What are we measuring? An empirical analysis of household electricity access metrics in rural Bangladesh

Sebastian Groh [a,*], Shonali Pachauri [b] Narasimha D. Rao [b]

[a] Microenergy Systems, Technische Universität Berlin, Hardenbergstr. 16–18, D-10623 Berlin, Germany
[b] IIASA, Schlossplatz 1-A-2361 Laxenburg, Austria

ABSTRACT

Measuring energy access through binary indicators is insufficient, and in some cases even misleading. In this work, we critically evaluate the World Bank's multi-tier framework (MTF) to measure household electricity access using a household survey in rural Bangladesh. We argue that the MTF addresses multiple objectives, thereby offering less value as a single composite index than as a set of dimensions along which to evaluate different aspects of electricity access. We test the robustness of the framework to alternative specifications as regards the choice of attributes and tier thresholds. The study shows that access measurement is highly sensitive to changes in parameter values, the application of different algorithms, and data availability. We also discuss the wider implications of applying the framework to current electricity access intervention programs in Bangladesh, provide feedback on the MTF's design, as well as suggest potential improvements for its application in the future.

© 2015 International Energy Initiative. Published by Elsevier Inc. All rights reserved.

Introduction

Recently, there has been growing interest in support of the sustainable energy for all (SE4ALL) goal of achieving "universal access to modern energy services by 2030" (Ki-moon, 2011). This has culminated in the recent uptake of universal access to affordable and clean energy as part of the *Global Goals For Sustainable Development* (Global Goals, 2015). These developments necessitate a robust set of measurement tools to track progress toward achievement of this goal. However, at least three issues still remain largely unclear — what we mean by access, what is useful to measure to track access, and how to design the right metrics to measure it. What is increasingly clear and widely agreed is that simply having an electricity connection or a modern cook stove is insufficient and incomplete measures of energy access (AGECC, 2010; Practical Action, 2013; IEA/WB, 2014). That is, any measure of energy access should contain multiple dimensions to reflect its multi-faceted nature.

The World Bank's Energy Sector Management Assistance Program (ESMAP) has been mandated to develop a new framework for measuring energy access. Their newly developed measurement approach is referred to as the multi-tier framework (Banerjee et al., 2015). It has been heralded as a new "milestone" in energy measurement (Bensch, 2013). The multi-tier framework (MTF) assesses energy access for households,

productive entities, and communities along several dimensions of access, referred to as attributes (see Fig. 1). Tier assignments along these individual attributes are aggregated by different decision rules to determine the overall tier assignment, which defines the level of access enjoyed by the household.

In this paper, we critique the proposed MTF for electricity access using a case study of 230 households in Bangladesh to illustrate our arguments.[1] We use the MTF as a vehicle to explore effective ways to measure household electricity access, because the MTF seems to be the most advanced framework available. Our main premise is that conceptual clarity and communication about what is being measured are critical to the evaluation of an appropriate metric. With this view, we argue that the MTF addresses multiple objectives, thereby offering less value as a single composite index than as a set of dimensions along which to evaluate different aspects of electricity access. In particular, a subset of attributes characterizes electricity supply, while others, related to consumption, characterize aspects of household energy poverty. The latter depend on the former, but are also influenced by a number of other household attributes. We argue that while both concepts – electricity supply and household electricity poverty – are multi-faceted and require the type of approach embodied in the MTF, they require separate metrics. We also discuss the pros and cons of the

---

* Corresponding author.
  E-mail addresses: groh@ztg.tu-berlin.de, sgroh85@gmail.com (S. Groh), pachauri@iiasa.ac.at (S. Pachauri), nrao@iiasa.ac.at (R. Narasimha).

[1] For the sake of clarity and focus, the present paper only deals with one dimension of energy poverty, namely electricity access for households, despite acknowledging an important demand for cooking and heating energy, and equally important productive and community needs.

Multi-tier Matrix for Access to Household Electricity Supply

ATTRIBUTES			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
	1. Capacity	Power[1]		Very Low Power Min 3 W	Low Power Min 50 W	Medium Power Min 200 W	High Power Min 800 W	Very High Power Min 2 kW
		AND Daily Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		OR Services		Lighting of 1,000 lmhrs per day and phone charging	Electrical lighting, air circulation, television, and phone charging are possible			
	2. Duration	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 1 hrs	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration < 2 hours
	4. Quality						Voltage problems do not affect the use of desired appliances	
	5. Affordability					Cost of a standard consumption package of 365 kWh per annum is less than 5% of household income		
	6. Legality						Bill is paid to the utility, prepaid card seller, or authorized representative	
	7. Health and Safety						Absence of past accidents and perception of high risk in the future	

[1] The minimum power capacity ratings in watts are indicative, particularly for Tier 1 and Tier 2, as the efficiency of end-user appliances is critical to determining the real level of capacity, and thus the type of electricity services that can be performed.

TABLE ES.2

Multi-tier Matrix for Access to Household Electricity Services

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Tier criteria	Not applicable	Task lighting Phone charging	General lighting Television Fan (if needed)	Tier 2 AND Any medium-power appliances	Tier 3 AND Any high-power appliances	Tier 4 AND Any very high-power appliances

TABLE ES.3

Multi-tier Matrix for Electricity Consumption

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Annual consumption levels, in kilowatt-hours (kWh)	<4.5	≥4.5	≥73	≥365	≥1,250	≥3,000
Daily consumption levels, in watt-hours (Wh)	<12	≥12	≥200	≥1,000	≥3,425	≥8,219

Source: Bhatia & Angelou, 2015

Fig. 1. Multi-tier matrices for household electricity access (2015 version).

definitions of individual dimensions and their method of aggregation, and suggest alternatives, where relevant. Using the example of our case study from Bangladesh, we test the robustness of the framework to alternative specifications of the choice of attributes and tier thresholds. We also discuss the wider implications of applying the framework to current electricity access intervention programs in Bangladesh. We finally conclude with our learnings from the application of the framework in Bangladesh, and provide feedback on the MTF's design, as well as suggest potential improvements for its application in the future. In particular, we argue for moving toward a framework focused more on measuring the actual service level a household with electricity enjoys rather than the current supply and consumption focus of the MTF that undermines efficiency considerations and rapidly innovating decentralized solutions.

The paper is organized as follows. The Measuring electricity access section provides a brief description of a few key approaches to measuring energy access and presents the essence of the MTF as well as a generic critique. The Applying the MTF in rural Bangladesh section briefly presents a country overview of Bangladesh and a descriptive analysis of the households surveyed in Bangladesh. It further applies the MTF to the case of Bangladesh followed by a qualitative and

quantitative critique. The Analysis and discussion of results section analyzes and discusses the results of applying the MTF and includes recommendations on how to improve the MTF. Lastly, the Conclusion section summarises our findings.

Measuring electricity access

Efforts so far

This section highlights a few key examples of the recent efforts and approaches to measuring energy access. More comprehensive reviews can be found elsewhere (Banerjee et al., 2015). The predominant criterion for measuring electricity access to date is the binary indicator estimated as the population share lacking access to an electric grid connection (IEA, 2010). At times this measure is supplemented by estimates of the number of people who suffer from an intermittent electricity supply, although "intermittency" itself lacks a clear definition (AGECC, 2010). Several alternative metrics have been put forward. Other uni-dimensional indicators include minimum energy consumption thresholds (Modi et al., 2005) and income-invariant energy demand measures (Barnes et al., 2011). Multi-dimensional approaches include the Multidimensional Energy Poverty Index (MEPI) (Nussbaumer et al., 2013), or the Total Energy Standard (TEA) (Practical Action, 2012). Recent reviews and comparative studies on different energy poverty indices include those by Pachauri (2011), Khandker et al. (2012) and Bensch (2013). Many of the current indicators measure electricity as an output (e.g. lack of access) rather than an outcome, which better reflects service needs and welfare gains (Pachauri and Spreng, 2011). This is mainly due to the fact that an accurate measurement of the service level is very challenging given the diversity of electricity applications, and heterogeneous target groups (household, micro-businesses and hybrid forms). Nonetheless, despite high data requirements, "there is a growing consensus that measurements of energy access should be able to reflect a continuum of improvement" in the services it delivers (IEA/WB, 2014).

