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

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Habitat International, 56: 212-221.

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.

Keywords

complexity, slums, upgrading, urban metabolism, energy, cities

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 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 demand in illegal settlements (Gaunt et al., 2012; Madlener & Sunak, 2011), and (iii) securing revenues for utility providers from informal settlement dwellers (Borchers, Euston-Brown, & Ndlovu, 2015; Sustainable Energy Africa, 2014b). We argue that the issues listed above stem from the reduction of uncertainty to technical issues and the failure to address the uncertainty linked to the challenge of meeting unplanned and fast changing energy demand with fixed infrastructure, and to the inadequate institutional arrangements in dealing with complex multi-dimensional issues and the underlying political challenges.

The objective of this paper is to assess how uncertainty affects the analysis of energy demand in townships and which types of uncertainty are taken into account, and which are ignored, by energy policies and upgrading strategies. Several levels of uncertainty (Maxim & van der Sluijs, 2011; Wynne, 1992) can be associated with the challenges of electrification of informal settlements. These include methodological uncertainty, technical uncertainty, and epistemological uncertainty. The paper shows how upgrading policies focus almost exclusively on technical uncertainty to the detriment of a better understanding of the challenges of representing (methodological uncertainty) and defining (epistemological uncertainty) informal settlements, leading to a purported de-politicisation of upgrading policies and deepening of social inequalities. The analysis aims to demonstrate how uncertainties associated with the representation and definition of informal settlements are pivotal to the formulation of policies.

This paper considers the case study of Enkanini, an informal settlement on the outskirts of the town of Stellenbosch, South Africa. The settlement was created in 2006, when the backyard dwellers of the neighbouring Kayamandi township occupied the adjacent land. The occupation was initially negotiated with the municipality and later continued in spite of the resistance posed by the municipality (Keller, 2012). The name of the settlement, Enkanini or “taken by force,” refers to the unauthorised occupation of land through which the settlement was created. The provision of public services is limited to 70 public toilets and 32 water taps (Community Organisation Resource Centre, 2012). Electricity, waste collection services, and medical services are not provided.

The Enkanini settlement has been the target of an incremental upgrading project endorsed by the Municipality of Stellenbosch and funded by the Bill and Melinda Gates Foundation, aimed at providing rooftop solar panels to shack dwellers (iShack Project, 2012). However, the solar panels are only partially able to meet energy demand, and paraffin and gas are still widely used. Moreover, the upgrading project has not solved the tensions between the municipality and Enkanini’s dwellers in relation to the official recognition of the settlement. The case study is indicative of how technical, methodological and epistemological uncertainty affects the understanding of informal settlement dwellers needs, as well as the governance of energy provision.

The paper is structured as follows. Section 2 introduces the Quantitative Story-Telling approach used to analyse complex and fast changing systems such as informal settlements. Section 3 details the data and methods used in the case study. Section 4 presents the results of the application of Quantitative Story-Telling to the assessment of the different levels of uncertainty identified for the case of the Enkanini settlement. Section 5 highlights the limitations of technical solutions in dealing with uncertainty and socio-political challenges, and points at the insights that can be gained through the analysis of complexity.

Approach

This paper uses the Quantitative Story-Telling approach (Saltelli & Giampietro, 2015) to assess the technical, methodological and epistemological uncertainty associated with energy provision in informal urban areas. Quantitative Story-Telling addresses the challenge of dealing with multiple non-equivalent definitions of complex issues, or what Rittel and Webber (1973) have named *wicked problems* in the context of planning. Problems are defined as wicked when the problem framing that is used affects the proposed solution. Roy (2005) provides a variety of examples of how different definitions of urban informality lead to the formulation of different policies towards informal settlements, which can only partially address the challenges of these settlements.

Quantitative Story-Telling makes the link between problem framing and quantification explicit, referring to the theoretical framework of hierarchy theory. Hierarchy theory is a branch of complexity theory, which focuses on the role of the observer in the analysis of complex systems (Ahl & Allen, 1996; Allen & Starr, 1982). According to hierarchy theory, quantification is not seen as an objective representation of a given issue, but rather as the result of a series of pre-analytical choices used in framing the problem. Quantitative Story-Telling is an operationalization of hierarchy theory. We speak of story-telling in order to highlight the role of the analyst, not just as a neutral observer of self-evident phenomena, but as an active agent in the definition of what should be observed and how. Different epistemologies are analysed through quantification in order to address the following questions: what insights are gained through each problem framing? What types of uncertainty are taken into account by each problem framing? What types of uncertainty are ignored, or deliberately hidden, by the choice of problem framing?

Quantitative Story-Telling utilises quantitative information in a heuristic way in order to assess the quality of the scientific information used for policy, as opposed to using more data, larger models or more precise quantification to reduce uncertainty. The use of quantification as a means to compare different story-tellings, highlights the ambiguity and subjectivity associated with the quantification. The analysis of uncertainty (presented in the following section) draws attention to the means through which quantification is used to formalise the choice of a given scale of analysis and level of observation (Kovacic & Giampietro, 2015). This approach is particularly useful when dealing with fast changing, dynamic and complex systems.

