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# Understanding electricity legitimacy dynamics in an urban informal settlement in South Africa: A Community Based System Dynamics approach

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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. Further, introduction of a technical solution – such as solar PV - to address energy access in urban informal settlements, is a complex process, and requires a systems thinking perspective. Using Community Based System Dynamics modelling, this paper therefore investigated the issues that affect energy fuel choice and energy access as related to the introduction of a renewable energy solution in Enkanini informal settlement. Different energy user groups were engaged in the identification of the factors that affect energy access and energy fuel choice; the relationships between these factors in order to improve future interventions; and development of causal loop diagrams to visualise the key feedback loops. The identified factors were economic and market related such as affordability, availability, and land ownership but also included a range of socio-political aspects. 17 feedback loops emerged, of which 13 were reinforcing loops, and 4 were 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.



## 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 paper, are: SDG 7, which aims to provide universal access to affordable, reliable, sustainable and modern energy for all; and SDG 11: Sustainable Cities and Communities, which addresses slums[1] or informal settlements. Despite energy being integral to development and the improvement of several other SDGs, including those related to gender equality, poverty reduction, health improvements, and climate change (IEA, 2017), much still 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, whilst requiring countries to embrace new technologies on an ambitious scale, such as solar photovoltaic (PV) or solar home systems.

Global energy access has improved in recent years, with the number of people lacking energy access dropping to below 1 billion, for the first time in 2017 (IEA, 2018). However, the IEA (2018) projects that up to 700 million people, stemming mainly from rural sub-Saharan Africa, will remain without energy access in 2040. At the same time, the demand for electricity has doubled in developing countries, placing a greater emphasis on the need for cleaner, available and affordable electricity (IEA, 2018).

Electricity access in South Africa has improved significantly since 1994; increasing from 66% of the population in 2000, to 86% in 2016

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[1] 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 housing, secure tenure and/or which are over-crowded.

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(IEA, 2017). At the same time, the proportion of 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 Word Bank, 2014). Since 1994, the South African government has followed a variety of approaches towards informal settlements, ranging from the provision of formal housing (in the form of RDP[2] 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 however has been associated with a 'wait for the grid' approach, with negative political consequences (Swilling, 2014). Whilst 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 8 years after legalisation or rezoning for communities to be 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 Shack[3] upgrade that includes solar PV in its design (Keller, 2012; Swilling, 2014), designated as improved Shack (iShack). The iShack was experimented in Enkanini, an urban informal settlement on the outskirts of Stellenbosch, South Africa. Enkanini was established as an illegal settlement, and does not have a legal recognition yet, suggesting that the community would likely be waiting more than 8 years for grid connections, despite bordering 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, 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 (Keller, 2012; Swilling, 2014, 2016; Glasser, 2017). 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 et al., 2018; Glasser, 2017; Swilling, 2014, 2016). 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 metabolic dimension of the Enkanini settlement (see Smit et al., 2017; Kovacic et al., 2016; Kovacic and Giampietro, 2016) indicate that a general roll-out may be problematic within the South African context. Whilst the adoption of solar PV 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 somehow negatively impacted further distribution of the solar PV systems, and 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 Bravo et al., 2008; Karekezi et al., 2008; Shrestha et al., 2008; Butera et al., 2016; Coelho and Goldemberg, 2013; Rahut et al., 2016; Puzzolo et al., 2016). Some studies focus on policies for transitioning from traditional energy sources to cleaner energy sources such as liquefied petroleum gas (Bravo et al., 2008; Coelho and Goldemberg, 2013); and others highlight political and legal issues related to for example land tenure, household income and legal status as major obstacles to energy access (Dhingra et al., 2008; Bravo et al., 2008; Jimenez, 2017). 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; whilst 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 multi-criteria sustainability analysis for assessing electricity alternatives for informal urban households, whilst 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 paper therefore uses the case study of Enkanini informal settlement to address the 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? In this regard, the paper makes an empirical and methodological contribution to understanding the relationships between the factors that affect energy access and energy choice in a particular context. The focus is thus on how a systems approach, using community based system dynamics, improves our understanding of these issues. The results are thus context specific, whereas the methodological approach provides general insights for application in different contexts.

## Method

In order to address the questions posed in the paper, 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 was founded by Forrester (1961), with major contributions by Meadows et al. (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 counter-intuitive nature of certain system feedbacks and the need to address flawed mental models[4] (Forrester, 2007).

However, in his review of the development of System Dynamics, 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

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

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

[4] 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).

stakeholders. Accordingly, this practice would not encourage organisational buy-in or support; thus, hindering long-term behavioural change. In response to this limitation, the field of Group Model Building emerged (see for example Richardson and Andersen, 1995; Vennix, 1996). 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 (Forrester, 2007; Hovmand, 2014). It 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 (Hager et al., 2015).

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:

> [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" (Hovmand, 2014).

Community Based System Dynamics has been applied to a variety of issues including alcohol abuse amongst 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 et al., 2016); and knowledge change amongst smallholder farmers in Zambia (Hager et al., 2015); whilst variants of the method is 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 (CBPR) is also recognised for its collaborative approach to effectively engage with communities by including community members as full participants (Frerichs et al., 2016; BeLue et al., 2012). Whilst Minkler (2010) proposes that Community-based Participatory Research is not a research method in itself, but rather an orientation to research; both 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, whilst 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 it was therefore the appropriate method in this study. Furthermore, Trani et al. (2016) promote the use of Community Based System Dynamics as giving voice to stakeholders, allowing them to share their views of a problem, whilst generating robust, sophisticated results with actionable policy recommendations, which is 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' (Trani et al., 2016; Rosenthal et al., 2017).