It is generally believed that electricity is the preferred choice for lighting and running appliances. For a user, it usually should not matter what type of supply system delivers electricity (e.g., grid, or off-grid) unless social status symbols and connotations are at play (e.g. perception of SHS as second class electrification option vs. the image of the grid as providing full power access) (Schützeichel, 2015). Of more importance is the quality of the electricity service. If we look at poverty as an "absence of sufficient choice" (Sen, 1999), according to the capability approach, we need to pin down individual welfare components and assess how they interact as multidimensional causes of development and deprivation. For instance, using the concept of an energy poverty penalty, Groh (2014) shows how a lack of access to affordable energy services, a deprivation, can lead to a situation where people are trapped – or at least delayed – in their capability to achieve welfare improvements. However, these deprivations are conceptually distinct from the electricity service conditions that may influence them, and therefore require different metrics. It is, therefore, important in defining metrics to communicate their purpose. For instance, Shyu (2014) reflects on the importance that a minimum amount of electricity for basic human needs should be assured. This is a normative criterion for one dimension of energy poverty — a basic minimum. An indicator that measures total connected electricity load, then, would be one potential indicator to track energy poverty, but not electricity supply. The latter may influence connected load, such as from a physical capacity constraint in electricity connections. In that case, a capacity constraint would be the appropriate electricity supply indicator.

The ESMAP multi-tier framework in brief

The candidate MTF distinguishes between multiple indices starting from the overall energy access index to indices based on households,

productive use engagements and community facilities again followed by sub-indices (pls. refer to *Appendix I Hierarchy of Energy Access Indices* for details). This study focuses on household access only, but addresses microbusinesses to the extent they are home-based. The household electricity access index includes three indicators, electricity supply, electricity service, and electricity consumption. Each indicator includes a set of attributes, which are shown below in Fig. 1.

The MTF has undergone several changes, in the indicators used to measure specific attributes of access, the thresholds that determine their tier assignment, as well as in the computation rule used to combine the different attributes into a single index (*Appendix II* shows an example where different indicator values apply). We compare several decision rules, including the most recent available decision rules, provided by ESMAP.

Each matrix includes a specific set of attributes. Indicators used to measure specific attributes are either binary or measured along a graded scale. Each attribute has a decision rule to determine its tier assignment. The lowest tier score among all attributes becomes the final tier assignment according to the latest decision rule. A household can be assigned to different tiers across the different matrices. Since the majority of the small stand-alone solar lighting systems certified by the *Lighting Global*[2] program initiated by the International Finance Corporation (IFC) do not qualify for even a tier 1 assignment based on the capacity attribute in the multi-tier matrix for access to household electricity supply and that for electricity consumption, a fractional measurement between tier 0 and 1 has been suggested to reflect less than tier 1 access. Both aggregated and dissected analyses are possible. The subsequent section discusses each matrix and its assigned attribute(s), as well as combinations of them based on a qualitative and an empirical assessment of applying a variety of decision rules that have been used in previous MTF versions.

Generic critique of the MTF for household access to electricity

An old management principle states that *what you measure is what you get*. But a prior question to be answered is, what do we actually want to measure? The MTF for household access to electricity states here that it wants to go *beyond connections* and also encompass the "quantity and quality aspects of improvements", later specified as the "amount and quality of electricity delivered" (Bhatia and Angelou, 2015, p. 1 and p. 4). This definition already reflects conceptual ambiguity. The term quality should refer to "the characteristics of [...] a service that bear on its ability to satisfy stated or implied needs" (ASQ, 2015). In the case of electricity, quality can be interpreted as comprising a number of attributes, including those in the supply attribute matrix, such as reliability and duration. However, quality is itself defined as one specific attribute of electricity supply (voltage), which may cause confusion to those not familiar with electricity industry jargon. Quantity, on the other hand, reflects consumption, which depends on household demand, and is not just a property of the "electricity delivered". Furthermore, the notion of quantity undermines any goals of energy efficiency, which has gained increasing attention with the advent of super-efficient appliances (Craine et al., 2014; Phadke et al., 2015). The matrix on electricity service actually measures access to household electricity appliances, which is again closer to a consumption metric than a supply metric. Consumption also seems over specified, by appearing explicitly in the consumption metric, and being somewhat implied in the capacity attribute of the supply metric and in the service (or appliance) matrix, since different types of appliances have very different ranges of consumption (e.g., consider a phone charger vs a TV). In sum, both the objective and operationalization of the MTF indices seem to combine electricity supply with energy poverty, and the indicators themselves have some amount of redundancy and ambiguity.

---

[2] More information can be found under https://www.lightingglobal.org/.

Applying the MTF in rural Bangladesh

In this section, we evaluate the MTF against the survey results to assess how effectively the indicators differentiate households, and reflect their actual conditions. Note that we do not know whether this sample is generally representative of household conditions in Bangladesh, let alone elsewhere. The MTF needs to be tested against a broad range of conditions globally to test its usefulness. The following critique should be considered a first step in this process, without any implications of generalizability.

Short country overview of Bangladesh

Recent metrics suggest that globally about 17% of the world population or 1.166 billion people lack access to the electricity grid. Most of this unelectrified population resides in Sub-Saharan Africa and South Asia (87%), and in rural areas (85%) (IEA/WB, 2014). With its 66.6 million off-grid people, Bangladesh ranks third among the countries with the highest electrification deficit and has been considered a high impact country to reach the SE4ALL goals. In 1971, the year of its independence, a mere 3% of the population of Bangladesh had access to grid electricity. Today, the share has increased to almost 60%. In the last couple of years Bangladesh's GDP has been growing at a steady rate between 6% and 7% (World Bank, 2013). In its development plan, titled *Vision 2021*, dated half a century after its struggle for independence, the Government of Bangladesh (GoB) has made the provision of access to electricity and achieving economic and social well-being of all citizens through a low carbon strategy a central goal (GoB, 2012). Universal access to electricity by the year 2020, with improved reliability and quality, is its declared goal. However, the GoB does not specify what it means by universal access. Should every Bangladeshi be at least tier 2, 3, 4, or even tier 5 as defined by the MTF? To highlight the complexity of measuring access, many of the on-grid population of Bangladesh, outside the capital city, may not fulfill the duration attribute for an assignment to a tier 3 level due to frequent load shedding, and a lack of access to back-up power supply. In extreme cases, such households might even get assigned to a tier 0 level, meaning no access at all, despite statistically being on the grid. At the same time, the question arises how the globally acclaimed SHS program, with its close to four million installations[3] to date (IDCOL, 2014) performs against the candidate measurement framework? The same question applies to the Rural Electrification Board's (REB) grid electrification program through its electrical cooperatives, the so called Palli Bidyut Samity (PBS) that for the most part is considered an equally great success (Khandker et al., 2009). Moreover, IFC and GIZ recently announced the Lighting Bangladesh program as part of Lighting Global with the goal to pave the way for the implementation of small stand-alone solar lighting systems in those households that so far could not be reached through other measures (IFC, 2015).