For example, there is much uncertainty in population estimates. Population estimates cannot be precise owing to the daily occurrence of births and deaths, and migration. For this reason, the population of a country for a given year can only be an estimate of the order of magnitude. Additionally, in the case of informal settlements, large portions of the population are not officially registered (UNHABITAT, 2003) and there is a high level of mobility. Population estimates are very important for policy, as they are necessary to plan for energy demand and supply, food requirements, health and education expenditures, *et cetera*. However, any quantification below the hundreds, or thousands in some cases, is spurious (Saltelli, Guimaraes Pereira, van der Sluijs, & Funtowicz, 2013). What is relevant for policy is the order of magnitude (for example a country of 45 million people, a city of 1.8 million people, a town of 200 thousand people), rather than a precise quantification.

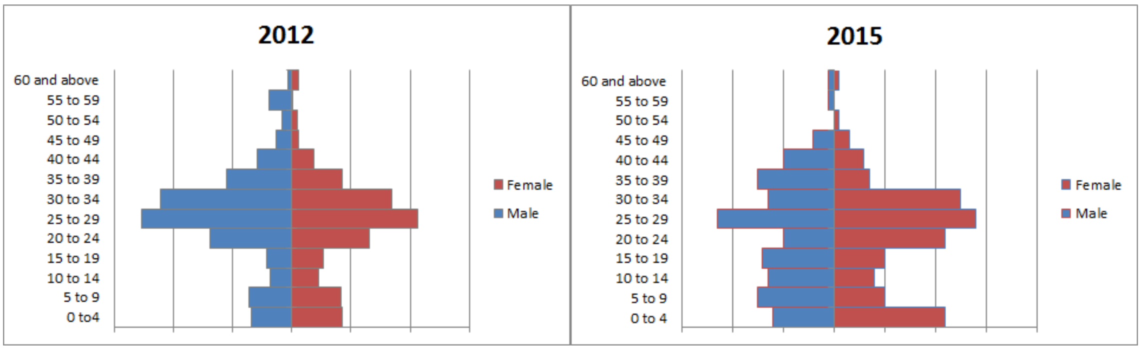
Precise quantification cannot be achieved in the context of uncertainty (Saltelli & Funtowicz, 2014). However, it is possible to observe patterns by combining approximate assessments of the size of the system with benchmarks used to characterize relevant characteristics of the system – for example, the level of consumption per capita, wage levels. It is then possible to analyse general trends and the possible clash against external constraints and/or the emergence of internal constraints. Instead of trying to tame complexity through quantification, Quantitative Story-Telling acknowledges complexity to better deal with uncertainty.

A system can be defined as complex when its representation changes depending on the scale of analysis used, and by the pre-analytical definition of its relevant attributes (Giampietro, Allen, & Mayumi, 2006). This happens in those cases where the whole is different from the sum of the parts. A complex system thus needs to be analysed simultaneously across different descriptive domains by taking into account multiple scales of analysis in order to account for non-linearity and the co-existence of different perceptions among different social actors (story-tellers).

An example of a complex system is population. Illustrating the case from South Africa used in this paper, the population of the Enkanini settlement has almost doubled in the last 3 years (from 4,500 in 2012 (Community Organisation Resource Centre, 2012) to approximately 8,000 in 2015 (own data)). However, the number of adults and children within the total has not increased in the same proportion, and the structure of the population has thus changed significantly (see Figure 1). In 2012, Enkanini was a settlement of young adults. That is, Enkanini's population could be defined as a stock, a provider of labour force that was not reproducing itself. In contrast, population growth in the last three years has been driven by the increased number of children, rather than by the influx of young adults. This change indicates that the population is starting to reproduce itself and is now turning into what Georgescu-Roegen (1971) defines as a fund; an element that reproduces itself in order to maintain its identity over time.

In this case, rather than counting the exact number of people that live in Enkanini, or the exact number of shacks that compose the settlement, it is much more useful to identify the patterns that explain how the system is changing over time. For example, job opportunities tend to generate stocks of adults, while stable living conditions tend to transform these stocks of people into funds of people (reproducing households). The consideration and integration of these two narratives – the population as a stock element focusing on the work supply that the population gives to the city or as a fund element focusing on the demand of services that the population requires from the city – is essential for the formulation of sound policies.

Figure 1. Change in population structure.
Sources: Data for 2012 (Community Organisation Resource Centre, 2012); Data for 2015 (own field research, sample size: 276 people).



According to Tainter (1990), complex societies are characterised by: (i) horizontal specialisation and diversification in functions – the number of parts (instances) and kind of parts (types) increase as societies become more complex; and (ii) vertical integration and organisation, which are needed for the different parts to work as a whole (system), as opposed to an assembly of pieces (Tainter, 1990). A simple society is one where there exist only a few occupations (hunters, gatherers, the chief, the spiritual leader, and a few more), while a complex society is one where there are thousands of different occupations and a hierarchical organisation amongst its members.

