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Towards a multidimensional framework for measuring household energy access: Application to South Africa

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ABSTRACT

Debate continues around appropriate metrics to measure energy access for the poor. Whilst the underlying principles of energy access, for example affordability or safety, may be universal, the ways in which we define or measure these may vary across different regions. Much of the literature on metrics focuses on standardisation of measures that can have universal applicability. Whilst important for the international community, there is also a need to develop metrics that reflect contextual specificities to be useful to in-country stakeholders. This study has sought to develop a multi-dimensional framework of indicators, with the focus on how to operationalise these in contextually distinct ways that respond to local issues. A framework is developed representing four key dimensions: fuel use, affordability, safety and reliability. The paper offers methodological insights into the development of each and they are developed for the South African context. This illustrates the ways in which a particular context influences both how an indicator is conceptualised, as well as the choice of methods to operationalise it. Indicators aim to be responsive to, and informed by, localised factors such as the particular energy user and supply contexts, the policy environment and data availability.

Introduction

Energy is a crucial input into social and economic development. Internationally there is more focus than ever on achieving universal access, as seen in the UN's Sustainable Development Goals (SDGs) inclusion of the goal to ensure access to affordable, reliable, and sustainable energy for all. Measuring progress thereon is crucial. But consensus around appropriate metrics remains outstanding. Delineating 'energy poverty' or 'access to modern energy services' is a complex and contested matter. Although various definitions, and their associated critiques, exist, a definitive framing remains outstanding (Serwaa Mensah et al., 2014; Bhanot and Jha, 2012; Bhattacharyya, 2012; Bazilian et al., 2010). The debates in the literature demonstrate many of the features of what Gallie (1956) first referred to as an 'essentially contested concept'. This term refers to situations where, despite widespread agreement about the existence of a concept, further definition or conceptualisation is disputed. Such concepts are characterised as being internally complex in character, subject to modification in light of changing circumstances, and involving value-judgements with different users of the concept allocating different weightings to its constituent elements (Gallie, 1956).

One of the key challenges of measuring energy access lies in operationalising a concept that is inherently multidimensional and, to a large extent, contextually defined (Groh et al., 2016; Sovacool et al., 2012; Pachauri and Spreng, 2011). Perhaps because of this complexity, many metrics remain dominated by supply side indicators such as access to an electricity connection or a modern stove. These are useful and necessary, but there is broad acknowledgement of the need to augment them with an understanding of the energy services they provide and how these are used (Bhanot and Jha, 2012; Sovacool, 2011; Practical Action, 2013; Nussbaumer et al., 2012; ESMAP, 2015). Shifting this emphasis is probably best illustrated by the definition of energy poverty as "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development" (Reddy, 2000:44).

Energy access, as a concept or a target to be achieved, is relatively defined. It is shaped by a variety of contextual factors, including geography, economics and culture. But many frameworks place a strong emphasis on standardising the ways in which we understand and measure access across all contexts. Whilst not disputing the usefulness of international metrics that enable cross-country comparability and target setting, universally set thresholds often end up producing information that is neither appropriate nor useful to country level stakeholders. To suppose that we can establish universality in what is affordable across all countries is perhaps misguided. This article seeks to shift the emphasis away from pursuing common standardised thresholds, towards indicators that can be flexibly developed depending on context, audience and purpose.

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Consensus on common methodological approaches is, however, far from conclusive. What is clear from the diverse literature on the subject is that while there may be some agreement on *what* to measure, for example 'safety' or 'affordability', *how* to measure such concepts remain contested. The concept of affordability, although undisputed in terms of its importance, has reached no real consensus in the energy poverty literature on a sound methodological approach to measure it. Likewise 'energy safety' – despite often being a primary justification for energy access initiatives, is often absent in measurement frameworks or dealt with in a very cursory manner. The paper presents a framework of four indicators to conceptualise and measure household energy access. It discusses methods to operationalize each dimension and demonstrates the development of each indicator applied to the South African context, in order to illustrate the importance of contextual input into indicator choice and operationalisation. Various contextual specificities shape what needs to be communicated, the institutional context and policy priorities, as well as the quality and availability of data. These considerations influence what indicators to use and how to construct them. Measurement frameworks for country-level application will always, to some extent, be contextually defined. The focus of this paper is on household uses of energy and does not consider measuring energy for productive uses. Although this is also an important consideration, it is outside the scope of this paper.

The paper is structured as follows. Section 2 reviews the literature to gain an overview of existing approaches to defining and measuring energy access. These conceptual schemes are then used to develop a measurement framework for this study that is presented in section 3. Section 4 then presents a more detailed discussion of the development of each indicator, describing methods and presenting the results of their application to two poor settlements that were surveyed in Cape Town, South Africa. This indicator development aims to critiques existing methodologies, and describes some of the issues related to data constraints, adapting measurements to reflect local conditions and defining and setting of thresholds. Finally Section 5 discusses the overall framework results in light of previous debates on methods, frameworks and measurement challenges.

A review of approaches to measuring energy access

Energy is a means rather than an end in itself. What is of importance is less the service itself than the human development outcomes that are theorised to be associated with its use. These can include improved health, wellbeing, education, etc. Measuring these outcomes is, however, a complex undertaking. To measure attribution, one must identify causal mechanisms and control for other contextual factors that may also influence outcomes (Rogers, 2008). Development is, however, a non-linear process, and is typically influenced by a vast number of environmental and other factors (Bazilian et al., 2010). Not surprisingly, such studies measuring outcomes, although they do exist, are limited (Pachauri and Spreng, 2011). Whilst not disputing the importance of understanding these, it may not be realistic to cost-effectively measure and monitor outcomes at large scale.