Survey description

For testing the MTFs, a sample of 231 Bangladeshi households were surveyed. Field selection was performed in a top down way, aiming to reflect diversity in terms of geographical location, weather conditions, remoteness, and culture. One random district was drawn from the Northern (Lalmonirhat), Central (Manikganj) and Southern (Bhola) part of the country (see Appendix IV). Within the respective division, an area was chosen where the Rural Service Foundation[4] has a regional

office (Rangpur, Manikganj and Bhola). Within the customer base of the regional offices, the sample was drawn based on the following criteria in order to have a diverse set of users (see Appendix IV for a sampling overview):

1st order past repayment performance,
2nd order system size,
3rd order income activity.

From the stratified groups a random selection was drawn. The remaining sample was randomly chosen on-site based on vicinity criteria. Data was collected based on the generic underlying questionnaire of the MTF provided by ESMAP, with slight country specific adaptations and extensions (see Supplementary material 3 for the detailed questionnaire).[5] Of the total interviewed households, the different electricity access types apply ranging from national grid access to no primary access (candles etc.) as shown in Table 1.

About 5% of the sample reported using multiple primary energy sources which is often referred to as energy/fuel or technology stacking (Brew-Hammond, 2010) and explains why total access points is bigger than the number of households sampled. National metrics suggest that 43% of rural households currently lack access to grid electricity in Bangladesh. While the sample selected in this study is by no means representative of rural Bangladesh, a comparison suggests that the communities selected in the study have lower national grid access than that of the average rural.

MTF decision rules

In this paper, we test six possible decision rules/algorithms for assigning tiers to households within different frameworks. A framework refers here to the respective metric (e.g. electricity supply; services etc.) whereas the decision rules or algorithms refer to the applied rule for the assignment of each household to its respective tier based on its performance on the individual attributes (e.g. capacity; duration; etc.):

a. Electricity supply (2014) — simple algorithm
The simple algorithm assigns a household the minimum of the tier assignments assessed for each attribute. The underlying questionnaire for the empirical analysis of this paper is based on the values of this version. The framework is similar to the latest version described under f. and shown in Fig. 1. It applies the same decision rule but follows different graduation levels for the tier assignment (e.g. affordability graduation is binding from tier 2 level onwards (2014 version) and not only from tier 3 level onwards (2015 version)). The complete framework is shown in *Appendix II*.

b. Electricity supply (2014) — complex algorithm
The underlying framework remains the same here as above (a.). However, the decision rule has been altered. Instead of using exclusively "and" criteria which makes each graduation value binding, it makes use of "or" criteria wherever deemed useful. This allows the framework to become more flexible as a short coming in one attribute does not necessarily bring down the overall tier rating. It also incorporates an alternative affordability criterion, namely that relative electricity expenditure is lower than 10% to reach tier 1, and lower than 5% to reach tier 3. The detailed coding algorithm can be found in Supplementary material 1.

c. Electricity appliances
This metric, originally referred to as *services* by ESMAP, assigns tier levels based on appliances the household is using (e.g. TV or fan for tier 2, a fridge or water heater for tier 4). The detailed coding algorithm can be found in Supplementary material 1.

---

[3] The systems consist of a 10–130Wp panel, battery, charge controller and LED lights. The system cost ranges from BDT 8100 to BDT 46,100, approximately, with about 10.15% down payment and the remaining balance paid in up to 36 monthly installments at an 6–12% flat interest rate (depending on the respective institution). Latest installation figures can be found under http://www.idcol.org/old/bd-map/bangladesh_map/.

[4] The Rural Service Foundation is a non-profit organization of Rahimafrooz Group and a partner organization (PO) of IDCOL's SHS program. To date, RSF has installed more than 500,000 SHS. Further information can be found under: http://rsf-bd.org/solar.html.

[5] It needs to be carefully noted that given the candidate MTF is a work in progress, modifications continued to be made and the provided questionnaire was based on attribute values that are in line with its 2014 version.

Table 1
Sample based electricity types.

Electricity access type	# of households	Share of households
National grid	69	30%
SHS[a]	107	46%
Solar lantern	1	0%
Diesel generator	5	2%
No primary access	55	24%
Other	5	2%
Total	242	
Sample size	231	

[a] All sampled SHS form part of the aforementioned IDCOL program.

d. Electricity capacity/consumption

This framework works as depicted in Fig. 1 where certain graduation levels for annual and daily consumption are fixed for the tier assignment. However, because consumption data are difficult to collect, particularly for off-grid systems such as solar, we use peak capacity as a proxy.

e. Electricity services

It has been designed by the authors as a hybrid metric between *b.* and *c.* in order to get closer to a representation of useful energy, namely combining indicators of supply and appliances.

f. Electricity supply (2015) — simple algorithm

This follows the same principles as *a.* just with different graduation levels and also represents the latest consensus of the MTF.

An in-depth discussion of the relative merits of the respective approaches is presented in Analysis and discussion of results section of the paper, and is based on applying the alternative decision rules and frameworks to assessing electricity access in Bangladeshi households using primary field data. Differences in tier assignment based on applying different frameworks and algorithms were tested with the help of the Wilcoxon signed-rank test. This is a nonparametric test allowing for ordinal variables and not assuming normality in the data (Snedecor and Cochran, 1989). It can compare two sets of scores that come from the same participant. The change variable in this case is simply the alternating algorithm/framework used to compute the respective scores. It further assumes that paired observations are independent, which is affirmative (see *Appendix IV.I*). Its modification, the *signtest*, further tests for the quality of matched pairs of observations. Furthermore, the correlation of tier scores with income is also tested (see *Appendix IV.II*). As the assumptions for the Pearson Product–Moment Correlation could not be met (e.g. variable of ordinal scale, no outliers), the Spearman correlation coefficient, as a nonparametric measure, is computed to determine this relationship (Spearman, 1904).

Analysis and discussion of results

Sample tier performance: descriptive statistics

Starting off from a macro picture, official statistics report that 43% of Bangladesh's rural population has access to the national grid, suggesting that 57% are energy or, at least, electricity poor (WBI, 2013). Income poverty is estimated to be lower, at 35%. These statistics are approximately in line with the estimations based on the minimum end-use energy indicator, according to which 58% of the population is energy poor[6] and 45% income poor (Barnes et al., 2011). In rural areas one can expect energy poverty to be higher than income poverty as physical access to modern energy infrastructure and supply is more of a constraint. Fig. 2

below showcases the sample based macro results applying the tier framework. It is clear that the multi-faceted and multi-tier nature of energy access is better captured by this approach than by a binary approach. But as discussed hereafter, very quickly the complexity of data needs, differing algorithms and frameworks applied can undermine the applicability and transparency of the approach. Differing frameworks and decision algorithms result in very different assessments of the electricity access situation in Bangladesh.

Almost the entire sample can be assigned to tier levels 0, 1 and 2 based on the simple version of the electricity supply algorithm from 2014 (*a. under 3.3*), whereas applying the new 2015 version or the complex algorithm (*f. under 3.3*) suggests a higher share being assigned to tier 2, and a considerable portion assigned even to tier 3 (11% and 8%, respectively). High sensitivities toward the affordability criterion emerge when setting the income variable to 0 (a large share of tier 2 households drop down to tier 1). It is interesting to note that the sample behaves almost exactly the same using the complex algorithm despite its higher flexibility in terms of tier assignment compared to the simple version, according to which households are simply assigned to the lowest performing tier. Affordability remains a critical factor also under the complex algorithm. For the testing of the electricity supply (2015) framework the affordability criterion no longer applies which is why the tier assignment is skewed toward higher tiers compared to the previous framework. Applying the appliance framework, a few households even get assigned a level of tier 4. Among others, equal shares remain between tiers 0 and 2. Electricity consumption data, as not adequately measured nor normally distributed, does not justify further interpretation and has therefore been excluded.