In this context, quantification can be used to identify types (for example, the taxonomy of relevant social roles found in a social system) and to measure the instances of these types (for example, the relative importance of the social roles in the population). Quantitative Story-Telling uses non-equivalent quantifications reflecting the different definitions of relevance found among the social actors. Instead of looking for precise quantitative measurements within a chosen problem structuring formalized in a given scale and dimensions, the goal is to provide rough estimates and a characterisation of different typologies making possible to discover the existence of different trends. Providing a richer characterisation of the system under study is a remedy against the risk of "hypocognition" (Lakoff, 2010) or "socially constructed ignorance" (Rayner, 2012), that is, the risk that the application of a given problem framing would determine a limited understanding of existing problems because of the filtering that it implies on alternative explanations and on the definition of relevant aspects.

Material and methods

The data for the case study presented here were collected through questionnaires, covering a sample of 100 households, equivalent to 276 people, in the Enkanini settlement. The questionnaires were designed to be somewhat redundant in order to check for missing information and data inconsistencies. For instance, respondents were asked which type of fuels they used for cooking, lighting, space heating, what percentage of each fuel they used for each activity, how much of each fuel they used per week or month and how much they spent per week or month on each fuel type. The redundancy in the questions made it possible to account for fuels (e.g. candles) that were reported only in the household expenditures, because of their very limited contribution to the energy mix of the household (e.g. lighting). Three field workers, hailing from the Enkanini community, carried out the surveys between August and September 2015. The original data were compared with secondary data from an enumeration report carried out by the Community Organisation Resource Centre associated with Slum/Shack Dwellers International in collaboration with the Municipality of Stellenbosch in 2012 (Community Organisation Resource Centre, 2012).

Using Quantitative Story-Telling for the analysis of uncertainty, different levels of uncertainty are probed in order to identify the different problem framings used to define the challenges of energy demand. This way, the positionality embedded in different representations is highlighted. Analytical choices cannot be defined independently from the observer. For example, both an informal settlement dweller and a city dweller require a small scale of analysis (fine grain), but the informal settlement dweller has an inside view and the city dweller an outside view of the informal settlement. As a result, the two observers produce non-equivalent descriptions of the informal settlement (for example, the informal settlement as the context or as a problem to be solved). It follows that the level of uncertainty that is taken into account also depends on the observer's decision of what to observe and how. The analysis of uncertainty levels makes it possible to probe the different story-tellings associated with the energy challenge of Enkanini.

Three levels of uncertainty are analysed: methodological uncertainty, technical uncertainty and epistemological uncertainty. Methodological uncertainty impacts the estimation of energy demand (Funtowicz & Ravetz, 1990) due to inadequate models and lack of knowledge of a given issue. The challenge is that the methodology or models used are unable to deal with *known unknowns*, such as estimating the population living in informal settlements, the energy demand, or how access to electricity would affect the energy mix of households in informal settlements. Methodological uncertainty highlights the challenge of analysing complex systems (Giampietro et al., 2006).

With regard to the expansion of the electric grid and of securing revenue, the uncertainty is technical (Funtowicz & Ravetz, 1990). In this case the challenges to be faced are known; related to expanding infrastructure and payment collection system, and increasing demand load and electricity supply. Technical uncertainty is therefore best explained in terms of technical bottlenecks, risk management and institutional challenges in dealing with dynamic complex systems.

Epistemological uncertainty is associated with problem framing. Problem framing entails a pre-analytical definition of what the system is and how it should be observed and measured. As a consequence, the choice of a given problem framing implies omission of alternative definitions and attributes that could be defined as relevant when adopting a different point of view. The choice of problem framing can thus generate the presence of *unknown unknowns*; that is, new dimensions of uncertainty that are not accounted for. In urban planning, the implications of the emergence of townships are *unknown unknowns*. Epistemological uncertainty is particularly relevant in explaining the failure of policies aimed at improving living conditions in informal urban settlements, which are often due to misunderstanding, inadequate problem framing, or de-politicisation (Roy, 2005) of the local context and needs.

The Quantitative Story-Telling approach is applied to the analysis of the different levels of uncertainty identified in relation to energy provision, namely: (i) methodological uncertainty of estimates of energy demand, (ii) technical uncertainty of extending electricity provision and securing revenue, and (iii) epistemological uncertainty associated with the chosen problem framing.

Results and Discussion

In this section, the results of how different quantitative representations reflect the epistemological pluralism that characterises the debate on informal settlements are presented.

