review*, 22(4), 291-320.

Notes

None

6.6 Appendix F: Variable elicitation script

The following script was utilised to assist in identifying possible variables related to energy fuel choice and energy access.

Variable Elicitation

This script is used to facilitate consensus-based group discussion about the model problem and boundaries early in the modeling process.

Status

Best practices

Primary nature of group task

Divergent

Time

Preparation time: 0 minutes

Time required during session: 20 minutes

Follow-up time: 0 minutes

Materials

1. Markers
2. Stacks of plain paper
3. Chalk/whiteboard markers

Inputs

None

Outputs

Prioritized list of variables

Roles

- Facilitator with moderate expertise in SD and small group facilitation
- Modeler with moderate expertise in SD

Steps

1. The facilitator gives each participant sheets of blank paper and markers.
2. The facilitator writes a task-focusing question such as, "What are the key variables affecting the process and outcomes of the [project name] project?" on the whiteboard or flipchart.

3. The facilitator asks participants to write as many problem-related variables as they can on the sheets of paper. Participants are given a few minutes to work individually on their lists.
4. Once they have finished the individual exercise, the facilitator uses the same process used in the "Hopes and Fears" script to put all individual variables on the board. When a variable name is open to several interpretations, the facilitator asks for a brief description or definition of the variable, including the units in which the variable can be measured.
5. The facilitator writes the variable name on the board, including any additional information in parenthesis.
6. The facilitator asks the participants to prioritize the variables by simple voting mechanisms. Individuals can vote for as many variables as they want. The number of votes for each variable is also written down on the board.
7. The facilitator makes a summary of the variables on the board, while the recorder captures the products of the process either photographically or in a word processor.
8. The facilitator suggests which variables can be considered stocks as they are mentioned. If the participants agree, the facilitator can add the words "level of" to these variables.

Evaluation Criteria:

- Identification of key variables and stocks



Example 1

Authors

Andersen and Richardson

History

Originally described in Luna-Reyes et al. (2006).

Revisions

None

References

Luna-Reyes, L. F., Martinez-Moyano, I. J., Pardo, T. A., Cresswell, A. M., Andersen, D. F., & Richardson, G. P. (2006). Anatomy of a group model-building intervention: Building dynamic theory from case study research. *System Dynamics Review*, 22(4), 291-320.

Notes

A variation of this script is the Nominal Group Technique.

6.7 Appendix G: Workshop questions

The following questions were directed to each energy fuel user group during the Community Based System Dynamics modelling workshop.

- Do you think that access to electricity is a problem in Enkanini?
- Why is it a problem? Or not?
- Why do you think this problem exists? (Variable elicitation)
- What causes this problem?
- How are these factors related?
- What are the main effects of this problem?
- What do you think will improve the situation?

Group A – Divergent users

- Why do you use only these fuels?
- What do you use it for?
- What is good and bad about it?
 - Does it meet your requirements? (Last till end of month, or is strong enough to complete desired activity e.g. heating, cooking, lighting)
 - What are its limitations?
 - Easy to maintain?
 - Is it affordable for you?
- Would you recommend it? Why? Why not?
- Effect on social standing or relationships in community
- Other risks
- What would make you change your energy mix?
- What do you think of solar?
- Would you get it?
- Why? Why not?
- What do you think of direct electricity connection?
- What do you see as the benefits? How would it improve your life?
- Do you think having solar will impact on Eskom electrification?
- Would you consider mix use (combination of solar, gas and Eskom)

Group B: For Solar users:

- Why did you get solar?
- What do you use it for?
- What is good and bad about it?

- Does it meet your requirements? (Last till end of month, or is strong enough to complete desired activity e.g. heating, cooking, lighting)
- What are its limitations?
- Easy to maintain?
- Is it affordable for you?
- Would you recommend it? Why?
- Other risks associated with this fuel
- Effect on social standing or relationships in community
- Do you think having solar will impact on Eskom electrification?
- What would make you change your energy mix?
- What think of indirect connections? Would you get one? Why, why not?
- Would you consider mix use (combination of solar, gas and Eskom)

Group C - Indirect users

- Why did you get indirect connection?
- What do you use it for?
- What is good and bad about it?
 - Does it meet your requirements? (Last till end of month, or is strong enough to complete desired activity e.g. heating, cooking, lighting)
 - What are its limitations?
 - Easy to maintain?
 - Is it affordable for you?
- Would you recommend it? Why?
- Effect on social standing or relationships in community
- Concern about legality
- Other risks
- Effect on relationships (with neighbours and indirect providers)
- What would make you change your energy mix?
- What do you think of solar?
- Would you get it?
- Why? Why not?
- Do you think having solar will impact on Eskom electrification?
- Would you consider mix use (combination of solar, gas and Eskom)

In general:

- What are main stumbling blocks for :
 - energy access (elec)
 - energy transition (to renewable)

- Why do you use the type and quantity of energy that you use?
 - Access
 - Affordability
 - Esteem (social and cultural consumption drivers)
 - Energy requirements
- Is there stigma related to different energy carriers?
 - Perceptions about Eskom electricity
 - Perceptions around Solar
 - Perceptions about other forms of energy (bio, paraffin, gas etc.)