### *Setting, study design and participants*

A Community Based System Dynamics workshop focusing on energy was held over 3 days in the Enkanini Research Centre in Enkanini informal settlement. Enkanini, which means to 'take by force', is located about 4 km 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 of municipal land (not zoned for residential purposes), when a small number of backyard shack dwellers were evicted from the neighbouring and officially recognised Kayamandi settlement (CORC, 2012; CST, 2016; Zibagwe, 2016). This development led to friction and a contentious relationship between the residents of Enkanini and Kayamandi as well as the local municipality (Zibagwe, 2016).

Enkanini informal settlement is fast changing and dynamic: its population nearly doubling from 4500 (in 2011) to 8000 people (in 2015), whilst the type of households has drastically changed from mostly single adult households (53% of the population in 2011) to mainly households with two or more people (76% in 2015).

After the local municipality's efforts to evict the residents failed, their focus changed to providing a limited number of taps and toilets and eventually towards re-zoning the settlement for residential use. 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, whilst the municipality has preferred to focus on Solar PV as a solution to the lack of energy access.

A variety of energy options are currently 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.[5] 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 unintentional as it was aimed to achieve a 50/50 split. The majority of participants (27 of 30) had achieved secondary level education, 2 had primary education and 1 had tertiary education, whilst none of the participants had taken part in a research study before. The sessions incorporated a series of scripts, or structured small group exercises, adapted from an online manual[6] for conducting structured group model building activities, and included the Hopes and Fears and Variable Elicitation scripts.[7]

In order to identify and address the issues influencing energy access in Enkanini, we first had to understand the factors influencing energy fuel choice in Enkanini. This led to the need for a deeper understanding of i) the types of energy fuel sources utilised 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 they use a particular energy fuel source and what they 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

[5] Indirect electricity users obtain electricity through informal connections via neighbours from the Kayamandi settlement (situated to the north of Enkanini) who are formally and directly connected to the electricity grid. Indirect electricity users purchase prepaid electricity vouchers that are passed on to the owner of the formal connection. As there is no record kept of actual electricity use by the indirect user, this arrangement relies heavily on trust.

[6] Available from: https://en.wikibooks.org/wiki/Scriptapedia.

[7] The Hopes and Fears script was used to address the group expectations and possible concerns, whereas the Variable Elicitation script was used to elicit the different variables or factors related to the problem.

**Table 1**
Constituents of causal loop diagrams.
Source: Adapted from Brennan et al., 2015.

| 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 | Two or more variables in a causal sequence that “feeds back” to the original variable, completing a loop.<br>There are two types of feedback loops:<br>**Reinforcing loop or Positive feedback**<br>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.<br>**Balancing loop or Negative feedback**<br>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 towards some stable goal. |

order to identify the energy biases of each group towards the other energy fuel sources and how these biases may impact on their ability or willingness to switch to an alternative energy fuel source. 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.

### *Modelling process and outputs*

Model building requires a team and the following roles were therefore adopted: 2 Community liaisons; 1 Process facilitator; 1 Modeller; 1 Translator/co-researcher; 2 Recorders; and 1 Photographer.

The outputs of the Community Based System Dynamics workshops were a series of causal loop diagrams (CLDs) that illustrate community members' perceptions regarding the issues around energy access and energy fuel choice in 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). They constitute several elements (see Table 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 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. The individual factors for all the causal loop diagrams were reported by the participants as both actual behaviours, for example as related to their energy choices and their engagements with Kayamandi residents and the local municipality but also as hypothetical behaviours, as related to their willingness to change energy fuel choice. The modelling team also added certain variables such as Total electricity provided and electricity capacity gap to improve the logical flow of the model. 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 3 groups was produced.

## Results

The Results section discusses: the factors that influence energy fuel choice, energy bias and energy switching in Enkanini; the issues that characterise energy access in Enkanini; and examines the causal relationships to identify the key feedback loops; and how they dynamically influence each other and affect energy fuel choice and energy access.

**Table 2**
Factors influencing choice of energy fuel source.

| Energy user group | Reason for using this energy source | Benefits | Disadvantages |
|---|---|---|---|
| Solar electricity users | • No other electricity access<br>• For charging cell phone<br>• Lighting<br>• Unable to establish relationship to access indirect electricity | • Safe | • Sometimes trips<br>• High charges<br>• Poor service<br>• Sometimes not available<br>• Delays and long wait before faults are fixed<br>• “Sometimes not strong enough” |
| Indirect electricity users | • Some can use it for cooking<br>• Lighting<br>• Charging cell phones<br>• Some can use it for refrigeration<br>• “Solar is not powerful, candles don't last, paraffin has smoke” | • Healthier, no smoke<br>• Cleaner | • Not easy to get connected, you must know someone<br>• Power trips often<br>• Risky - can cause fatality<br>• “Don't know how much electricity (many units) really used”<br>• Fire hazard/electrocution<br>• It's temporary |
| Divergent energy users | Paraffin - Lighting and cooking | • Easy to light<br>• Easy to get<br>• Heats house well<br>• Cheap | • Gives bad taste to food<br>• Causes fires<br>• Prices vary a lot<br>• Causes fever<br>• Not always available<br>• “Makes chest burn” |
| | Candles – Lighting | • Cheap<br>• Gives good light | • Causes fire |
| | Gas - Cooking | • Quick lighting<br>• Less smell<br>• Lasts longer<br>• No bad taste on food<br>• Good value for money | • Highly flammable - causes fire<br>• “Difficult to monitor (don't know how much in cylinder)”<br>• “Danger of carbon monoxide poisoning if leaks”<br>• Not easy to get (have to go far) |

*Factors influencing energy fuel choice in Enkanini informal settlement*

The factors that influence energy fuel choice for the different energy fuel user groups are presented in Table 2. Solar users are 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, is currently unavailable for Enkanini residents because the settlement does not receive municipal services. In order to obtain an indirect connection, the Enkanini household has 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, thus acting as a barrier to access. Furthermore, solar users are prohibited by their service provider (iShack) from having an indirect electricity connection. In terms of perceived health benefits, solar PV systems do not produce smoke and are less likely to cause electrocution in contrast to indirect connections, which tend to cause fires and lead to electrocution and paraffin and gas, which are prone to fire risk and produce toxic fumes.