Methodological uncertainty

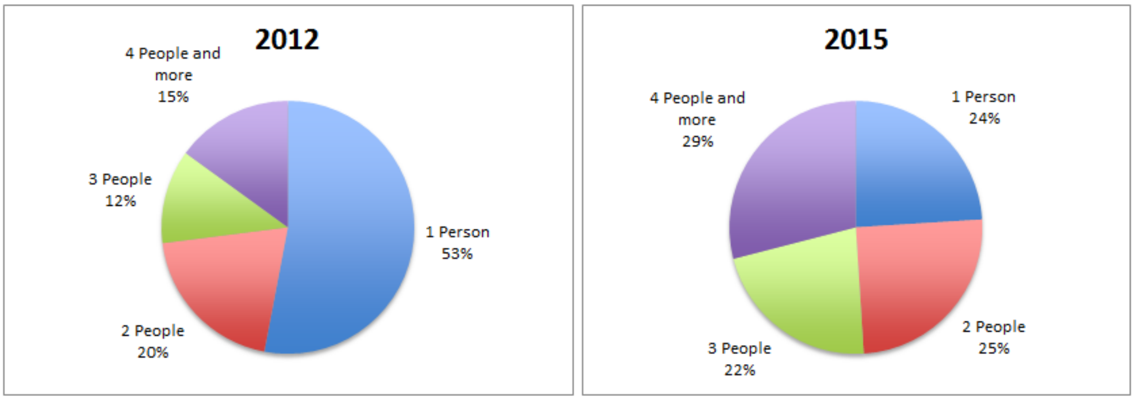
Estimating energy demand is a difficult task in informal settlements, as households that do not have legal land tenure are not entitled to public services provision (Durand-Lasserve & Royston, 2012; Payne, 2001). Therefore, there is seldom any record of their electricity consumption. In this context, methodological uncertainty is associated with the task of estimating how demand increases with population growth. Quantitative Story-Telling shifts the focus away from conventional estimation methods to the identification of general trends and the characterization of types. The first observable trend is that energy demand is not linearly correlated with the size of the population. In the case of the Enkanini settlement, the population has doubled in the period 2012 to 2015, whilst consumption of paraffin has increased by 70% (less than population growth), and consumption of gas has increased three-fold (much faster than population growth). In order to explain these trends, it is necessary to analyse the system at a lower scale of analysis, identifying which typologies can be used to explain the differences.

There are two factors that determine changes in total energy demand. The first factor is the change in the composition of households. Using a lower scale of analysis, it is possible to distinguish among the different types of households by looking at the household composition. Households may be composed of: (i) 1 Adult; (ii) 1 Adult and 1 Child; (iii) 2 Adults; (iv) 1 Adult 2 Children; (v) 2 Adults 1 Child; and so forth. Different types of household have different consumption patterns. For example the same amount of fuel used to cook food for 1 adult is also sufficient for 1 adult and 1 child, or for 2 adults. However, a household of four adults will use more fuel. Thus the energy demand is not linearly correlated to the number of household members, but rather to the type of household.

As the household composition of the settlement changes, total energy demand will also change. At least three factors have to be used to describe the drivers of changes in energy consumption: (1) taxonomy of household types; (2) the expected pattern of consumption of each type; (3) the profile of distribution of instances of households over the different types. As shown in Figure 1, the structure of the population has changed significantly in the last 3 years.

At the level of households, this structural change can be represented as a change in the household composition (see Figure 2).

Figure 2. Change in household composition
Sources: Data for 2012 (Community Organisation Resource Centre, 2012); Data for 2015 (own field work, sample size: 276 people).



The results of the questionnaires carried out in the Enkanini settlement show how energy demand varies depending on the number of people in the household. From Table 1, it can be observed that paraffin and candle use are relatively stable across all household types, whereas the tipping point for gas use occurs when there are four or more persons in the household.

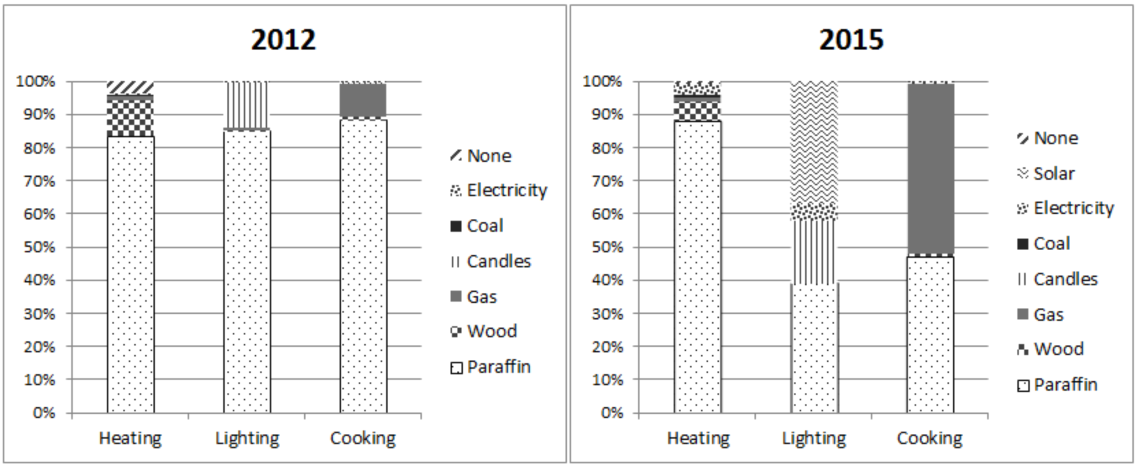
Table 1. Fuel consumption per household type

No. of people	**Paraffin** (litres)	**Gas** (kilograms)	**Candles** (units)
1	1,25	1,25	1,50
2	1,44	1,25	1,25
3	1,25	1,25	1,00
4 or more	1,25	2,25	1,38

The second factor that explains changes in energy demand is the change in the fuel mix used by households, that is, the expected pattern of energy consumption of the types. In the case of Enkanini, rooftop solar panels have been installed on approximately 60% of the shacks since 2012 (own data). The supply of electricity from solar panels is not as stable as electricity supplied from the grid, due to the solar panels' sensitivity to weather conditions and the reduced capacity of the batteries used for storage (one car battery is available per shack (Keller, 2012)). As a consequence, solar panels are mainly used for lighting and powering small appliances (television sets, charging cell phones). Paraffin is still the main fuel used for space heating (90%). The use of gas for cooking has increased significantly in the time period analysed. Figure 3 indicates the change in energy mix observed between 2012 and 2015.