The dominant framing used to conceptualise and measure energy access has traditionally been from the supply side. Indicators relate to the penetration rates of 'modern' or commercial fuels or end-user technologies (Pachauri and Spreng, 2011). Nussbaumer et al.'s (2012) multi-dimensional energy poverty index (MEPI), for example, measures access to cooking and lighting by the types of fuels used and appliance ownership. These types of supply indicators provide essential information in a simple and easily communicable way that enables comparability across regions, but they are also limited in what they convey. They do not, for example, tell us about the quality of services that users actually derive. They cannot illustrate where poor supply reliability compromises the use of electricity services, nor where on-going usage of biomass fuels may continue in conjunction with electricity use, offsetting the intended health benefits of electrification.

Energy poverty encapsulates multiple dimensions such as consumption, affordability and service quality. Measuring these aspects is, however, substantially more challenging than measuring supply. Defining consumption levels that meet basic needs is inherently complex and is both geographically and temporally influenced. No definitive consensus exists on basic needs thresholds for food for example, nor on what energy consumption levels would be required to provide for those at a household level (Pachauri and Spreng, 2011; IEA, 2012). Any definition of basic needs necessarily involves a degree of subjectivity and value judgements (Pachauri, 2011; Bhanot and Jha, 2012).

There are energy access measures that do attempt to set thresholds for consumption. The IEA's (2012) definition of energy access uses regional average electricity consumption as a benchmark to measure appropriate consumption levels. Barnes et al. (2011) estimate an energy consumption poverty line based on surveys of existing demand profiles of households. Both of these assume that the regional average or existing demand represents an adequate amount of consumption. Practical Action (2010) proposed minimum thresholds for energy services themselves, specifying desired indoor ambient temperatures, lumens of light required, fuel for cooking etc. Cultures, climates and socioeconomic factors can, however, all influence these, implying that standardised thresholds developed in one context many not be transferrable to another. These thresholds are also dynamic over time as incomes and/or aspirations change (Bhattacharyya, 2012). Energy access cannot be understood as something a household either has or doesn't have, but is rather a continuous and dynamic process over time, with various dimensions and intermediate 'states' of access (Practical Action, 2013). It might best be understood as a process of increasing the energy consumed over time and the quality of fuels and appliances used. The appropriateness of static thresholds will therefore always be somewhat limited, and yet of course, they are still necessary. Trade-offs exist in taking different approaches in terms of what information one would like to convey and practical considerations. These approaches are more onerous in terms of the cost and practicality of measuring and collecting data, and often the reason supply-side data, easier to capture and monitor continues to dominate metrics (Bazilian et al., 2010).

Reddy (2000) put forward a definition of energy access in the UNDP's World Energy Assessment report that places the focus firmly on the energy service itself and the desired attributes it should encompass. These include safety, affordability, reliability, user adequateness and environmental considerations. This conceptualisation of modern energy services has found wide support and is reiterated in many studies (Bhanot and Jha, 2012; Pachauri, 2011; Sovacool, 2011, Bhattacharyya, 2012; ESMAP, 2015; Gonzalez-Eguino, 2015). It is notably neutral on fuel or technology, but rather places attention on the attributes of the services that people derive from different fuel/technology combinations.

One of the most notable contributions towards operationalizing this definition is in the recent multi-tier tracking framework developed by ESMAP in the Sustainable Energy for All's Global Tracking Framework report (ESMAP, 2015). Consisting of several measurement frameworks measuring electricity and cooking services, the attributes framework measures capacity, availability, reliability, quality, affordability, legality, convenience, and health and safety for electricity, cooking and heating services. This approach to measuring energy services has many distinct advantages. It is multi-dimensional and brings into focus the various inter-related factors that influence 'access'. Scores for each are measured on a continuum of different thresholds specified in tiers, rather than with a single binary threshold. It also captures important aspects related to quality – a dimension typically absent in most metrics (Bazilian et al., 2010).

The operationalisation of some the indicators in this framework do not, however, have a coherent conceptual or methodological grounding. The safety indicator for example is measured by past accidents and perceptions of future risk by householders (ESMAP, 2015). This offers little concrete information about the presence of current risk factors in the household, and of what type. Likewise the setting of a reliability threshold, proposed at a certain number of hours a day, may not be suitable to all country contexts. What is politically and publicly acceptable in terms of daily outages is highly variable across different countries. Reliability metrics need to be informed by an understanding of the context and the impacts on populations rather than merely number of hours of outages. Factors such as the time of day outages occur and what alternative backup fuels households use during outages are key to understanding impacts. The tracking framework is also heavy on data needs, computationally complex, and relies on household survey based data with little reference to the potential for information errors associated therewith (Groh et al., 2016). It also captures only electricity use and cooking services. By focussing on a particular energy sources and service, it does not capture energy use in its entirety in the household. This means it may not capture vital information on what other fuels may continue to be used in conjunction with electricity, for example paraffin for lighting.

This framework, like many others, also presents the same challenges with regards to the usefulness of externally developed indicators to country level stakeholders. In a recent review of the tracking framework with respect to Bangladesh, Groh et al. (2016) encountered limitations in the applicability of certain indicators and their thresholds to that context (Groh et al., 2016). Whilst metrics that enable universal comparison of country level progress are certainly important, it is key to remember that energy poverty is a relative rather than absolute concept, and is contextually defined. Thus integrating a degree of flexibility in data collection and methods to enable the concurrent development of country specific thresholds is important. The emphasis should be on building principles and methods for indicator development, rather than just setting thresholds at which indicators are set.