Indirect electricity users suggest that their preference lies in the capacity of the energy fuel source (however limited it is) to fulfil their cell phone charging and refrigeration needs and as being superior to the solar systems. However, in contrast to this perception, the results of the study indicate that in practice, the solar system users and indirect electricity users tend to have similar limitations in terms of their energy fuel source usage. Further, both groups still rely on paraffin, candles and gas to fulfil their energy service requirements, such as for cooking, lighting and heating.

Divergent energy users mainly rely on paraffin, gas and candles to provide their needs due to the affordability, accessibility and availability of these sources. However, they also recognise the disadvantages and risks of these fuels for their health and wellbeing.

The energy bias and switching requirements for each of the three energy user groups are depicted in Table 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.

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

*Issues that characterise energy access in Enkanini informal settlement*

The various factors and issues that contribute to the lack of direct electricity provision to the Enkanini settlement are presented in Table 4.

The factors identified in Table 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 Fig.1). The word cloud, which may be considered an unconventional tool, was found to be visually robust and instinctively effective in the context of the study. It

**Table 3**
Energy bias and switching requirements.

| User group | Thoughts on Solar PV | Thoughts on Indirect electricity connections | Thoughts on paraffin and gas | What would change your energy mix? |
|---|---|---|---|---|
| Solar electricity users | • Generally satisfied with solar, however it sometimes doesn't last the month;<br>• Need to top up with candles and pay others to charge phones; Still use gas and paraffin to supplement for cooking and lighting<br>• It is affordable, depending on the package<br>• Not considered good value for money | • Also limited in terms of what you can use it for<br>• Unsafe - fire and electrocution risk<br>• Can't cook with it<br>• You need to have social connections to get the indirect line<br>• Solar cheaper than indirect | • Expensive<br>• Need special lamp<br>• Price varies a lot during winter<br>• All use Gas for cooking | • Solar capacity needs to be improved<br>• Need to be able to cook and refrigerate with it |
| Indirect electricity users | • Not strong - can't do much with it<br>• Weather affects it - when it rains, gadgets don't work well<br>• Not reliable | • Would prefer to have electricity metered or direct – so can monitor and control use | • Gas is good for cooking, quick, cheap and lasts more than a month<br>• Paraffin smokes and burns eyes | • If solar capacity improves, then would consider having both sources, as a backup and to reduce costs |
| Divergent energy users | **Positives** –<br>• Solar is good for lighting and television,<br>cell phone charging and running some small appliances<br>• It has health benefits - does not cause fire<br>• Gives better and brighter light than candles<br>• Inexpensive, Does not experience load shedding<br>**Negatives** –<br>• Can't cook with it<br>• Unreliable (weather)<br>• Limited in use, which can affect business<br>• Access barrier - must be four households together to apply for solar<br>• Can't run a business with it | • It's not right (legal and safe)<br>• Dangerous - causes fire and electrocution<br>• Expensive<br>• Does not last the month<br>• Prone to load shedding and power failures | • Paraffin - cheap, warms up house but health risks<br>• Gas - good value for money and for cooking, less health risks but is still a fire risk | • Would include solar into energy mix if entry barriers were removed<br>• Prefer solar to indirect electricity<br>• Would use solar mainly for lighting |

**Table 4**
Factors contributing to the lack of electricity access in Enkanini.

| User group | What issues/factors contribute to lack of electricity in Enkanini? | Variables |
|---|---|---|
| Solar electricity users | • Households moved in without permission from municipality | • Land ownership |
| | • "Think Municipality thinks it's a waste of money to invest" | • Cost Recovery |
| | • Shacks too close to each other to put in electricity poles | • Density/Layout |
| | • Councillor - policy maker issue | • Representation |
| | • Political issues between parties | • Party politics |
| | • Social issues - unrest | • Social issues/Violence |
| | • Lack of communication | • Communication |
| | • Lack of trust in community representatives and municipality | • Trust/Ubuntu |
| | • No feedback from municipality on community issues | • Communication |
| | • Slope/steep | • Layout/geography |
| | • High cost | • Cost |
| | • Non- participatory processes | • Representation |
| | • Lack of community space for meetings | • Organisation |
| | • Lack of accountability | • Accountability |
| | • Lack of choice | • Legitimacy |
| Indirect electricity users | • Non-performance by councillors | • Accountability/Politics |
| | • Enkanini not on map, not recognised | • Recognition/Legitimacy |
| | • Lack of leadership from Enkanini | • Organisation |
| | • No organisation in Enkanini that is not politically motivated | • Politics |
| | • Lack of feedback from councillors | • Communication |
| | • Land is illegally occupied | • Land ownership/Legitimacy |
| | • Lack of leadership due to misrepresentation | • Representation |
| | • Misrepresentation leads to corruption and competition for resources | • Corruption/Competition for resources |
| | • Councillors afraid of us - violence | • Social issues/Violence |
| | • Councillors powerless at municipality level | • Party politics |
| | • Councillors lives threatened | • Violence |
| | • Can't talk directly to municipality | • Representation |
| Divergent energy users | • Solar causes delay from municipality | • Substitution |
| | • Lack of leadership; Lack of effective street committee | • Leadership |
| | • No feedback from councillors | • Communication/feedback |
| | • Poor organisation | • Organisation |
| | • Disconnect between communities (Kayamandi & Enkanini) No Ubuntu | • Representation/Ubuntu |
| | • Lack of support | • Ubuntu/Legitimacy |
| | • Not enough power (people standing together) | • Organisation/Community cohesion |
| | • Lack of services (infrastructure) | • Infrastructure/Service delivery |
| | • Competition for resources (with Kayamandi) | • Competition for resources |

facilitated further engagements with the community for identifying key factors for the causal loop diagram development. The use of unconventional tools is one way of making science relevant to society and policy.