Moreover, illegal connections to grid electricity via neighbours in the adjacent Kayamandi settlement (6% of households in our sample) do not significantly change the energy mix of households. The stability of connections via neighbours decreases with distance and the number of connections on the line, so that households with an illegal connection do not have enough voltage to power electric appliances. As in the case of solar power, electricity obtained via illegal connections is mainly used for lighting. Changes in the pattern of energy consumption of the whole are illustrated in Figure 3.

Figure 3. Change in the energy mix
Sources: Data for 2012 (Community Organisation Resource Centre, 2012); Data for 2015 (own field work, sample size: 276 people).



At this point, it is possible to estimate the extent to which the increase in energy consumption at the scale of the Enkanini settlement as a whole is due to the change in the household composition and to the change in energy mix. Total energy consumption can vary due to a change in the number of instances of each typology of household. Here the issue of evolution (becoming or emergence) enters into play. Changes in the overall metabolic pattern of the township can be due to the emergence of new household types, or because of a change in the technical coefficients that determine energy demand for each household type; for example, the introduction of a new energy carrier, or the use of a different type of stove. In this case, an increase in the complexity of the society, such as change in the profile of distribution of instances over types and/or new types, will change the overall behaviour of the energy demand system. An analysis of the metabolic pattern based on the combination of types, benchmarks, instances and their profile of distribution makes it possible to better handle the challenge of complexity.

For the sample of 100 households, the change in household composition accounts for 7% of the increase in the consumption of paraffin and for 9% of the increase in the consumption of gas (see Figure 4). This is due to a relative increase in the number of families with two or more people in the last three years. If the energy mix used per household is maintained or constant, the doubling of the population would imply a 110% increase in paraffin consumption and a 120% increase in gas consumption (see Figure 5).

Figure 4. Effect of the change in household composition on energy demand

Household composition 2012

HH type	Number of Instances	Consumption per HH	Total consumption per 100 HH	Consumption per HH	Total consumption per 100 HH
		Paraffin		Gas	
1 Person	53%	5	265	5	265
2 People	20%	6	120	5	100
3 People	12%	7	84	6	72
4 People and more	15%	6	90	8	120
			≈560		≈560

+7% +9%

Household composition 2015

HH type	Number of Instances	Consumption per HH	Total consumption per 100 HH	Consumption per HH	Total consumption per 100 HH
		Paraffin		Gas	
1 Person	24%	5	120	5	120
2 People	25%	6	150	5	125
3 People	22%	7	154	6	132
4 People and more	29%	6	174	8	232
			≈600		≈610

Figure 5. Effect of the doubling of the population on energy demand

Household composition 2012

HH type	Number of Instances	Consumption per HH	Total consumption per 100 HH	Consumption per HH	Total consumption per 100 HH
		Paraffin		Gas	
1 Person	53%	5	265	5	265
2 People	20%	6	120	5	100
3 People	12%	7	84	6	72
4 People and more	15%	6	90	8	120
			≈560		≈560

+110% +120%

Household composition 2015

HH type	Number of Instances	Consumption per HH	Total consumption per 200 HH	Consumption per HH	Total consumption per 200 HH
		Paraffin		Gas	
1 Person	24%	5	240	5	240
2 People	25%	6	300	5	250
3 People	22%	7	308	6	264
4 People and more	29%	6	348	8	464
			≈1200		≈1220

The increase in paraffin consumption by only 70% can be explained by the introduction of solar panels for lighting and by the increased use of gas for cooking. On one hand, the emergence of a new metabolic pattern in the energy mix to be associated with household types, has led to a relative decline in the overall use of paraffin in the informal settlement. On the other hand, the consumption of gas increased much more than expected (200%), due to the relative increase in the use of gas for cooking because of the emergence of a new metabolic pattern among the household types.