This review illustrates the wealth of conceptual work that has developed around measuring energy access. Whilst contestations remain, some key principles for measurement purposes do emerge. Firstly, measurement frameworks should, as far as possible, communicate the multi-dimensional nature of energy access. Secondly, they should represent a range of 'intermediate states' of access rather than a binary. Thirdly, they should not enforce undue technology biases but be flexible in considering a range of fuels and technologies. And finally any measurement framework needs to be responsive to the context for which it is developed. In light of the gaps highlighted above, this study aims to develop a multi-dimensional framework that focuses on attributes of energy use at a household level, and that can be operationalized in a flexible and contextually relevant way. This is presented and discussed in the next two sections.

A multi-dimensional framework for measuring household energy access

This study builds on the conceptualisation of energy access, first outlined by Reddy (2000) and more recently in ESMAPs global tracking framework report. The key dimensions highlighted by this previous work are physical access, affordability, health and safety, quality and reliability. These dimensions have been consolidated into four attributes in this study: fuel use, affordability, safety and reliability. These are considered to provide a comprehensive overview of both demand and supply aspects of a household's state of access to modern energy services. Trade-offs always arise between the pursuit of comprehensive indicators and the realities of data limitations and computational complexity. For this reason some attributes, such as quality and capacity, have been excluded. Neither of these indicators proved feasible to operationalise in terms of the data obtainable from either households or suppliers. Dimensions of health are measured and recorded on in the safety indicator. In contrast to ESMAPs approach, the attributes are conceptualised at the level of the household rather than as attributes of a particular service, such as cooking, or particular energy carrier, such as electricity. Focusing on the household encapsulates the totality of energy use. Given that fuel stacking is a common way in which households use and combine energy sources, focusing on particular services or fuels may miss the implications of others.

The framework is briefly presented here before a more detailed discussion on each indicator in the following section. The methodological discussion is deliberately discussed within the South African context to illustrate the development of indicators that are relevant to local priority issues, and contextual specificities. The framework was tested using data collected in household surveys in two low-income urban communities in Cape Town, South Africa called Manenberg and Masilunge.

Fig. 1, shows each indicator together with the proposed metrics to operationalise it. Each was calculated individually using different methods, and then normalised to a score of 1 to enable easy visualisation on a single graph. Zero on the graph indicates poor access and a score closer to 1 represents good access. The framework aims to be simple and avoid undue complexity, so as to enhance its accessibility to a wide range of stakeholders. The indicators were not aggregated into a single score for several reasons. First, aggregating involves a loss of information and abstraction into a single value that may not be easily understandable on its own. Keeping the indicators separate also directs attention to the multi-dimensional nature of energy access. Although there are undoubtedly varying degrees of inter-relatedness between attributes, this paper has not attempted to address this issue computationally. The objective of this framework is to highlight and make 'visible' to stakeholders the distinct dimensions of a complex whole. The framework aims not to introduce undue technology biases, nor rule out specific energy carriers (e.g. biomass). Rather, decisions on appropriate fuels and technologies get made as the indicators are constructed based on the particular context for which it is developed. Thus any rating of fuels for the first indicator, fuel use, would be different depending on the context in which they are derived. Scores are developed along a continuum rather than a binary and no predefined thresholds are set.

Operationalising the indicators and their application to the South African context

This section discusses the methodological development of the four indicators together with their application to the South African local context. South Africa has a high electrification rate, particularly in urban areas. Since the early 1990s the South African government has implemented a large-scale electrification programme. The city of Cape Town has residential electrification rates of approximately 90%. There are concerns, however, about the extent to which this is adequately meeting households' demand for energy services and the on-going use of other undesirable energy sources, such as candles and paraffin. Access to energy remains almost exclusively conceptualised in South African policy as access to grid electricity and there has been little concerted policy attention directed towards other fuels, like paraffin and biomass, or to addressing wider objectives such as safety or reliability of energy

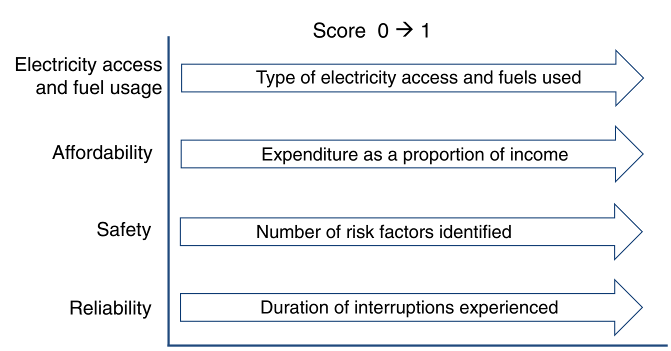

Fig. 1. Overview of the measurement framework.

services (Matinga et al., 2014). A reliance on supply side metrics to represent access, feeds into a discourse that is dominated by the provision of fuels and infrastructure, as opposed to *services*.

Fuel use indicator

The first of the four indicators aims to give a simple overview of the fuels households use. It provides information related to multiple fuel use, or energy stacking, and aims at rating the 'desirability' of fuels in use along a continuum. Multiple fuel use is an important and yet often poorly captured aspect of energy use. The on-going use of traditional fuels, with their negative health and safety impacts, can undermine the intended benefits of clean energy investments and is an important issue to understand.

When rating the energy sources to develop this indicator, the starting point should be one of technology and fuel neutrality. Many energy sources can arguably deliver a 'modern energy service' (although perhaps to differing degrees along a continuum of 'modern'), provided that the energy delivery system is well regulated, and meets certain standards. What is deemed an acceptable fuel in one context may differ in others. For example wood use could be rated differently depending on whether it is sustainably harvested and there are clean cookstoves in widespread use compared to where traditional fire methods of cooking are used and harvesting is non-sustainable. Thus, it is essential that this scoping exercise is informed by local contextual conditions. This rating requires consideration of more than just the fuel itself but the entire delivery configuration of actors, institutions, equipment, and resources (Jaglin, 2014). This should include whether there are safe and efficient appliances in use, whether a reliable distribution system for the energy carrier is established, if an appropriate regulatory framework exists, and whether usage practises of households in relation to the fuel present any other problematic issues.