As shown in Fig. 1, the main factors contributing to the lack of electricity in Enkanini, relate to: (i) representation; (ii) lack of organisation; (iii) poor communication; (iv) legitimacy; and (v) ubuntu.[8]

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 their ability to effectively organise themselves. The ability of Enkanini residents to mobilise and 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. Whereas the term Legitimacy denotes validity as a community, both in terms of land ownership and participation in the political process, whilst it has also been described as relating to direct electricity access, indicating that these factors are somehow interrelated.

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

### *Key feedback loops influencing energy fuel choice in Enkanini informal settlement*

Based on the identified factors in the section on Factors influencing energy fuel choice in Enkanini informal settlement, the following sections discuss the various feedback loops related to energy fuel choice, and energy access.

#### *Direct access (R1) and Indirect access feedback loops (B1)*

Enkanini residents' energy fuel choice is influenced by the amount of total electricity provided. The direct access and indirect access loops are shown in Fig. 2 and the variables are described in Table 5.

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

[8] The term ubuntu means humanity and relates to a sense of community and shared compassion.


**Fig. 1.** Main factors affecting energy access in Enkanini.

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 due to 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 Fig. 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 less indirect connections there would be, and the number of indirect connections would reduce, thereby, reducing 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.

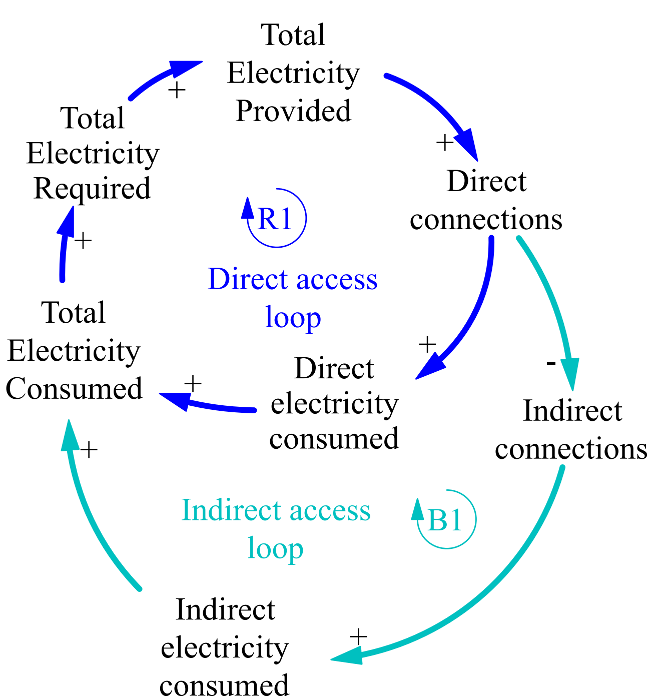


**Fig. 2.** Direct (R1) and Indirect (B1) access loops.

**Table 5**
Variable description for Direct (R1) and Indirect (B1) access loops.

| Variable | Description |
|---|---|
| Total electricity provided | Refers to the total amount of electricity provided for both direct and indirect connections. |
| Direct connection | Electricity is 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 home owner 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. |

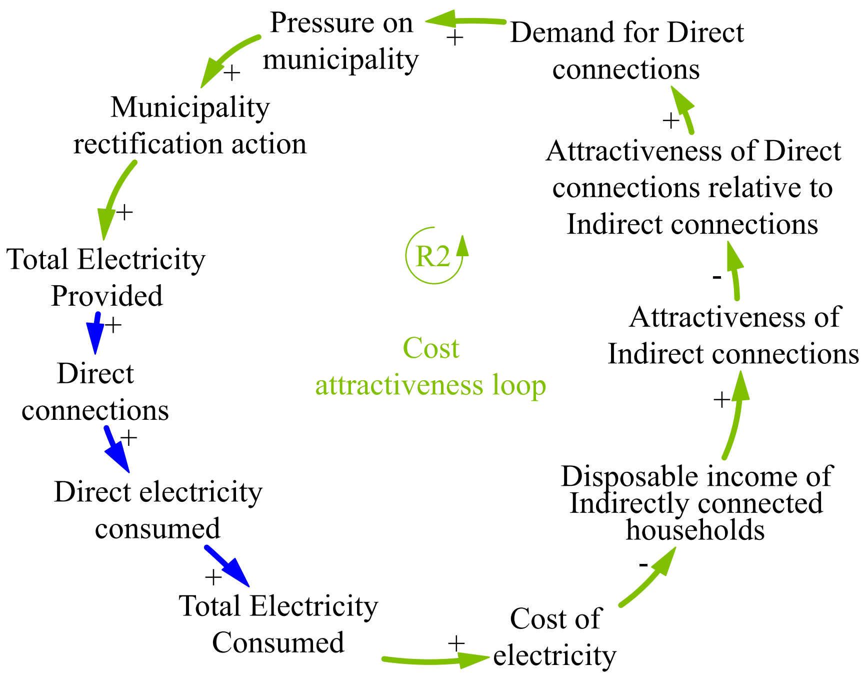


**Fig. 3.** Cost attractiveness (R2) loop.

*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 Fig. 3). The variables for Fig. 3 are defined in Table 6.