Table 2 shows the average assignment (mean) of all observations based on the answers given in the coded questionnaire and the framework/algorithm used. This mean tier assignment can be interpreted as the final indicator of energy access.

Statistical differences in means are tested for through a comparison of the equality of matched pairs (Wilcoxon, 1945) (refer *to Appendix IV.I* for the detailed test description and assumptions, as well as *Appendix IV.II* for an overview table of its results). The electricity service framework (*e. under 3.3*), with the most degrees of freedom embedded in its algorithm, exhibits the most diverse distribution (highest standard deviation) and also the highest average tier assignment. It results in significantly higher (at 1% level) tier assignment than all the other frameworks applied (except for the complex version without considering income). This is mainly due to its increased flexibility in measurement among the individual attributes, where a poor performance in terms of low capacity can be compensated by a good performance in terms of used appliances. This is a strong result in favor of the combined framework as it suggests a better reflection of the multi-faceted status of energy poverty along with an adequate evaluation of modern energy technology interventions. The electricity supply framework of 2015 under the simple rule (*f. under 3.3*) in turn, scores high not because it has higher degrees of freedom, but because several attributes do not apply any longer at the lower tier levels. A finer distinction between lower level tiers might be of particular relevance to lower-income nations and those with a large electricity access deficit. The higher value of the electricity appliance index (*c. under 3.3*) than the three versions of the supply index is contrary to expectations as evidenced by the statement made by the IEA/WB that "electricity services [appliances] typically lag behind improvements in supply" (IEA/WB, 2014, p. 52). Still, closer scrutiny of statistical difference shows a different picture. The complex algorithm produces significantly different and higher results than the electricity appliance tier measurement (at the 1% level). This means that despite a higher mean, triggered by individual high differences in tier results of the service tiers, in depth analysis of the paired differences reveals that supply is, in fact, even 'further ahead' of appliances. In several cases, the complex algorithm allows a higher tier assignment resulting in a significantly higher tier average at the 1% level.

---

[6] Basic minimum energy consists here of energy needed for a minimum quantity of lighting, cooking, and heating, whereas this paper is focused on services based on electricity.
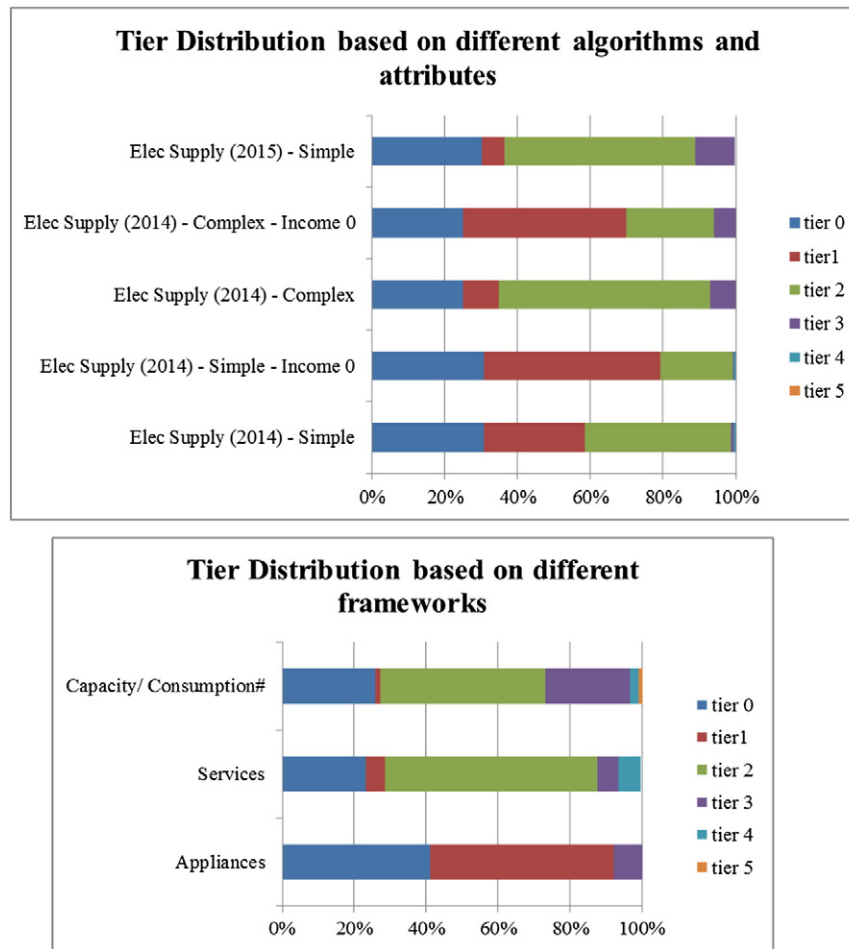
Fig. 2. Multi-tier measurement of access to electricity.
Please note that a different affordability criterion has been used here, and is described in detail in Supplementary material 1.

The stratified sample of households included in this study contains 46% with SHS, 30% with national grid access and 24% with no option for electricity. If a household has no electricity access it is assigned to tier 0, except in one case, where based on the services framework this household is in fact assigned to tier 1. 98% of the SHS users are assigned to either tier 1 or 2. A fairly diverse set of assignments is obtained from using the simple supply algorithm for grid-connected households ranging from tier 0 (16 observations) to tier 4 (1 observation). The latter result clearly showcases the limitations of the binary assessment of physical grid access. *Appendix IV.III* exhibits the detailed result tables of the tier assignments based on a household's electricity source. Table 3 below further shows that SHS users perform better on average when there is a higher degree of flexibility in the underlying algorithm, as is evidenced by significantly higher tier 2 assignments when applying the complex version as compared to the simple versions of the supply

framework, and an even more pronounced result in the case of applying the service framework. It is even more striking that, on average, on-grid households get assigned to lower tiers than households with SHS, when applying either of the simple supply frameworks, because of their poor performance on the duration attribute (and because the lowest attribute performance determines the overall household tier assignment according to this framework). This is not the case for the complex or the service framework. The fact still remains, however, that on average on-grid households tier assignment is at a maximum (in the case of applying the service framework) at an index level of 2.49, as compared to 1.91 for households with a SHS.

Table 2
Tier based sample distribution.

Variable	Obs	Mean	Std. Dev.	Min	Max
supply_simple _2014	231	1.13	.88	0	4
supply_simple_inc0	231	.91	.75	0	4
supply_complex	231	1.48	.95	0	3
supply_complex_inc0	231	1.13	.86	0	3
appliances	166	1.54	1.02	0.5	4
services	222	1.62	1.08	0	4
supply_simple_2015	231	1.45	1.04	0	3

Table 3
Electricity source and tier assignment.

Tier	Obs	Mean	Std. Dev.	Min	Max
SHS tier performance					
supply_simple _2014	107	1.56	.54	0	2
supply_complex	107	1.80	.40	1	2
services	107	1.91	.29	1	2
supply_simple_2015	107	1.52	1.00	0	3
On-grid tier performance					
supply_simple_2014	69	1.28	.89	0	4
supply_complex	69	2.04	.53	0	3
services	65	2.49	.83	1	4
supply_simple_2015	69	1.38	1.08	0	3

The analysis above shows that tier assignment results are very sensitive to the respective framework and algorithm used. Generally, applying a more flexible algorithm provides more distinguishable results. On the other hand, complexity is increased. Therefore, the following section scrutinizes more closely the performance of the sample along different attributes and assesses the sensitivity of the final tier assignment to the inclusion of individual attributes.