Developing an indicator for South Africa

The most widely used household energy carrier in Cape Town is grid-connected electricity, but households access the grid in a variety of ways. Most have their own formal connections, but where this is absent due to legal or planning restrictions, households generally self-connect either by illegally tapping into the grid or buying from neighbours. Although these forms of access present concerns, from both a utility and a user perspective, they do address gaps and shortfalls in the formal market provision of electricity and provide a valuable form of access for households. From a household welfare point of view an informal connection, even if used only for lighting, still provides a superior quality lighting service to either candles or paraffin – and reduces exposure to their associated safety risks. Nonetheless, concerns about informal and illegal connections should not be ignored. Safety, reliability and affordability of energy services are all compromised to some extent with these connection types.

The survey results revealed that other fuels in use were liquefied petroleum gas (LPG), paraffin, wood, coal and candles. These were typically used in conjunction with electricity. Considering these energy sources in the South African context, 'adequate' energy supply configurations only exist for grid-connected electricity, LPG and potentially for solar electricity. Solar was, however, not used by any households in the sample and was scoped out. Candles, wood, paraffin and coal all have negative implications associated with their use and do not provide a safe or modern energy service in the South African context (Matinga, 2011; Kimemia and Annegarn, 2011; Kimemia et al., 2014; Muller et al., 2003; Le Roux et al., 2009; Cowan, 2008).

In order to construct an indicator for fuel use in South Africa, the following classification of fuels were used:

0 – No access to electricity.
1 – Informal or illegal electricity connection.
2 – Metered electricity connection and usage of inadequate fuels.
3 – Metered electricity connection and only usage of adequate fuels.

Each household was given a score between 0 and 3 to measure a scaled hierarchy of access to different types of energy carriers. The overall score for each settlement area is calculated on the sum of the proportion of households in each tier multiplied by the score for that category. The score is calculated as follows:

$$Score = \Sigma\,(Proportion\ of\ households * Category\ scale)/3$$

Fig. 2 indicates the results, based on the survey data, for each settlement surveyed.

Affordability indicator

Affordability is a much-cited component of energy access, but does not easily lend itself to objective measurement and verification. The concept is certainly related to objective variables such as income and the prices of the goods or services in question, but also includes a degree of subjectivity. It is, to a large extent, 'socially constructed', influenced by personal priorities related to consumption patterns (Matinga, 2011; Niëns et al., 2012). Different personal preferences, and variations in individuals' thresholds of what they deem acceptable to spend, means that any notion of affordability can vary.

Niëns et al. (2012:1) propose that affordability involves securing a good, service or a standard of living, at a price that 'does not impose, in the eyes of a third party … an unreasonable burden on household incomes'. Two commonly used methods to define an 'unreasonable burden' are the catastrophic payment method and the impoverishment method (Niëns et al., 2012). The former calculates the ratio of the payment for the good to a household's total resources, the payment regarded as unaffordable when it exceeds a certain proportion. The latter determines what the residual income would be after paying for a good, and whether such payment would move a household below a poverty line.

In the energy access literature, a commonly used expenditure burden is the former catastrophic payment method, with 10% of household income often set as a 'reasonable' threshold of energy expenditure (DoE, 2012; Bazilian et al., 2010; Boardman, 1991). Despite the common usage of this method there is often no accompanying justification for the level at which this expenditure burden is set (Bazilian et al., 2010). Expenditure burdens may also be misleading as to the actual welfare of households, as they say little about whether a household consuming an amount of energy deemed affordable (e.g. spending less than 10% of their income) is actually consuming enough to meet their needs. Illustrating affordability in purely financial terms can only represent a part of the concept. Nevertheless, such metrics do help to delineate a concept that, because of its subjective elements, would otherwise make comparison difficult.

The energy purchasing behaviour, income elasticities and expenditure burdens on poor households are poorly understood in general. For many countries, there is often no detailed microeconomic research into household energy expenditure patterns at different income levels and thus little evidence to guide the setting of an appropriate energy affordability threshold. Defining an unreasonable burden therefore entails a value judgement. But whose judgement? Studies into other aspects of poverty have often attempted to resolve this by comparing subjective and objective measurements to inform an appropriate threshold. This approach has been widely used in setting income poverty lines by comparing objective household poverty estimates with self-assessments of whether people consider themselves poor (Posel and Rogan, 2013; Singh-Manoux et al., 2005; Wagle, 2007; Pradhan and Ravallion, 2000). Drawing on both objective and subjective measures can contribute to a more comprehensive understanding of complex and subjective concepts. This technique is applied to the setting of expenditure thresholds for the affordability indicator. Subjective self-assessment of energy affordability by householders are used to validate locally appropriate energy expenditure/income ratios.

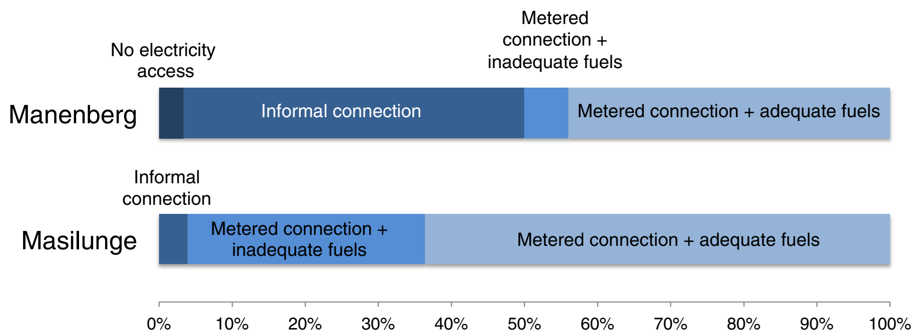

Fig. 2. Overview of fuel use in each area.