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. In order to manage electricity consumption, and reduce strain on the national supply, Stellenbosch municipality applies an inclining block rate tariff structure which leads to an increase in cost per kilowatt hour with increased consumption (Stellenbosch Municipality, 2017). This means that the more electricity is consumed by the indirect users, the greater the cost of electricity will become for the directly connected user, who will in turn increase the amount indirect users must pay. Any increase in the cost of electricity reduces the amount of disposable income a household has available to spend on their 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 owner 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. This in turn would increase 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 that is consumed, the higher the cost of electricity becomes per unit for formally connected users (Stellenbosch Municipality, 2015) who 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.

**Table 6**
Variable description for Cost attractiveness (R2) loop.

| Variable | Description |
|---|---|
| Cost of electricity | Indirect electricity costs are determined by the formal home owner 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 taxes to spend or save. |
| Attractiveness of Indirect connections | The appeal of having or getting an indirect connection |
| Attractiveness of Direct connection relative to Indirect connections | The appeal of direct connections over indirect connections |
| Demand for Direct connections | The continued desire and request for gaining 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 |

*Energy fuel source attractiveness*

The attractiveness of a particular energy source is relative to the attractiveness of other energy fuel sources when comparing aspects of cost, access, availability et cetera. 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.

*Capacity adequacy (R3) feedback loop.* Fig. 4 illustrates the effect of inadequate capacity and connects to the direct access (R1) and indirect access (B1) loops as described in Fig. 2. The variables related to capacity adequacy are described in Table 7.

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, indirect connections 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

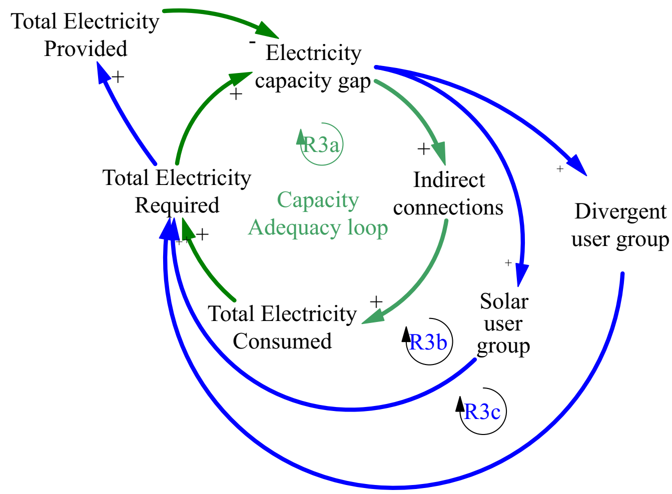


**Fig. 4.** Capacity adequacy (R3a; R3b; R3c) loops.

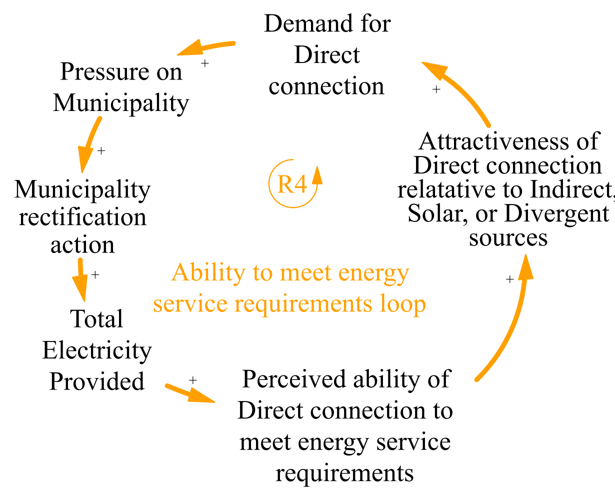


**Fig. 5.** Ability to meet energy service requirements (R4) loop.

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, whilst driving up total electricity consumption.

The total electricity provided however, is contingent on factors such as willingness by the municipality to invest in electricity infrastructure (represented as Municipality rectification action), but 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 Fig. 2) as being limited and under strain. This would suggest that even if the municipality was 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 amongst 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.

*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 Fig. 5). Table 8 describes the variable for loop R4.

Overall, the participants indicate that their preference for direct connections is influenced by its ability to meet their energy service requirements. Hence, the greater the perception that direct connections will fulfil their energy needs, the more attractive direct connections becomes in relation to either indirect, solar or divergent energy sources. This leads 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 that are connected to the grid, the more their energy service requirements are met, which, in turn, drives the perception that direct electricity connections are able to meet energy service requirements; making this a reinforcing feedback loop.

*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 Fig. 6 and the variables are described in Table 9.

Although all user groups recognise the need for energy fuel sources that are safe, divergent energy users would still choose paraffin and gas over indirect electricity connections, as they view indirect connections as more hazardous to their health. In contrast, indirect connection users consider their choice safer than relying on paraffin or gas. In all cases, participants have the perception that direct connections are safest, which makes direct connections more attractive than indirect or divergent energy sources. This in turn feeds the demand for direct connections, forming a reinforcing feedback loop.

On the other hand, the more attractive direct connections become relative to indirect or divergent fuel sources, the less attractive indirect or divergent energy sources become, thereby reducing demand and reducing the number of indirect and divergent user groups. The smaller the indirect and divergent user groups become, the less these sources are perceived as being safe thereby increasing the attractiveness of direct connections relative to other sources.