Gap analysis along the seven attributes for the case of Bangladesh

Complementing the overall tier result with the full array of results for individual indictors/attributes is essential to understand where the strengths and weaknesses of the MTF lie. *Appendix IV.III* provides further insights on the performance of the households along the seven attributes of the electricity supply framework. We briefly comment on each attribute based on its empirical assessment and draw our critique from these results.

Capacity

The gradation variable in question A.02 is not sufficiently graduated. A finer distinction among the lower level tiers is needed. The great majority of observations fall into the range of 51 W–500 W. Only the more recent 2015 version has an intermediate option of 200 W included. The inclusion of an "or" decision rule for appliances is useful as it corrects for the shortcoming of ignoring appliances that do not fulfill the power and capacity minimum values due to their high efficiency. This will usually occur in stand-alone systems or nanogrids based on direct current (DC) supper-efficient appliances.

Duration

The "hours per day" attribute seems less useful than the "evening supply" indicator. The majority of the households (about 90%) fall into the range of having at least 8 h of electricity supply per day. Evening supply, in contrast, seems to be far more relevant, as almost 20% have less than 2 h of supply and about 43% state they have exactly 2 h of evening supply. The grid seems to have capacity problems, especially at peak load times, which is typical for Bangladesh (BPDP, 2015). Survey respondents' recall is also likely to be more reliable for just evening supply, since electricity is mostly used in the evening hours. The hours per day criterion further turns out obsolete given that it is already implied in the daily capacity indicator as this contains the multiplication of power and daily use. The evening hour criterion in turn, is important and has been improved recently, now distinguishing more closely between tier 1 and 2.

Reliability

This indicator seems arbitrary and not sufficiently differentiated. It is also not clear why reliability applies only in the case of supply of more than 16 h per day, thus applying to only tiers 4 and 5 (in an earlier version it was from tier 3 onwards). In the sample, 69% of the households suffer from more than three interruptions per week, and about 93% of the households undergo regular outages, lasting more than half an hour each. However, only 11% of the surveyed on-grid households have less than 16 h of supply per day.

Quality

The quality (voltage) dimension is described only vaguely. In the survey, 19% of the people with a connection to the national grid report appliance breakage due to voltage drops which rules out tier 4 and 5 assignments under the current graduation levels. A more detailed and differentiated set of criteria is needed here. As more and more decentralized systems ranging from pico- or nanogrids to minigrids cover the spectrum from tier 1 to tier 3 (Alstone et al., 2015), an inclusion for this spectrum is recommended as it provides valuable information for comparative evaluation. Criteria should then go beyond voltage problems toward usability of desired appliances based on the technical

infrastructure (e.g. based on direct versus alternating current and different voltage levels within the houses).

Affordability

Affordability is measured here based on relative electricity expenditure, as it is considered adverse if a high share of income is spent on it (Bazilian et al., 2010). Table 4 below summarizes the results. On average, the sampled household spends between 6% and 8% of their income on electricity, depending on whether we consider those who incur some expenditure or all households. Since more than 50% of the sample Bangladeshi households do not fulfill the tier 3 graduation level, a further tiered analysis would be useful for more in depth analysis.

As can be seen, 20% of the interviewed households end up spending more than 10% of their total income for electricity, which would result in them being assigned to the tier 1 level or below. It should be noted that electricity expenditure is highly dependent on quality and quantity of services, which an expenditure share metric doesn't capture. The affordability indicator does not adequately capture affordability constraints faced by households. Neither the upfront nature or lumpiness of costs is easily measured by the recommended indicator, nor are the costs (discounted) associated with appliances needed to convert electric supply into useful service, included in this indicator. Comparing kWh prices for electricity while ignoring quantity used can further be misleading. The updated affordability measurement (Fig. 1) consists of a standard electricity package of 365 kWh per annum that should cost less than 5% of a household's total expenditure in order to qualify for tier 3. This is effectively a measure of the unit price of electricity, since for a household with a given income the affordability criterion implies a fixed expenditure associated with a fixed usage. A 365 kWh per annum package translates into a consumption of 1 kWh per day which is about 10 times as much as a remote household would need following the example of a 25 W solar powered household with average daily use of 4 h (Phadke et al., 2015). As an example, Hindustan Unilever sells 10 g packages of washing powder in remote villages. A comparative assessment to a 1 kg package of the same powder in an urban supermarket would most likely also raise concerns. It should be the goal of such a framework to get closer to allowing a comparative analysis of what an hour of TV, light or fan costs to a household instead of comparing peak capacities and kWh prices, while always taking into consideration economies of scale. Consequently, affordability cannot be captured in a single metric but requires multiple measures instead. Moreover, affordability should apply also for the lower tiers as it is among the key evaluation aspects of decentralized energy options.

Legality

This attribute seems out of place as it only impacts the household's electricity supply indirectly, if at all. The MTF states that "illegal connections may cause significant financial losses to the utility, while also increasing the risk of accidents" (Bhatia and Angelou, 2015, p. 4). Instead it should rather apply for an institutional assessment. In the case of the current survey, there is not a single household officially stating that it is not paying electricity bills. On the other hand, only 61 households state that they have a meter, whereas 69 are considered grid connected. There seems to be a good tracking of the electricity users

Table 4
Average relative electricity expenditure for the sample.

Electricity expenditure/total income	Sample share
Mean expenditure (all)	6%
Mean expenditure (only those with some expenditure)	8%
Sample share with no expenditure	17%
Less than 5%	46%
5%–10%	17%
More than 10%	20%

affiliated to the PBS scheme. Furthermore, all SHS users indicate that they pay their bill to the respective partner organization of the IDCOL program, making legality a minor issue in the present context.

Health & safety

It is only reflected in the productive use section of the questionnaire, and thus only received 34 responses from the microbusinesses in the dataset. Based on this data, it seems a negligible factor, as only one unit states an incidence in the past. Moreover, this attribute is vaguely defined, but can be applied to evaluate the extent to which electricity connections comply with safety standards for electric equipment (for e.g., adequate insulation on equipment).

In a nutshell, the gap analysis based on the 2014 MTF suggests that health & safety, as well as legality seem to be less of an issue. Affordability, in turn, measured here as energy expenditure as a share of income, seems to be of potential concern if applied for all tiers as described in Appendix III.II. *Reliability* and *(technical) quality* only affect the ability to reach at least a tier 3 level. Here, for the on-grid customers, a better load management and transformer improvement may have the potential to move up to 93% of the on-grid households (under the simple algorithm) to a higher tier level, provided that the second most pressing issue of evening hour supply is also tackled. A more detailed analysis of these issues is needed, however. Also, these results are estimated for less than the full sample. The smaller sample is a consequence of various skipping patterns applied in the questionnaire.[7]

Sensitivity of MTF to individual attributes

Given the presented descriptive statistics, Table 5 compares the relative share of households assigned to each tier based on the 2015 MTF version for the cases that all attributes are applied, individual ones are left out and lastly when only capacity and duration are applied. As it turns out the latter ones are the only attributes that in fact cause a significant difference, at least in the current set up of the MTF. As far as duration is concerned the key question seems to be the supply in the evening hours whereas daily supply turns out irrelevant in the given sample.