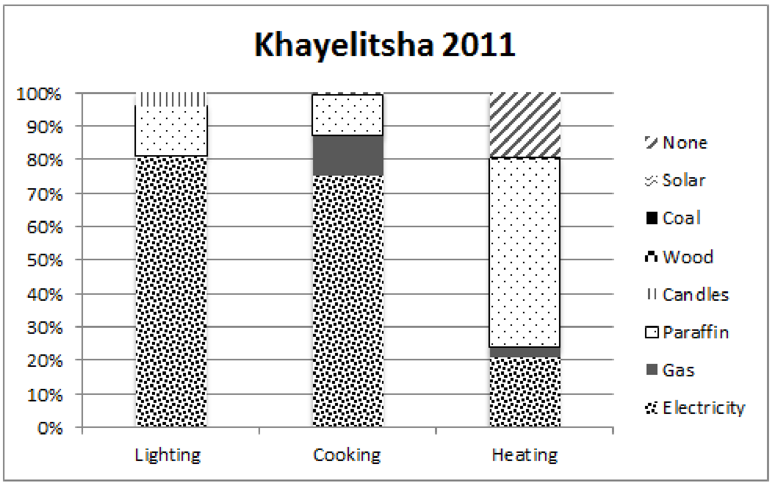
In terms of estimating electricity demand, it is important to take into account the differences in the quality of the service provision between rooftop solar panels, which is weather dependent and has limited power capacity, and electricity supplied from the grid, which is more stable and has higher power capacity. Power capacity is "*the ability to convert a flow of energy carrier input into a flow of applied power at the local scale in order to perform a defined task*" (Giampietro et al. 2014: 106). This can be measured by the power (e.g. kW) as associated with the number of exosomatic[1] devices in the case of households.

The future increase in electricity demand depends on the possibility of using electricity both for lighting and cooking, which at the moment is not possible for households using rooftop solar panels. Potential increases in electricity consumption should also be coupled with an increase in the number of electric appliances owned by households. Currently, only 5 households in the Enkanini settlement own a refrigerator. Increasing energy consumption therefore requires increasing power capacity.

The effect of the connection to the grid on the energy mix of households is illustrated with a nearby informal settlement of Khayelitsha, situated in Cape Town (see Figure 6). Even though the settlements of Enkanini and Khayelitsha have very different characteristics, and therefore a direct comparison cannot be made, it is possible to observe a general trend favouring the use of electricity over paraffin and gas. In the case of Khayelitsha, paraffin remains the main energy carrier only for space heating.

Figure 6. Energy mix of household connected to the electric grid in Khayelitsha.
Data source: (Strategic Development Information and GIS Department, 2013)

[1] The terms exosomatic and endosomatic energy were introduced by Georgescu-Roegen (1975) to distinguish between the energy that is consumed outside of the human body and the energy that is consumed inside the human body respectively.



Demand estimates can be obtained by looking at the characteristics of informal settlements in terms of typologies and expected benchmarks. The complexity and the richness of information required to describe the evolution of energy consumption of informal settlements is lost when analysing the settlement as a whole, or at just one level of analysis.

Technical uncertainty

Technical uncertainty refers to the management of risk (Knight, 1921), and unknown probabilities of known events (Wynne, 1992). Technical uncertainty arises when standard solutions have to be applied to unconventional problems. Uncertainty is not linked to missing data in this case, but to the difficulty posed by the situation or context faced. In the case of Enkanini, technical uncertainty is associated with securing revenues for utilities operating in informal settlements and with extending the electric grid.

With regard to securing revenue for utility providers, two main concerns are often cited, namely the ability of informal settlement dwellers to pay for the electricity they consume, and the use of illegal connections from nearby electrified areas (Gaunt et al., 2012). The evidence in Enkanini seems to contradict both assumptions. Only 6 out of the 100 households covered by the survey were connected to the electric grid via a neighbour, and the connection is not stolen. The dwellers pay the neighbour for the electricity they use. As a matter of fact, dwellers pay more for the connection through a neighbour than for the maintenance services of solar panels. Solar panel users in Enkanini pay a monthly fee of 150 Rand (equivalent to 11 US$) for the service, while households with an illegal connection report spending 300 Rand per month for the connection. As noted by Hardoy and Satterthwaite (1986) in relation to water, while the upper-income groups are undercharged for services delivered to their houses by public agencies, the poor pay many times as much for electric connections of poor quality from their neighbours.

It should be noted that almost all of the energy carriers used by the households have to be purchased, with the exception of wood. Households spend on average about 10% of their income on electricity and fuels, which is considered to be the threshold for energy poverty (Department of Energy, 2012). Nearly 50% of households in South Africa are considered energy poor (Ibid). This 10% represents a much higher proportion than the mean household energy expenditure of higher income countries, which was approximately 5% for the European Union at 28 countries in 2010 (Eurostat, 2015). In this case, the households show both willingness to pay for electricity provision and ability to pay. It is not possible to know whether, given the option of a connection to the electric grid, the rest of the households living in Enkanini would express the same behaviour.

Tipple (2015) discusses a number of similar unproved assumptions about informal settlement dwellers in relation to housing policy. His main point is that assumptions based on the experience of formal settlements do not necessarily apply to informal settlements. The fact that Enkanini's residents have to pay their Kayamandi neighbours for the connection to the electric line flags the emergence of a new form of vertical integration. There is a hierarchical relationship between dwellers with direct access to grid electricity and dwellers without direct access to grid electricity. The vertical integration between different types of urban settlements, the formally recognised Kayamandi and the informal settlement of Enkanini, adds to the complexity of the system. This further suggests that informal settlements are not simply a low income neighbourhood but rather another hierarchical level of residential organization that should be considered within the analysis of urban systems (Smit, Musango, Kovacic, & Brent, 2016).