*Availability of divergent fuels (B2) and cost of divergent fuels (B3) loops.* Divergent fuel users describe their fuel choices as being driven by the access barrier to direct connections and the cost of divergent fuels (see Fig. 7). The variables for B2 and B3 are described in Table 10.

The less direct connections are available, the more attractive divergent fuels become to households, which increases the Divergent user group. The more people use divergent fuel sources, however leads to a reduction in the amount of fuel available to the settlement as paraffin and gas supplies can run low during winter months, which, in turn, reduces the attractiveness of divergent fuels. When divergent fuels become scarce, participants indicate that the cost of paraffin and gas

**Table 7**
Variables describing Capacity adequacy loop.

| Variable | Description |
|---|---|
| Electricity capacity gap | The difference between Total Electricity Provided and Total Electricity Required. |

**Table 8**
Variable description for Ability to meet energy service requirements (R4) loop.

| Variable | Description |
|---|---|
| Perceived ability of Direct connection 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 connection relative to Indirect, Solar or Divergent sources | The appeal of a direct connection as preferred to indirect, solar or divergent energy fuel sources |

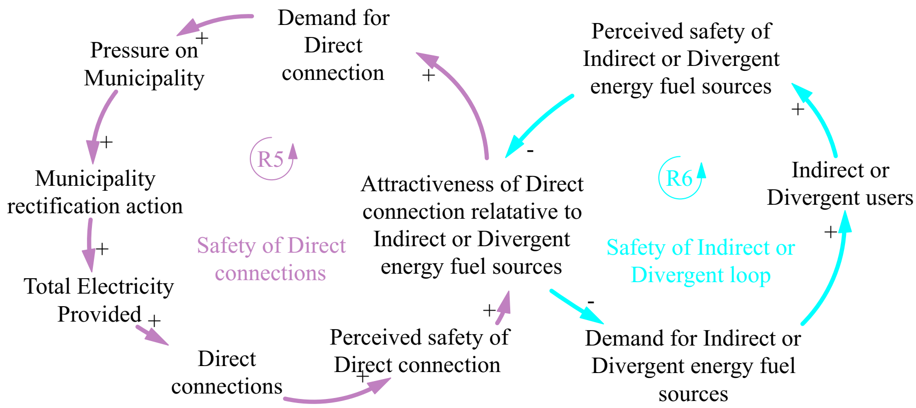


**Fig. 6.** Safety of Direct connections (R5) and Safety of Indirect and Divergent (R6) loops.

escalates. In the case of paraffin, the cost can increase up to four-fold, which ultimately reduces the attractiveness of divergent fuels and in turn can lead to a greater demand for direct electricity. Both the availability (B2) and cost (B3) of divergent fuels loops are balancing loops.

*Social status (R7) loop.* Participants attach a level of importance and position to different energy fuel sources, which also influence their fuel choice. This perceived status is linked to the ability of the energy fuel source to fulfil energy requirements, but in particular it relates to a household's ability to have cell phone charging facilities; use of an electric oven and refrigerator. However, none of the current energy fuel sources meet these criteria fully. For example, in the case of the solar users, running an oven or refrigerator is not possible. Whereas with indirectly connected users (depending on their location), some are able to run a small fridge and charge cell phones, but ovens take too much power. Divergent energy users cannot do any of the above.

All user groups indicate that Direct connections offer the most status of all energy sources. The higher the perceived status of direct connections are, the more attractive direct connections become relative to the other energy fuel sources, thereby leading to an increased demand for direct connections. The Social status (R7) loop is reinforcing, indicating that it will become stronger over time (Fig. 8).

*Access barrier to Direct connections (R8) and Solar threat (R9) loops.* Solar users indicated that their preference for solar stems from the lack of access to direct connections in Enkanini, whilst Indirect and Divergent users are concerned that solar may be obstructing a future roll-out of direct connections. This is illustrated in Fig. 9, whilst the variables are described in Table 11.

As per Fig. 9, the less total electricity is provided by the municipality, the greater the access barrier to direct connections. Solar 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

**Table 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. |

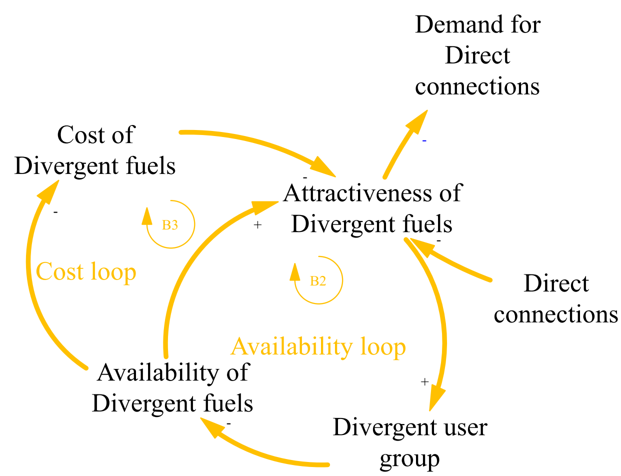


**Fig. 7.** Availability of Divergent fuels (B2) and Cost of divergent fuels (B3) loops.

support to the initiative through a transfer of the electricity subsidy to the 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 getting direct connections.

This fear and frustration thus leads 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 as impacting 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, if they do not perceive it as a threat to direct connections.