Developing an indicator for South Africa

A household questionnaire was used to ask households whether they felt they could afford their energy requirements all of the time, some of the time, or could not afford enough energy to meet their needs. This was then compared to their income/expenditure ratios calculated from the survey data. The two measures are compared in Fig. 3. On average, across both samples those households that felt they could afford energy spent on average 10% of their income on energy. Those who answered 'sometimes' spent on average 18% of their income, and those that answered negatively to subjective question of affordability spent on average 20% of their income. The two approaches illustrate consistency between higher expenditure burdens and higher self-reported affordability. Utility data on electricity purchases provided an interesting way in which to interrogate respondent bias in the sample. In Masilunge, where perceptions of affordability were higher, respondents tended to under-estimate their electricity spend. In contrast, in Manenberg, where perceptions of affordability were lower, respondents tended to over-estimate their electricity spend.

A score for the affordability indicator is shown in Table 1. In constructing a score, no single threshold of affordability was defined; instead the score represents a continuum of different levels of expenditure/income ratios. A comparison of indicator scores constructed with expenditure income ratios and subjective self-assessments is shown.

Safety indicator

All energy sources and carriers can potentially present safety risks to users. But the types of risks different localities face are highly variable. Depending on the type of energy carrier, risks could include respiratory and other health impacts from pollution, burns, fires, electric shocks and poisonings. The vulnerability of populations to energy risks is influenced by environmental, social, political and economic factors, and poverty is often associated with an increased incidence of energy-related risks (Maritz et al., 2012). The rate of deaths among children from burns, for example, is twice as high in developing countries as developed ones (Gevaart-Durkin et al., 2014).

Safety indicators and measurements have not been well developed in the literature to date. Reliance on simplistic indicators such as 'ownership of an improved cookstove' are common. These over-simplified proxies do not represent the full scope of risk or give information about whether or how a stove is used, whether children are kept away, whether traditional cooking methods are continued in conjunction with use of an improved stove. Assessing risk is both a function of the likelihood of an event occurring and the consequence thereof. In turn consequences are influenced by both the impact of the event and the vulnerability of the population.

The approach taken in this study was to first scope the range of common energy risk factors in the South African context. This was then used to construct a questionnaire aimed at identifying the incidence of physical, behavioural and environmental factors in the home that could influence the likelihood of energy health or safety hazards. The limitations of using survey questionnaires to identify risk factors are acknowledged. Certain social and environmental risks, such as alcohol abuse, are difficult to capture this way, but it remains at this stage the most practical means of conducting risk profiling.

Developing an indicator for South Africa

In South Africa, burns and fires are among the most significant energy-related hazards, particularly in urban informal settings. Common risk factors contributing to these incidents include paraffin stoves, candles, alcoholism, and high abuse and assault rates. Environmental factors also contribute - housing materials and high-density living conditions allow fires to spread more quickly. Small homes often make it hard to keep children away from cooking activities. Dense and unplanned settlement layouts make access for fire response teams difficult (Gevaart-Durkin et al., 2014; Maritz et al., 2012).

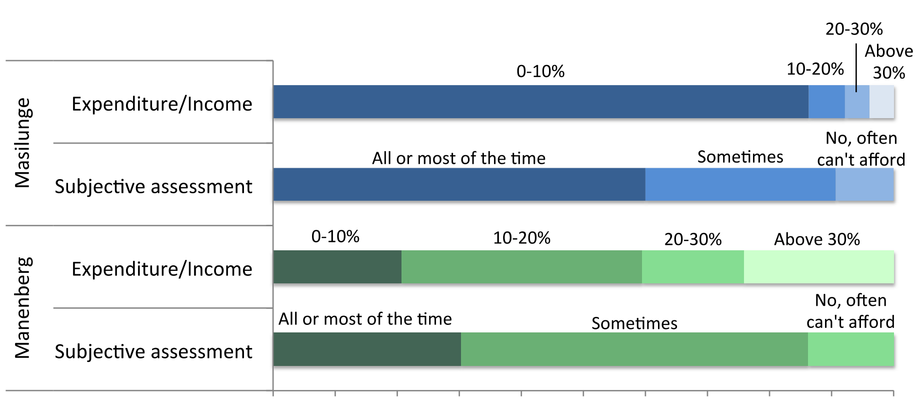

Fig. 3. Objective and subjective measures of affordability.

Table 1
Calculation method of scores for each measure.

Expenditure method		*Subjective method*	
1	Less than 10%	1	Yes
2	10–20%	2	Sometimes
3	20–30%	3	No
4	Above 30%		
Score $= \Sigma\,(P^1\ x\ S^2)/4$		*Score* $= \Sigma\,(P^1\ x\ S^2)/3$	

Comparison of scores using each method

Expenditure method		Subjective method	
Manenberg	0.64	Manenberg	0.72
Masilunge	0.94	Masilunge	0.84

[1]P – proportion of households in each category
[2]S – scaled score for each category

Another significant energy risk is the inhalation of toxins from the combustion of certain energy carriers. This includes not only biomass fuels, but also paraffin. Research on exposure patterns to pollutants from paraffin used for cooking in settlements in Durban, found that paraffin users experienced significant health risks from exposure to benzene and nitrogen dioxide (Muller et al., 2003). Accidental ingestion of paraffin by children is another major energy hazard (Balme et al., 2012; Gevaart-Durkin et al., 2014). Despite the declining usage of paraffin in South Africa's residential energy mix it remains the single most common substance in childhood poisonings in the country (Balme et al., 2012).