In general terms, the MTF itself lacks conceptual clarity and communication about what is being measured. It is crucial here to find the right distinction between measures of household electricity access, institutional service supply quality and household based energy poverty. If all of those are being mixed up within the different attributes and a combination of (in part) redundant matrices, appropriate inference is impeded. Furthermore, all attributes should be defined so as to have attribution in all tier levels as this will bring us closer to the declared goal of evaluating the contribution of all types of energy interventions aiming to move users to higher levels of attributes. A more detailed discussion on the subjectivity of some of the factors would also be useful.

Specific recommendations regarding attribute measurement, tier frameworks and assignment algorithms

This part of the analysis evaluates the underlying decision rules as well as differences and sensitivities of applying different algorithms across the respective frameworks.

Rethinking the capacity attribute in light of new appliance efficiencies evident in the market

The simple algorithm undermines the SE4ALL goal of energy efficiency. With higher efficiency appliances,[8] a lower demand and storage capacity is needed to provide the same duration of service supply. Higher efficiency can lead to lower energy consumption. *Appendix V*, as an example, computes the implications of applying the consumption framework to the present SHS program in Bangladesh as well as to the up-coming IFC solar lantern program under the Lighting Bangladesh initiative (IFC, 2015). As a matter of fact, the products that fall under this program (<5Wp), hardly reach the tier 1 level based on the consumption framework, or the capacity attribute as applied in the updated supply framework. The products falling under the much acclaimed Bangladeshi IDCOL SHS program (usually <=75Wp), also fail to attain a performance higher than tier 1. Based on an apparent trade-off between energy efficiency and energy consumption, one finds a paradox that applying the present frameworks, may result in a lower tier ranking for a better energy service level. Using the latest simple algorithm, a lower score in peak capacity would rule out a higher possible overall tier score supported by sufficient daily and evening supply hours in connection with a good performance in electricity appliances available. This line of argument finds support by Craine et al. (2014) and has further implications for the investments estimated for achieving universal energy access by 2030. Pachauri et al. (2013) estimate that globally, US$$_{2005}$ 65–86 billion per year would be required to achieve near universal access to electricity and clean cooking by 2030 (US$$_{2005}$ 10.7–15.2 billion per year for rural electrification alone). They also state, however, that taking into consideration feasible decentralized options, investments are likely to be lower compared to their estimates that assumes all access is achieved via grid extension alone and a minimum consumption threshold of 420 kWh/household/year. Craine et al. (2014) argue that the investment estimations could potentially decline from a level of USD 32 billion per year over the next 20 years to as low as USD 10 billion per year, largely as a result of revised efficiency values for decentralized energy options.[9] For the lighting example in SHS, up to 50% of capital cost can be saved by efficiency gains, since a lot less expensive storage (and generation) capacity is needed, which impact lifetime cost much more than the higher initial appliance cost (Jacobson, 2015). The Global Tracking Framework report from 2015 has now corrected its prediction to USD 15.2 billion of annual investment to reach universal electrification by 2030 (Banerjee et al., 2015, p. 119). By universal electrification they refer to a purely consumption based level of 420 kWh/household/year (somewhere between tier 3 and 4 on the consumption framework and derived from a daily usage of 115 W for 10 h). This is considerably higher than previous estimations, e.g. by Pereira et al. (2011), who set this threshold at 10 GJ/year or 88 kWh/household/year of direct energy consumption per rural household based on empirical data from Brazil ending up just above the minimum consumption graduation cut-off for tier 2. The drawback of both consumption based measurements is that they end up measuring at the "final energy" level as that is easiest to measure, whereas what really needs measuring is the "energy services" this enables, so the "useful energy" level is in fact the most appropriate. The suggested service framework is a first step to overcome this problem. However, the appliance framework still assumes certain wattages for household appliances (e.g. TV 31–150 W) and determines the capacity requirements accordingly. These do not reflect the latest market developments in appliance efficiencies.

---

[7] The skipping pattern is based on the household's primary electricity source. Many questions apply only to households connected to the national grid. Whereas this is useful for some of the questions in order to keep the questionnaire time short, the authors recommend not following the skipping pattern for many decentralized options in order to get a better tier based evaluation of these types of energy interventions. Please refer to the questionnaire provided with the Supplementary material, Q.A01 to review the exact skipping pattern.

[8] E.g.: There are 15 inch color LED DC TVs presently in the market that consume about 6 W and DC brushless ceiling fans consuming approx. 5 W. The best LED lights have a ratio of 120 + lm/W. If all of these appliances run 4 h a day, this would constitute 56 kWh (if two lights are assumed). This is by far lower than the required 200 kWh for tier 2 assignment.

[9] This, in turn, has been heavily criticized by Trembath (2014) as being far too low.

Table 5
Sensitivity analysis based on the attributes.

Tier assignment	All attributes	W/o legal	W/o afford	W/o quality	W/o reliability	W/o evening hrs	W/o daily hrs	W/o capacity	W/o health/safety	W/o afford quality reliability legality
Tier 0	30.30%	30.30%	30.30%	30.30%	30.30%	29.44%	30.30%	1.73%	30.30%	30.30%
Tier 1	6.06%	6.06%	6.06%	6.06%	6.06%	1.30%	6.06%	4.76%	6.06%	6.06%
Tier 2	52.38%	52.38%	52.38%	52.38%	52.38%	41.56%	52.38%	12.99%	52.38%	52.38%
Tier 3	11.26%	9.52%	11.26%	11.26%	11.26%	27.71%	11.26%	74.89%	11.26%	9.52%
Tier 4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.43%	0.00%	0.00%
Tier 5	0.00%	1.73%	0.00%	0.00%	0.00%	0.00%	0.00%	5.19%	0.00%	1.73%

Re-designing the affordability attribute

In addition to the need for multiple expenditure-based indicators for affordability as discussed above, we recommend adding another dimension to the affordability attribute, related to the poor's cash flow constraints. Collins et al. (2010) explain the complexities of the portfolios of the poor that require an array of sophisticated methods to overcome various liquidity traps. Pay-as-you-go (PAYG) solutions have revolutionized the SHS market in East Africa, allowing its customers increased flexibility in their payment plans both in terms of up-front payment as well as amount and frequency of monthly installments (Moreno and Bareisaite, 2015). This in some cases even leads to payments far ahead of the plan making sure the available income is not spent otherwise. These financing/technology innovations, that are expected to be implemented soon in Bangladesh, among other countries, need to be reflected in the tier framework. This could be done through a flexibility indicator feeding into the affordability attribute, as greater flexibility in repayments can substantially improve a household's medium term cash-flow management. Consequently, affordability ought no longer to be defined merely as an indicator reflecting relative share of electricity expenditure (either for consumption packages, or kWh, or lumen hours), but should also reflect the degree of payment flexibility as a service improvement (Moreno and Bareisaite, 2015; Groh et al. 2015). Again, these innovations, especially in the early market phase, are more costly. Without a tier framework reflecting their added value, a cost–benefit-analysis remains very difficult.

(Ir-)relevance of the electricity consumption framework

First, as pointed out earlier, consumption really is more an energy poverty measure than one of supply. Furthermore, if electricity supply performance is measured high on the tier assignment, but extremely low values are measured on consumption, the reasons behind this can be manifold. There may not be an ability to pay, there may not be the need for bigger amounts (possibly due to un-availability of appliances or availability of an appliance of higher efficiency than expected) etc. But aren't all these reasons already reflected in the attribute of the supply and the appliance framework? And if so, why is an additional consumption framework needed, especially if its values coincide with the daily capacity value already included in the supply framework? But here the question remains, what additional information do higher or lower consumption values give us really for measuring energy access, which are not already reflected in one of the access attributes or in the appliance framework? Furthermore, the implication of applying the consumption framework in its current form, for attaining energy efficiency goals, is at the very least questionable.