**Table 10**
Variable description of Availability of Divergent fuels (B2) and Cost of divergent fuels (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 Kilogram of gas. |

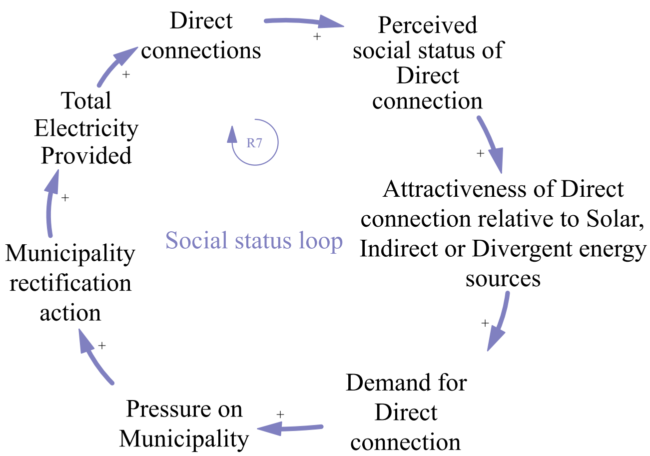


**Fig. 8.** Social status (R7) loop.

*Key energy access feedbacks*

Based on the identified factors in the section on Issues that characterise energy access in Enkanini informal settlement, 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.

*Representation feedback loop (R10)*

The representation feedback loop is shown in Fig. 10 and the variables are described in Table 12.

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

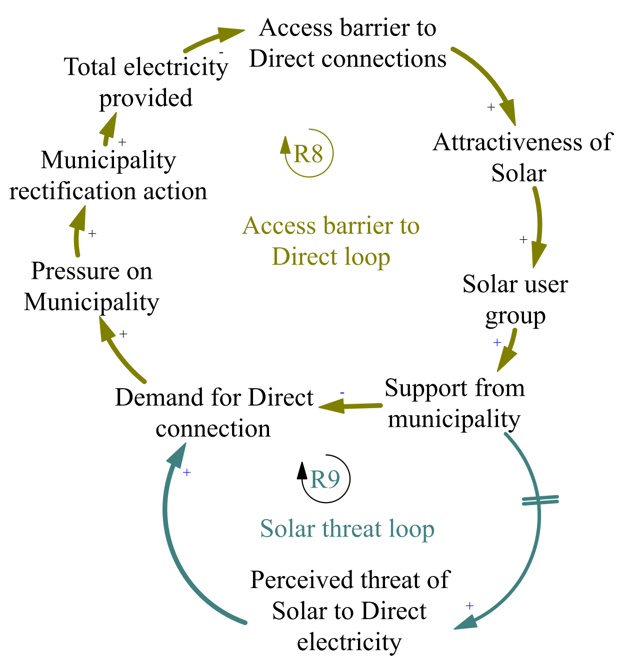


**Fig. 9.** Access barrier to Direct connections (R8) and Solar threat (R9) loops.

**Table 11**
Variable description for Access barrier to Direct connections (R8) 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. |

These views are captured in Fig. 10, which indicates that the greater the level of representative leadership, the more political pressure they are able to apply on the municipality, which 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 have 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 their ability to apply pressure on the municipality.

*Legitimacy (R11) and Zoning feedback loop (R12)*

The variables related to the Legitimacy and Residential zoning loops are described in Table 13 and illustrated in Fig. 11.

As per the Legitimacy loop (R11), the better the community is represented, the more likely the settlement will gain Legitimacy, which in turn improves their ability to compete for resources. The more the community can compete for resources, the more pressure they can apply to 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 also negatively 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 themselves and set up representative leadership that is non-partisan, whilst the total electricity provided can either increase or decrease polarisation within the community.

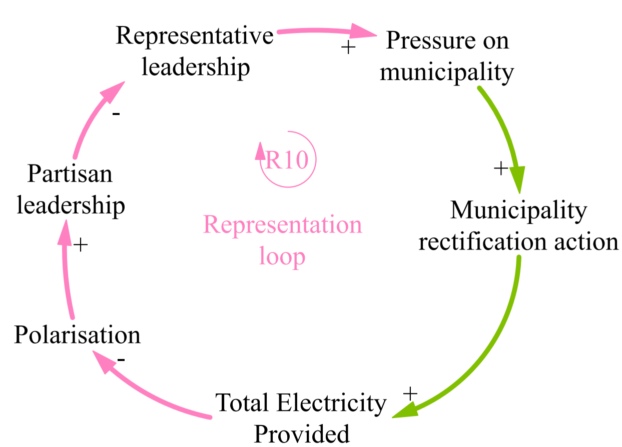


**Fig. 10.** Representation feedback loop (R10).

**Table 12**
Variable description for Representation (R10) loop.

| 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 |

**Table 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 |
| Partisan leadership | Relates to partiality - being unduly influenced by a broader political agenda |
| Community mobilisation | Active citizenship - including organisation |
| Residential Zoning | Zoning that regulates the development of land and land use to include residential accommodation. |

*Community empowerment (B4) and Ubuntu (R13) feedback loops*

Fig. 12 illustrates the community empowerment and Ubuntu feedback loops and the variables are discussed in Table 14.

According to the participants, the lack of electricity provision by the municipality has led to an electricity gap, which has reduced the sense of community or ubuntu in Enkanini. This lack of ubuntu is one of the factors that impedes their ability to effectively organise themselves, whilst the lack of organisation impedes or reduces the likelihood of community mobilisation. If the community is not mobilised, then they are less likely to achieve proper community representation, which will reduce their chance or gaining legitimacy and effectively compete for resources.