A lack of safety awareness and knowledge amongst users heightens the consequence or impacts of accidents. For example, although paraffin is not toxic in all cases, incorrect response by a parent or caregiver (for example giving milk to induce vomiting) significantly increases the risk of chemical pneumonitis and other complications (Gevaart-Durkin et al., 2014). A number of ‘energy myths’ abound which can worsen impacts of events. Common misperceptions include that putting toothpaste on a burn or using water on a paraffin fire, instead of sand (the correct method).

Five different categories of risk factors were scoped. These either affect the probability of an event occurring, or affect a household's capacity to cope with such an event. These include:

- Use of unsafe fuels – defined for the local context as users of wood, candles or paraffin;
- Indoor air pollution – measured as paraffin use only, no respondents reported using wood indoors;
- Lack of fire safety knowledge – measured as respondents knowing the correct response to a paraffin fire, knowledge of correct response if clothes catch fire, and how to treat burns correctly;
- Electrical safety risks – measured as overloading plug sockets and exposed electrical wires around the house;
- Behavioural risks – measured as leaving children unattended in the home, leaving cooking and heating appliances unattended, or stoves located near flammable items.

In calculating a score for this indicator, no weighting process was adopted. Whilst certainly an important consideration, in the absence of a detailed risk assessment and quantification of variables such as probability of occurrence and impacts, a theoretically sound weighting process could not be constructed. Therefore this indicator was calculated based on the number of risk categories that a household scored in the questionnaire. The score is calculated as:

$$Score = \Sigma\,(proportion\ of\ households\ x\ no.of\ risk\ factors)$$

Fig. 4 indicates the type and prevalence of different risks in each sample. Electricity-related risks were the most prevalent. This is unsurprising given that it is the most commonly used energy carrier. Fig. 5 simply illustrates the proportion of households that scored in one or more of risk categories, together with the indicator score. These scores for each sample were 0,55 and 0,71 for Masilunge and Manenberg respectively. Together, the graphs show that not only are most energy risk factors more prevalent in Masilunge households, but that Masilunge households typically displayed a greater number of risk categories than the Manenberg sample. It allows for easy identification of what interventions could be prioritised in which areas.

Reliability indicator

Poor reliability of electricity supply is a challenge common to many developing countries (Eberhard et al., 2008; Foster and Steinbuks, 2009). Interruptions are caused by generation capacity constraints, network design (for example feeder length), under-investment in maintenance of the distribution network, the theft of cables and vandalism, weather-related events, and encroachment of trees and vegetation on lines (Cameron and Carter-Brown, 2012; Dyer and von Holdt, 2008). In the low-income residential sector, unreliability not only impacts households directly but also has wider socio-economic impacts. Particularly frequent interruptions have the potential to undermine the positive socio-economic gains from investment in electrification. Despite its importance, data constraints and the lack of methodological consensus on devising reliability metrics makes measurement challenging.

The electricity industry uses a range of measures for electricity service quality. These typically describe the frequency and duration of interruptions, number of customers affected, or amount of power not supplied. Although useful for measuring utility performance, an index measuring the number of hours a customer is without service does not measure the actual *impact on consumers*. But measuring impact on consumers is fraught with difficulty. Some negative impacts may only occur over the long term, or be experienced above a certain threshold of lost hours of service (Küfeoğlu and Lehtonen, 2015). Apart from the frequency and duration of incidents, factors such as the time of day of outages, the types of activities that are interrupted and whether these can be postponed are also relevant (Nahman et al., 2014). For low-income residential consumers some of the *potential* impacts of unreliability may be direct financial loss if productive activities are undertaken, spoilage of food, inconvenience, social and economic costs of using alternatives like candles and paraffin, as well as the increased vulnerability to crime if interruptions occur at night. Very bad reliability may impact a full transition away from undesirable energy carriers.

There are few studies and little consensus around methodologies for measuring impacts in the residential sector. Most studies focus on the cost of interruption to the customer in different sectors, with a strong focus on monetisable losses. But in poor households, electrification is often a social investment – thus translating impacts into financial terms may miss or understate many non-monetisable impacts that are nonetheless important or relevant for policymakers to understand. There are also examples of other methodologies using price discrimination metrics such as willingness to pay, willingness to accept certain service levels, or the direct worth of an outage (Küfeoğlu and Lehtonen, 2015; Herman and Gaunt, 2008). However it not clear that these actually provide a robust methodological approach to understanding impacts and thresholds. There is no previous work in the South African low-income residential sector investigating impacts of electricity outages that may provide insight into understanding appropriate thresholds. Nor is it necessarily appropriate to use values from other countries. Impacts can be highly variable across different contexts, influenced by factors such as methods of heating, climate and availability of alternative energy carriers (Nahman et al., 2014). Acceptable levels of service quality may also differ significantly for various regions and customer types.

Developing an indicator for South Africa

In light of data and methodological constraints, this study used service interruptions as a means of understanding reliability in the

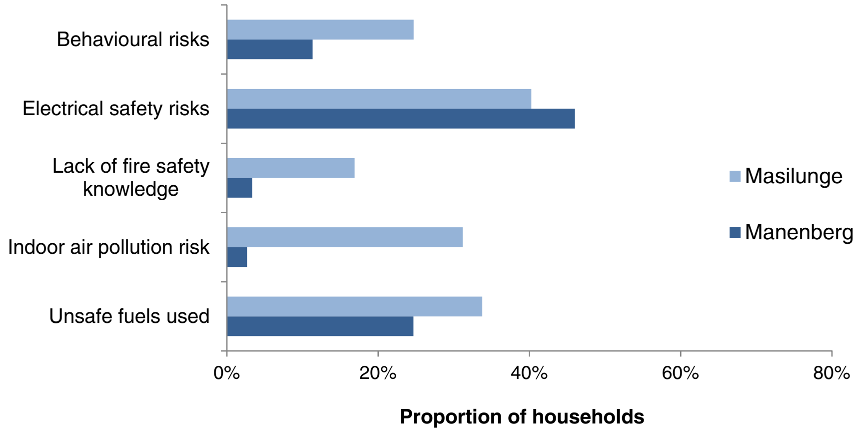

Fig. 4. Type and prevalence of risk.