Further refinement of attributes

Each attribute ought to have a set of indicators that allow for distinction across all tier levels. Through this, the performance of specific energy interventions can get reflected in a much better way. Once the goal of the measurement has been clearly defined, the respective inclusion of necessary attributes should follow. This, however, should be clearly communicated in the first place. For example in the case of the health attribute, it should be defined as a measure of energy poverty rather than electricity supply. As such, it may be defined to reflect the adverse

health impacts due to kerosene lighting (direct effect), lead acid batteries and their lifecycle impacts (indirect effect), among others. Also, it is worth noting that some of the household attributes can be measured at different levels (household level versus utility/ESCO/provider level), which may increase data reliability.

Comparison of tier assignments based on differing algorithms and frameworks

Neither of the tier assignment algorithms – simple or complex – to measure electricity supply is ideal and results in very different assessments of electricity access. These, in turn, differ from the tier assignments that result from applying the alternative frameworks. However, it seems clear from the analysis that a higher degree of flexibility, reflected through an algorithm that evaluates combinations of attributes or even frameworks, provides a more nuanced measure of electricity access. This also bears on the ability to better reflect decentralized energy interventions. At the same time, however, the complex algorithm is more prone to errors, as it is more complicated to calculate, which may undermine the approach's simplicity, applicability and transparency. Furthermore, it too is equally subject to a certain degree of arbitrariness. The suggested service framework shares this shortcoming as it merges the conditions of the complex access framework with the ones from the appliance framework.

Lastly, we argue that the majority of measurements critically hinge on a measure of income (especially, for the affordability indicator), which is presumably the most difficult indicator to measure reliably. This causes very high sensitivities in almost all measurements. *Appendix VI* shows the Spearman correlation coefficients for all modifications of the different frameworks and how they relate to household income. The appliance framework does not show any significant correlation with income, whereas the simple and complex supply algorithm of the access framework as well as the service framework are positively correlated with income (1% significance level). Here the higher average tier value that results from applying the complex algorithm (0.41) over the simple rule (0.26) stands out. The 2015 simple algorithm does not show a significant correlation to income, but only because here the affordability criterion was only applied for higher tier levels where the majority of the sample does not fall under. These results confirm the outcome of the sensitivity analysis (Fig. 2), that reveal that excluding income from the decision rules, results in a much higher tier performance. It also suggests that the complex algorithm places more value on income than the simple one, as it appears more often in its decision rules. The suggested service framework shows the same pattern here (0.41, 1% significance level), so is equally prone to income measurement errors. Further improvements are, therefore, needed. Nonetheless, *Appendix VII* also shows a considerable amount of data points with a fairly high income but a tier 0 assignment, which, in turn, suggests that affordability, is not necessarily always the key decision factor, but rather one important element among several that manifest in a status of energy poverty.

Conclusion

The objective of any measurement framework must ultimately lie not in measuring the supply of energy/electricity, but rather whether

this supply enables certain vital services (communication, illumination, thermal comfort, entertainment, etc.), which ultimately improve human wellbeing. However, measuring energy at the level of services is difficult. This is because it requires a measurement of much more than the energy carriers themselves (e.g. transformation and end-use equipment). Recognizing the urgent need of a theoretical underpinning for the measurement of progress toward the first SE4ALL goal, this paper strongly advocates in favor of the MTF. It also values the need for pragmatism in light of the urgent need of an indicator that is fairly easily computable. Nonetheless, it concludes that the presently favored simple version of the algorithm for tier assignment does not give sufficient justice to the multi-faceted and multi-tiered nature of energy access, especially in the current times of rapid technology innovation in the decentralized energy sector (e.g. DC super-efficient appliances; PAYG business models; spread-out of different sizes and typologies of minigrids).

We recommend revising the algorithms aiming at a compound framework that combines elements from the supply and the appliance framework analysis for several reasons. First, this seems to be the most promising approximation in the absence of a direct measurement of energy services, by measuring energy at the useful level. Second, it reflects advances in energy efficiency. Third, it overcomes the shortcoming of a decision rule based on a single metric. Moreover, we suggest further consideration and refinement of several of the attributes. Foremost among these, we consider that affordability cannot be captured by a single metric, but requires multiple measures instead. Also, each attribute ought to have a set of indicators that allow for distinguishing across all tier levels. We are aware, however, that these changes could add further layers of complexity to the algorithm in comparison to the simple version. Therefore, in addition, we recommend a rigorous evaluation of required attributes in order to bring down the computational complexity of the MTF, as well as overall confusion about what is actually being measured. We therefore recommend an immediate reflection on what it is we want to measure here. Based on this result, the MTF should be improved and thinned out for obsolete attributes, which, in turn, may be measured in separate matrices with a different goal altogether. There will always remain a trade-off between an approach that is more reflective of reality, but is fairly complex and hence prone to errors, and an approach that is simpler, easily computable, but also has several shortcomings.

As the new framework allows for a reflection of country specific energy interventions, this paper for the first time evaluates the widely acclaimed solar home system program of Bangladesh. Currently, SHS, despite vast numbers of installed units (more than 3.8 million to date), are not reflected at all in (inter-)national statistics on energy access. According to the MTF, the sample households with SHS score at the tier 1, or at best at the tier 2 level, depending on the application of the capacity attribute. Based on the latter criterion, eligible products under up-coming programs such as the IFC Lighting Bangladesh program do not even qualify for a tier 1 assignment and are therefore subject to a fractional measurement. A major challenge, despite opposing rhetoric, remains the issue of affordability, including higher flexibility in repayment plans. Monthly installments of the microcredit based scheme are still too high compared to expenditures for kerosene and on-grid access, as well as in relation to overall household income. There is also a need for actions that address households at lower income levels, as present schemes address largely higher income rural customers. The latest trends in energy efficient appliances that are already available locally, however, are presently paving the way for higher tier performances provided a more sophisticated tier assessment algorithm, as is suggested herein, is adopted.

It should be carefully noted that all tier assignments are highly sensitive to parameter changes, different algorithms, and data requirements. The performance evaluation of country specific energy interventions can differ significantly, depending on the type of algorithm used, which may lead to conflicts when it comes to building consensus for a

universal measurement framework among the SE4ALL member countries. Once this is achieved, pro-poor policies that influence energy access by enabling households to achieve higher tier levels can be designed and implemented more effectively. The MTF is definitely a step in the right direction, and refinements based on our assessment and application of it to the case of Bangladesh will further improve it. Its ultimate test will lie in its application within various country contexts.[10] Still, only what gets measured, also gets managed, so immediate action is needed here.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.esd.2015.10.007.

References

AGECC. Energy for a sustainable future. Secretary-general's Advisory Group on Energy and Climate. Summary Report and Recommendations. New York: Sustainable Energy for All; 2010.

Alstone P, Gershenson D, Kammen DM. Decentralized energy systems for clean electricity access. Nat Clim Change 2015;5:305–14.

ASQ. American Society of Quality, Quality Glossary. See http://www.asq.org/glossary/q.html, 2015. (Last accessed August 30th 2015).

Banerjee S, Bhatia M, Azuela GE, Jaques I, Sarkar A, Portale E, Bushueva I, Angelou N, Inon JG. Working Paper 77889. Global Tracking FrameworkWashington, DC: World Bank; 2015. (May).

Bangladesh Power Development Board. Index of Maximum Daily Generation. Available online under http://www.bpdb.gov.bd/bpdb/pdb_utility/maxgen/dailygen_archive/, 2015. (Last accessed: March 5, 2015).