Thus, according to Enkanini residents, the greater the electricity gap, the greater the need for Ubuntu. However, the continued lack of electricity provision means that the electricity gap does not decrease and over time, and as frustrations grow, the lack of electricity becomes a point of contention thereby leading to community mobilisation, in the form of violent protests. This increase in community mobilisation may lead to improved community representation, thereby increasing their chances of gaining legitimacy and improving their 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 surmised that Enkanini residents need to mobilise themselves effectively through organisation and by electing active leaders that represent their views. On the other

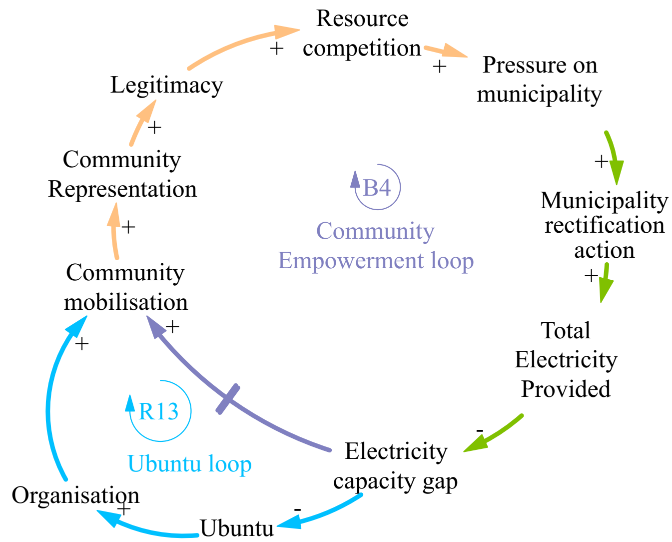


**Fig. 12.** Community empowerment (B4) and Ubuntu (R13) loops.

**Table 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. |

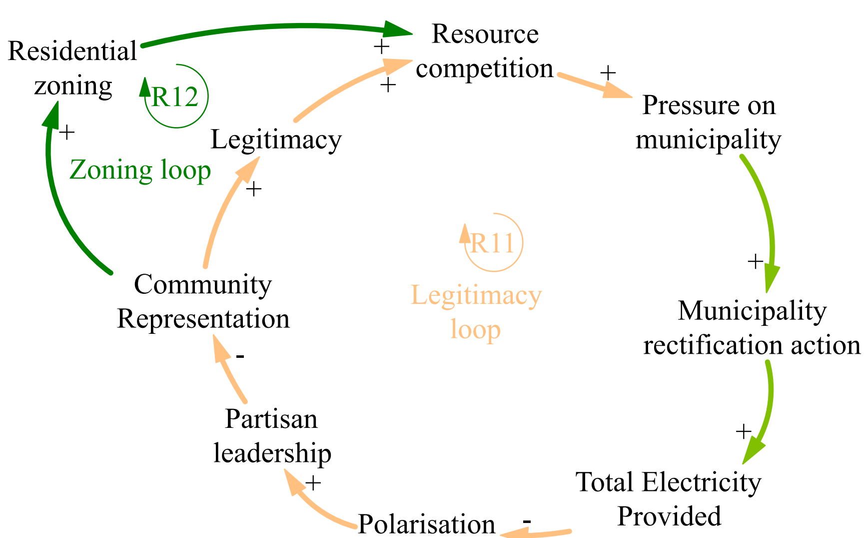


**Fig. 11.** Legitimacy (R11) and Zoning (R12) loops.

hand, the municipality can assist in improving community representation and participation by recognising community structures and strengthening their support of and interaction with these structures.

*Integration of the factors influencing energy fuel choice and energy access in Enkanini*

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, certain leverage points emerge, which may contribute to improving either energy access or energy fuel choice. For example, whilst 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 their 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 pro-active and preferred to a passive approach that would see the municipality only react 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 (due 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 in improving energy access in Enkanini, whilst 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.

## Conclusion

This paper identified 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, it provided an understanding and insights into how these factors are causally related. Using Community Based System Dynamics modelling, various causal relationships were identified and visualised, resulting in 13 reinforcing and 4 balancing feedback loops. Through this process, the Enkanini case has confirmed that the aim to achieve universal access to affordable, reliable, sustainable, and modern energy within an unequal society is a complex problem. Whilst lacking financial infrastructure and political will, the problem of improving energy access requires more than technical solutions in the form of solar PV, despite being affordable, renewable or sustainable. As indicated by the resistance to solar (Fig. 9) and the drive for empowerment, representation and legitimacy (Fig. 12) within the community, it requires a deeper understanding of the socio-political aspects as well as the contextual realities and interconnected nature of the factors that influence energy fuel choice and access in urban informal settlements, particularly those regarded as unrecognised or illegitimate.

The results of the 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 as threatening residents' struggle for legitimacy. The use of Community Based System Dynamics, also revealed the following:

- The methodology takes a bottom-up approach and is capable of capturing and representing the views of a marginalised community, making it an appropriate approach for these type of settings.
- The socio-political aspects that influence energy access and energy fuel choice, are brought to the fore. Although this initially adds to the complexity of the process, it leads to deeper insights into these spaces, which may result in more appropriate and context specific interventions and policies.
- The focus on relationships between factors, improves our knowledge and understanding of the system under investigation and may improve the efficacy of interventions if these are taken into account.
- The mental models that influence the participants' behaviours are represented, which offers an opportunity for improved future engagement between the Enkanini residents and the local municipality. Knowing how the residents perceive and understand certain aspects around energy access and fuel choice is the first step towards meaningful engagement. Going forward, the local municipality could improve the relationship with the community, by addressing knowledge gaps, and misunderstandings. This may go a long way towards diffusing the recurring violent protests and contentious relationship between the community and the municipality.

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; whilst 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 energy behaviours.

Going forward, the local municipality will be engaged to present the views and perceptions of the Enkanini residents on energy access and energy fuel choice, to gain insights on potential leverage intervention points that the municipality can consider in enhancing the energy access for all agenda.

- 17 causal loop diagrams visualise the key feedback loops.
- Community empowerment and representation were the key feedback loops.
- Direct electricity connections were observed necessary for legitimacy.

## Acknowledgement

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