It should be noted that the focus on technical issues, such as the dwellers' ability to pay, neglects the political and social challenges associated with electrification. As Roy (2005) highlights, the collection of payments may exclude the poorest section of the population, exacerbating inequality within the settlement, or may cause a problem in terms of the fixed rhythm of payments required by service providers in a context of systemic irregularity of employment. The iShack project suffers from such shortfalls itself, as only part of the residents was selected as participants without clear criteria. Regular payments are required for the maintenance of the solar panels and batteries provided. About 35% of employed adults in Enkanini have temporary contracts and may not be able to meet monthly payments throughout the year. As a result this excludes the underemployed, unemployed and extremely poor households, leading to the creation of differentiated residencies within Enkanini to which the technical approach is blind.

The second challenge relates to the uncertainty associated with the provision of electricity. Provision of electricity entails facing a number of issues, for example informal settlements may or may not be built close to existing infrastructure; the increasing density and number of shacks may require a continuous upward revision of connection points and transmission lines; multi-story shack development may lead to a higher demand load on existing lines, and so forth.

In the case of Enkanini, the situation is quite simple: connection to the electric grid would require no additional infrastructure, since the settlement is located close to an industrial area on one side, and to the Kayamandi settlement on the other side, which are both connected to the electric grid. However, the uncertainty regarding the building and maintenance of infrastructure remains.

When new infrastructures need to be built in order to extend the electric grid to remote areas, densely populated areas are easier to serve than settlements that develop in the form of low density urban sprawl. Higher density is seen as beneficial in terms of sustainability and efficiency (Sustainable Energy Africa, 2014a). High density and unplanned urbanisation, however, may make it difficult to install the infrastructure needed to expand the electric grid (Madlener & Sunak, 2011). Mayumi (1991) argues that the intensification of human activity and densification of land use are only possible due to the use of fossil fuels (primary energy resources that do not need to be produced), which allow for a temporary emancipation from land and from the need of producing energy resources with a very low land and labour productivity (Mayumi, 1991). In other words, modern society is facing a conundrum determined by high performance standards obtained by a fossil fuel driven economy and the lower-density and lower labour productivity obtained when using renewable energies. This is evident in the case of Enkanini, as the rooftop solar panels installed make it possible to supply electricity avoiding the dependence on fossil energy but at the same time do not provide the same performance obtained by the supply of electricity through the grid.

It is evident that the sustainability of energy solutions in the long run does not depend solely on technology. The organisation of society is closely dependent on the energy sources that it uses: high quality[2] energy sources, such as fossil fuels, make it possible to increase the pace of economic activity, increase land and labour productivity, and reduce the requirement of land use. The use of low quality energy sources, such as solar radiation, wind, and animal power, limit the pace of growth of economic activity to the availability of land and labour force, and limit the increase in land and labour productivity. As a consequence, the electrification of informal settlements requires decisions about the type of social organisation and economic model one wants to reproduce given the available technology, rather than a decision about the technology one wants to use.

Epistemological uncertainty

The consideration of the relationship between society, political arrangements and technology raises the issue of how to deal with epistemological uncertainty. Epistemological uncertainty is the uncertainty generated by the existence of relevant knowledge claims that are excluded by the given representation. Epistemological uncertainty can arise from: (i) the existence of multiple stakeholders with legitimate but discording goals, and (ii) the existence of multiple dimensions of analysis.

Roy (2005) identifies four different epistemologies used in the context of informal settlements, which portray informality as (i) a matter of space and physical conditions both of settlements (poor housing) and of dwellers (poor, uneducated, unemployed), (ii) as opposed to formality, legal rights and land tenure, (iii) as a temporary state of emergency that needs to be regulated, and (iv) as a localised problem in dichotomy with global problems, which needs to be addressed at the local scale. Both the epistemology of space and the epistemology of emergency state are present in the case of Enkanini, the former leading to a focus on technical infrastructure provision and the latter leading to the regulation of payments for electricity provision, irrespective of the formalisation of social inequalities that may follow.

[2] Energy quality refers to the ability of a primary energy source to produce good and services (Cleveland, 2014).

Epistemological uncertainly is evident in the contrasting assessment of the pros and cons of informal settlement electrification from the point of view of informal settlement dwellers, and of the municipality. For informal settlement dwellers, connection to the grid would allow for a considerable improvement of living standards (less reliance on paraffin, more services based on a more stable and abundant electricity supply), security (provision of street lighting) and fair pricing for electricity (compared to the higher fees paid for illegal connections via neighbours). For the municipality, the electrification of Enkanini would imply its official recognition, transforming it into a formal township. Besides the initial infrastructural costs linked with the extension of the electricity cables, the municipality would also be required to provide the settlement with waste collection services, health services and schools, increasing and protracting the costs over time. A number of political issues may arise regarding the matter of land tenure, and the municipality's dependence on the nation's only electricity supplier, Eskom. In the long run the provision of services may create an immigration pump – a friendly niche will attract more and more immigrants into the municipality – which the municipality may or may not be able to manage in terms of financial and organisational capacity.