Barnes DF, Khandker SR, Samad HA. Energy poverty in rural Bangladesh. Energy Policy 2011;39(2):894–904.

Bazilian M, Nussbaumer P, Cabraal A, Centurelli R, Detchon R, Gielen D, Rogner H-H, Howells M, McMahon H, Modi V, Nakicenovic N. Measuring energy access: supporting a global target. Expert Meeting "Galvanizing Political Commitment for Universal Energy Access," 31 March 2010. New York, NY, USA: The Earth Institute; 2010. (Available online under http://en.openei.org/wiki/Measuring_Energy_Access:_Supporting_a_Global_Target. Last accessed: January 26, 2015).

Bensch G. Inside the metrics: an empirical comparison of energy poverty indices for Sub-Saharan countries. Ruhr Economic Papers, No. 464; 2013.

Bhatia M, Angelou N. Beyond connections: energy access redefined. Executive Summary. ESMAP Technical Report 008/15. Washington. USA: The World Bank Group; 2015.

Brew-Hammond A. Energy access in Africa: challenges ahead. Energy Policy 2010;30(5):2291–301.

Collins D, Murdoch J, Rutherford S, Ruthwen O. Portfolios of the Poor: How the World's Poor Live on $2 a Day. Princeton University Press 0691148198; 2010.

Craine S, Mills E, Guay J. Clean Energy Services for All — Financing Universal Electrification. Washington: Sierra Club; 2014 (Available online under http://action.sierraclub.org/site/DocServer/0747_Clean_Energy_Services_Report_03_web.pdf?docID=15922. Last accessed: January 26, 2015).

Global Goals. The Global Goals For Sustainable Development. http://www.globalgoals.org/, 2015. (Last accessed: October 1, 2015).

Government of Bangladesh. Perspective plan of Bangladesh — making vision 2021 a reality. General Economics Division Planning Commission Government of the People's Republic of Bangladesh 2010–2021; 2012 (Available online under http://www.plancomm.gov.bd/wp-content/uploads/2013/09/Perspective-Plan-of-Bangladesh.pdf. Last accessed: August 21, 2014).

Groh S. The role of energy in development processes — the energy poverty penalty: case study of Arequipa (Peru). Energy Sustain Dev 2014;18:83–99.

Groh S, Philipp D, Edlefsen B, Kirchhoff H. Swarm electrification — investigating a paradigm shift through building up microgrids bottom-up. In: Groh S, Straeten J, Edlefsen Lasch B, Gershenson D, Leal Filho W, Kammen D, editors. Decentralized Solutions for Developing Economies — Addressing Energy Poverty Through Innovation. Springer Proceedings in Energy; 2015. p. 3–22. (2015, XXIV, ISBN: 978-3-319-15963-8).

IEA. World Energy Outlook 2010 - Special Report - How to make modern energy access universal? Technical Report. Paris, France: International Energy Agency; 2010.

IDCOL. http://www.idcol.org/old/bd-map/bangladesh_map/, 2014. (Last accessed: January 10, 2015).

International Energy Agency (IEA) and the World Bank (WB). Sustainable Energy for All 2013–2014: Global Tracking Framework Report. Washington, DC: World Bank; 2014.

International Finance Corporation. Lighting Bangladesh. https://www.lightingglobal.org/ifc-partners-with-giz-in-bangladesh-to-increase-energy-access-for-off-grid-communities/, 2015. (Last accessed March 29, 2015).

Jacobson A. Efficiency, affordability, and quality: three drivers for growth in the off-grid solar industry. Quality Assurance Workshop. Dhaka: IFC Lighting Global; 2015. (March 16, 2015).

---

[10] See CEEW for a recent application of a modified version of the MTF to certain rural Indian States (Jain et al., 2015).

Jain A, Ray S, Ganesan K, Aklin M, Cheng CY, Urpflainen J. Access to clean cooking energy and electricity — survey of states. Report. New Delhi, India: Council on Energy, Environment and Water (CEEW); 2015.

Khandker SR, Barnes F, Samad HA. Welfare impacts of rural electrification — a case study of Bangladesh. Policy Research Working Paper 4859. Washington: The World Bank; 2009.

Khandker SR, Douglas R, Barnes F, Samad HA. Are the energy poor also income poor? Evidence from India. Energy Policy 2012;47:1–12.

Ki-moon B. Sustainable Energy for All: A Vision Statement. New York: United Nations Organization; 2011 (Available online under www.sustainableenergyforall.org. Last accessed: July 31, 2014).

Modi V, McDade S, Lallement D, Saghir J. Energy Services for the Millennium Development Goals. Washington DC/New York: International Bank for Reconstruction and Development/The World Bank and the United Nations Development Programme; 2005.

Moreno A, Bareisaite A. Scaling up access to electricity: pay-as-you-go plans in off-grid energy services. Livewire. 2015/34. Washington: The World Bank Group; 2015.

Nussbaumer P, Nerini FF, Onyeji I, Howells M. Global insights based on the Multidimensional Energy Poverty Index (MEPI). Sustainability 2013;5:2060–76.

Pachauri S. Reaching an international consensus on defining modern energy access. Curr Opin Environ Sustain 2011;3(4):235–40.

Pachauri S, Spreng D. Measuring and monitoring energy poverty. Energy Policy 2011; 39(12):7497–504.

Pachauri S, van Ruijven BJ, Nagai Y, Riahi K, Van Vuuren DP, Brew-Hammond A, Nakicenovic N. Pathways to achieve universal household access to modern energy by 2030. Environ Res Lett 2013;8:024015. (7 pp.).

Pereira M, Sena J, Freitas M, da Silva N. Evaluation of the impact of access to electricity: a comparative analysis of South Africa, China, India and Brazil. Renew Sustain Energy Rev 2011;15(3):1427–41.

Phadke A, Jacobson A, Park WY, Lee GR, Alstone P, Khare A. Powering a Home With Just 25 Watts of Solar PV: Super-efficient Appliances Can Enable Expanded Off-grid Energy Service Using Small Solar Power Systems. USA: Ernest Orlando Lawrence Berkeley National Laboratory; 2015.

Practical Action. Poor People's Energy Outlook 2012. Rugby, UK: Practical Action Publishing; 2012.

Practical Action. Poor People's Energy Outlook 2013: Energy for Community Services. Rugby, UK: Practical Action Publishing; 2013.

Schützeichel H. No Grid? No Problem! 32 Practical Tips for Sustainable Off-Grid Business. Sun-Connect/ Solar Energy Foundation; 2015.

Sen A. Development as Freedom. Oxford University Press 978-0-19-829758-1; 1999.

Shyu CW. Ensuring access to electricity and minimum basic electricity needs as a goal for the post-MDG development agenda after 2015. Energy Sustain Dev 2014;19:29–38.

Snedecor GW, Cochran WG. Statistical Methods. 8th ed. Ames, IA: Iowa State University Press; 1989.

Spearman C. The proof and measurement of association between two things. Am J Psychol 1904;15:72–101.

Trembath A. The Low-energy Club. Breakthrough Institute. Available online under http://thebreakthrough.org/index.php/programs/energy-and-climate/the-low-energy-club, 2014. (Last accessed: January 26, 2015).

Wilcoxon F. Individual comparisons by ranking methods. Biometrics 1945;1:80–3.

World Bank. World Development Indicators. Bangladesh: The World Bank Group; 2013 (Available online under: http://data.worldbank.org/country/bangladesh. Last accessed: July 31, 2014).