low-income sector, acknowledging its limitations. In future more methodological work on understanding the impacts of interruptions on households would be a useful contribution to this area. In this study data on frequency and duration of interruptions over time was used to develop a comparative benchmarking approach to understanding reliability across different geographic areas. Data was collected from two sources – the distribution utility and households. Both had limitations. Distribution utilities in South Africa do not collect data on all types of interruptions. In Cape Town data exists for incidents of long duration that occur on high (HV) and medium voltage (MV) lines. The available data thus excludes momentary interruptions as well as incidents occurring on low voltage (LV) lines. Typical events that can affect LV lines include weather, trees or vegetation interfering with lines, theft or vandalism as well as technical faults.

Fig. 6 shows the average frequency and duration of higher voltage incidents over a five-year period obtained from the utility. The study was undertaken prior to the commencement of loadshedding in South Africa caused by national generation shortages. Overall the picture shows a good level of supply in both areas, with only a few hours of service lost per year, and is not suggestive of major negative impacts. The data omissions for incidents on LV lines mean this could be an under-estimate, but this cannot be reliably confirmed. Whilst these data omissions are less pressing in a large metropolitan municipality such as Cape Town that has relatively well-maintained distribution networks, many smaller municipalities in South Africa present a very different picture. In these areas huge backlogs in the maintenance of distribution infrastructure lead to much higher rates of service interruptions (Dyer and von Holdt, 2008). In these areas, such data omission may be more serious.

To support the distribution utility's data on frequency and duration, a subjective assessment of householders' perceptions of reliability was undertaken. The survey asked households to estimate the frequency of interruptions they experienced in a typical month. Householders' estimates of monthly outages were significantly higher than the utility data. Average estimates were 2.6 times in a typical winter month in Manenberg and 1.8 times in Masilunge. In comparison, the utility recorded between one and three incidents over a whole year. The disparity could be indicative that the utility data under-estimates outages because of excluding momentary interruptions and incidents on LV lines. However self-reported data in surveys on recollections about past events must also be treated with caution. Accuracy can be affected by recall bias, especially in relation to emotive topics. Service delivery and electricity outages are highly politicised and inflammatory issues in South Africa. The tendency for respondents to exaggerate negative events or losses in this circumstance cannot be discounted (Küfeoğlu and Lehtonen, 2015).

The indicator was calculated as the number of hours lost to interruptions as a proportion of total hours over a five-year time period. A score of 1 would indicate no interruptions. A score of 0,95 was calculated for Masilunge and 0,96 for Manenberg.

$$Score = 1 - (\Sigma\,(hours\ lost/total\ hours)/5)$$

Summary and policy implications

Fig. 7 presents the overall framework results for the two sample communities surveyed. A higher score indicates a better state of 'access' in respect of that particular dimension. The aim is not to make a definitive judgement overall of a household being in our out of energy poverty. Rather the framework serves to communicate where areas of relative deprivation lie and implications for policy. The benefit of developing indicators is to summarise a diverse range of information about complex

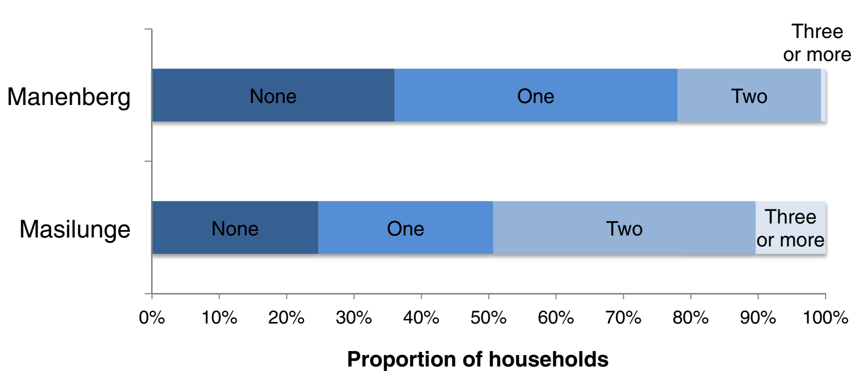

Fig. 5. Proportion of households with number of risk categories.

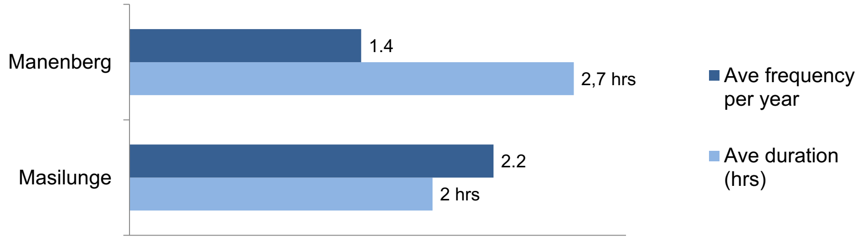

Fig. 6. Utility data on service interruptions.

issues in a concise and accessible manner. It enables both communication and comparison. The framework aims to communicate a broad range of energy related information to stakeholders in a visually compelling, easy to understand way. Using a dashboard of several indicators brings attention to the diverse range of policy objectives that energy access policies should consider. It also reveals the diversity in issues that different areas face, challenging assumptions about blanket approaches to interventions.