In addition to the existence of multiple perspectives, multiple dimensions have to be considered by the same stakeholder. For example, from the municipality's point of view, the provision of public services such as electricity, waste collection and health care can be seen as a cost in monetary terms, but also as a prevention policy in terms of public health, given that the current open air waste dumps in Enkanini pose a serious health hazard to the population of Enkanini and for Stellenbosch, with respect to the pollution of the local rivers system.

Epistemological uncertainty relates to issues that are not accounted for; the *unknown unknowns* (Wynne, 1992), and is thus absent from the list of problems to be dealt with in the electrification of townships. Nevertheless, the uncertainty regarding the most appropriate way of framing the issue is often key, and can be used to explain why many policies failed to achieve their goals. In the case of Enkanini, two story-tellings about electrification can be identified: one referring to electrification as a technical issue – how to supply electricity to the household, and the other referring to electrification as socio-political integration –recognition of the settlement as part of the urban system requiring adequate provision of services.

The attempt to solve the dwellers' claim for access to electricity with the installation of rooftop solar panels (justifying action on the basis of the technical narrative) did not solve political tensions. This story-telling was endorsed by the municipality of Stellenbosch but not endorsed by the local story-tellers, Enkanini's dwellers. Within the technical story-telling, access to electricity is just a matter of technology and therefore solar panels offer a solution. On the contrary, the story-telling of socio-political integration sees access to electricity as a means towards the official recognition of the settlement. This story-telling implies a very difficult decision for the municipality, because it would open the door to the possibility of generating a powerful immigration pump and may amplify the growth of illegal settlements in the area.

Conclusion

This paper proposes the use of the Quantitative Story-Telling approach in order to analyse the uncertainty and the complexity associated with the electrification of informal settlements. The choice of story-telling leads to a specific problem framing and creates a situation of hypocognition (Lakoff, 2010). The pre-analytical definition of what to observe and how, implies that other *whats* and *hows* are excluded from the representation of the problem and its possible solution(s). Three levels of uncertainty are identified: methodological uncertainty referring to the *how* of dealing with complex systems such as informal settlements (estimating energy demand), technical uncertainty referring to the *how* of electrification (extending the electricity grid and securing revenue), and epistemological uncertainty (referring to the *what* in the definition of the issue) as a technical problem rather than a political problem.

The installation of rooftop solar panels on some of the shacks of Enkanini has contributed to the improvement of living standards in the settlement, as can be observed from the relative decrease in the use of paraffin and its associated health risks. Nevertheless, the initiative offers only partial relief. The framework of analysis developed in this paper shows that the installation of solar panels considers only technical uncertainty on how to provide electricity to informal settlement dwellers, but fails to address methodological uncertainty (electricity demand is not met) and epistemological uncertainty (solar panels do not address the issue of formal recognition of the settlement, service provision by the municipality, and the political challenge of managing the growth of informal settlements and alleviating social inequality), thus de-politicising the issue of electricity provision and reducing the understanding of the needs of Enkanini's residents to a physically and territorially confined lack of infrastructure.

Informal settlements are complex and fast changing systems, which make it difficult to identify the so-called best course of action, or win-win solutions. A multi-scale analysis based on the identification of: (1) a taxonomy of household types; (2) the expected pattern of consumption (energy mix) of each type; and (3) the profile of distribution of instances of households over the different types, helps explain changes in consumption patterns without having to use sophisticated models or having to solve the problem of missing data in energy planning. Methodological uncertainty can thus be addressed with the use of soft quantitative methods, which make it possible to test hypothesis and develop scenarios based on heuristic tools.

The deployment of solar panels in Enkanini reduces the issue of access to electricity to a technical problem and the understanding of the settlement to its physical infrastructure (Roy, 2005), and fails to challenge the social and political order by which marginalisation and poverty are created in Enkanini. We argue that the focus on technical uncertainty responds to what Tversky and Kahneman (1974) define as cognitive ease, that is, the tendency to substitute a difficult question for which one does not have an answer with an easier question for which an answer is available. Technical uncertainty can be solved through upgrading programmes. Methodological and epistemological uncertainty have no obvious solutions, and require a messy governance approach (Strand & Cañellas-Boltà, 2006).

The irresponsiveness of public policies to move beyond informal settlement upgrading programmes can thus be understood as a preference for technical solutions, which are unable to respond to more complex problem framings and multiple epistemologies. In her study of philanthropy, Kohl-Arenas (2016) points out how the preference for technical solutions systematically fails to alleviate poverty. The choice of technology is intrinsically linked to the social organisation and structure where this technology is used. For this reason, Rommetveit and colleagues speak of socio-technical structures (Rommetveit et al., 2013). We argue that upgrading policies not only fail to address higher levels of uncertainty, but by doing so also fail to address the socio-political adjustments (Benessia & Funtowicz, 2013) required by complex transitions.

Acknowledgements

The research leading to these results was supported by the research project “PARTICIPIA – Participatory Integrated Assessment of Energy Systems to Promote Energy Access and Efficiency” funded under the EDULINK II Programme by the European Development Fund (EDF) and the Development Co-operation Instrument – Relations with South Africa (DCI), under grant agreement no. DCI-AFS/2013/320-333. We are very grateful to the two reviewers who greatly helped improve the quality of this paper.

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