The two household samples, whilst both poor, illustrate significant variation in the type and severity of issues they experience, as seen in Fig. 7. The results suggest there might be different policy priorities in each area, for example around safety in Masilunge or affordability in Manenberg. Affordability is a topical issue in South Africa given the significant price increases of electricity since 2008. Manenberg scored much lower than Masilunge on this indicator. Not only do they spend a greater proportion of household income on energy, but they also do not receive as much tariff protection against price rises. This is because distributors use consumption based targeting methods to allocate subsidies, and Manenberg's higher consumption levels exceed the subsidised consumption brackets. This higher consumption is very likely driven by bigger household sizes measured in this area and multiple households sharing meters. Their higher consumption does not correlate with being less poor. In fact the opposite - average income levels of both samples were very similar but household size much larger in Manenberg. This evidence supports concerns about the limitations of using consumption-based targeting mechanisms in isolation to allocate subsidies (Palmer and Jooste, 2013).

Despite South Africa's high electrification rates, this multidimensional framework illustrates that electrification, on its own, is not a panacea for all household energy issues. This is highly relevant to policymakers in South Africa, who continue to follow a singular supply-based approach to energy access. In Masilunge, despite virtually all sampled households having a metered connection, paraffin use continues, which with its various negative externalities, compromises other outcomes related to health and safety. Energy health and safety has long been a neglected aspect of South African energy policy. The results from this small study suggest a range of risk factors are present in poor households. Whilst electrification has undoubtedly improved the risk profiles of many households, electricity carries with it its own set of risk factors that should not be ignored. Many of the risk factors identified in the survey could be mitigated through more public awareness and information campaigns, specifically around electrical safety, fire safety knowledge and the hazards associated with paraffin.

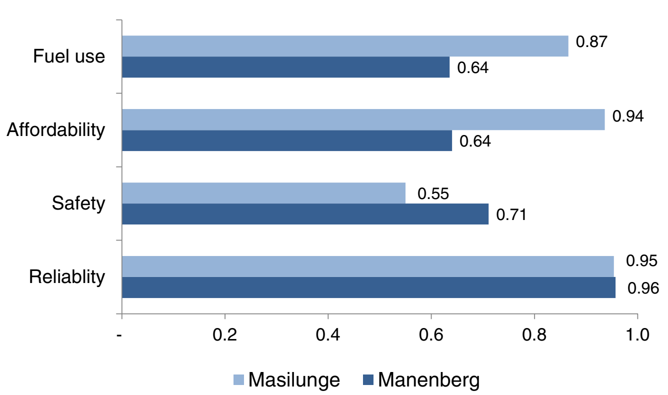

Fig. 7. Summary of energy access indicators.

Whilst utility data suggests that reliability in both areas is good, this is contradicted to some extent by householders' perceptions and satisfaction ratings, particularly for Masilunge. Given that there are data gaps, there is potentially a need for more research to investigate this issue further. The reliability indicators are a first step, but would benefit from both better data and more work on developing approaches to understand the impact of interruptions on households. This may require further detailed survey work in the low-income residential sector to better understand how households are impacted by service interruptions. Although the existing data picture for this indicator is incomplete, reporting on it still has value in bringing visibility both to an under-reported aspect of energy access, and to the limitations in current utility monitoring systems. To better measure the level of interruptions experienced by customers would require both more extensive monitoring systems but also increases in the organisational and IT capacity of local governments to manage them.

The multi-dimensional metrics shows the diversity of issues and deprivations that different areas face, which can be useful in developing and prioritising interventions for different localities. Representing energy access in a more holistic manner facilitates a more nuanced discussion around the targeting and prioritisation of different energy-related interventions for policymakers. The results suggest that South African energy policy for poor households needs to target multiple objectives including affordability, safety and reliability; and that these must apply to all fuels that are in use – not just electricity. South Africa's singular pursuit of electrification and consumption subsidies has not resulted in achieving wide-scale 'modern energy access' for all households. Whilst an improved evidence base is a very necessary input into improving policies, this paper does not attempt to suggest that evidence is, on it's own, sufficient to induce policy change. Unlike data collection and analysis, policy formulation and implementation are neither linear nor methodical (Najam, 1995). The policymaking process is affected by many factors, like politics for example, which are beyond the scope of discussion for this paper. Nonetheless appropriate policy formulation is not conceivable unless it is based on robust and appropriate evidence that is easily communicable to a wide range of stakeholders.

Conclusion

This study has demonstrated the value of developing metrics that are both multidimensional and contextually responsive to supporting better policymaking on energy access for the poor. Whilst the underlying principles of energy access may be universal, when it comes to setting thresholds, the local context is paramount. The operationalization of each indicator here has considered the particularities of the user and supply contexts, the policy environment and the intended audience for the indicators. This article has sought to contribute to the methodological discussion on how to operationalise various dimensions of energy access.

There remain, however, important further contributions to metrics debates. One key argument this article seeks to advance is the importance of nuancing measurement frameworks to be responsive to contextual conditions. This is not to underplay the usefulness of universal measurement frameworks that enable cross-country comparisons. But it is to acknowledge that indicators are a communication tool, and those who use them need to be mindful of the objectives and audiences for which they are developed. The type of information that is useful at an international level, may be different to what is useful at a national or sub-national level.

Some of the key principles that influenced the development of this measurement framework were firstly that it be flexible in the type and number of fuels it should capture, that it should communicate different degrees of access rather than visualise it as a binary. The practicality of data collection and availability has also been a key input into choice of methods. Considerations around data collection, or the robustness of user-generated information collected in household surveys is central to methodological discussions, and yet often absent. The value going forward is for practitioners and academics from other countries to apply these methodologies and principles to other contexts to advance the understanding of the frameworks relevance and wider applicability.

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