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Application of an alternative framework for measuring progress towards SDG 7.1

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E-mail: setu.pelz@rl-institut.de**Keywords:** energy access, sustainable development goals, measurement, indicators, multi-tier frameworkSupplementary material for this article is available [online](#)Original Content from this work may be used under the terms of the [Creative Commons Attribution 4.0 licence](#).

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**Abstract**

Global progress towards Sustainable Development Goal 7.1: ‘By 2030, ensure universal access to affordable, reliable and modern energy services’ continues to be measured by mere access to energy carriers, using binary indicators that inadequately reflect the multi-dimensional nature of the goal. In this work, we describe and apply an alternative framework to track critical dimensions of energy provisioning and household capabilities that aligns more closely with the original SDG 7.1 target wording. We provide new empirical evidence from ten countries describing the extent to which the current indicators underestimate energy poverty and neglect decent access. We find that households officially counted as having access to modern energy sources, in many instances, still benefit only from minimal energy services, receive unreliable energy supply, and struggle with being able to afford energy services they need to enjoy a decent standard of living. We also find that poorer households are systematically over-represented in this population and are more likely to suffer multi-dimensional constraints when counted served by the current indicators. Notwithstanding challenges in data collection and standardisation, we argue that we must improve on binary indicators for measuring progress towards SDG 7.1, to pave the way for agenda setting and policy development that recognises and addresses broad inequities in household capabilities to use modern energy towards achieving a decent living standard.

1. Introduction

The United Nations 2030 Sustainable Development Agenda formally included energy among the seventeen Sustainable Development Goals (SDGs) in 2015 (UN 2015), following the recommendations of several high-level international bodies and global assessments (UNDP 2005, UNDP and WHO 2009, AGECC 2010). This represented a step forward from the Millennium Development Goals, which failed to include energy despite its widely recognised role in sustainable development (Goldemberg *et al* 1985, UN 1992, Reddy 2000, Johansson *et al* 2012, World Bank 2015).

SDG 7.1 specifically states: ‘By 2030, ensure universal access to affordable, reliable and modern energy services’ (UN 2015). The clear and broad

wording of this goal is, however, not reflected in the indicators used to track progress towards it. Rather, the official SDG 7.1 indicators remain binary and unidimensional in nature, measuring access by mere connections to a modern energy source rather than the actual supply provided or use thereof. With less than a decade till the SDG 7 targets should be met, we argue it is time to reflect on the adequacy of the existing indicators and consider refinements to guide progress beyond the current 2030 Agenda.

Binary indicators are attractive because of their simplicity, but are inadequate in terms of describing the actual energy services people use or the benefits they derive from them (Bhatia and Angelou 2015, Trace 2015). The official SDG 7 indicator for electricity (SDG 7.1.1) identifies about 789 million people as without access to electricity in 2018 (IEA 2020).

However, recent estimates suggest that as many as 3.5 billion people live without access to reliable electricity (Ayaburi *et al* 2020). Moreover, many people struggle with being able to afford key energy services essential to their wellbeing. For instance, between 1.8 and 4.1 billion people are estimated to lack access to adequate cooling services in the Global South (Mastrucci *et al* 2019). Similarly, the official SDG 7 indicator of access to clean cooking counts just under 3 billion without access. But recent assessments suggest that most of the population counted as primarily relying on clean cooking in developing countries continues to use solid fuels in parallel as secondary cooking solutions (ESMAP and GACC 2020).

A growing literature now points to the shortcomings of the current binary indicators of energy access (Jain *et al* 2015, Trace 2015, Tait 2017, Falchetta *et al* 2019, Ayaburi *et al* 2020). Most of these studies argue that the official globally agreed SDG 7 indicators mask differences in the quality and conditions of energy supply, and types of energy services people have access to and benefit from. Improving on the existing indicators through a broader interpretation of the energy goal could help provide the right signals to improve planning and investment decisions in support of the universal access goal by 2030.

In this work, we build further on an alternative framework (AF) for measuring global progress towards SDG 7.1 first presented by Pachauri and Rao (2020). The AF attempts to align as closely as possible to the wording of the SDG 7.1 target and builds on the foundation established by the World Bank Energy Sector Management Assistance Program (ESMAP) Multi-Tier Framework for measuring energy access (MTF). The innovation of the AF lies in clearly distinguishing between two critical aspects of access: the quality of supply provided and the capability to translate this into requisite energy-related services that meet specific end-user needs. The latter aspect is motivated by literature that links basic needs, such as keeping oneself cool, with energy related capabilities and approximate material and energy requirements, in turn defining a decent living energy standard (Rao and Min 2017, Rao and Pachauri 2017). The AF thus represents one avenue by which both aspects of energy access can inform global agenda setting and direct country-level policy efforts where they are most needed, that is, to energy suppliers and/or to households (end-users).

We provide empirical support for the use of a more nuanced set of indicators included in the AF that align more closely with the intention of the SDG 7.1 target of affordable, reliable and modern energy services for all. This draws from nationally representative household surveys conducted across ten countries under the recent ESMAP MTF survey effort to assess access to electric energy services and clean cooking. We find that a sizeable subset of households considered served by the current

SDG 7.1 indicators remain without access to modern, reliable or affordable energy access. We also find that poorer households are systematically over-represented in this population and are more likely to suffer multi-dimensional constraints when counted served by the current indicators. While recognition of the importance of energy for development has significantly advanced under the 2030 Agenda, it is evident that we must improve on the official indicators if they are to guide progress towards decent access for all and thereby achieve the desired development outcomes that energy can unlock.

2. Methods and data

Building on the original AF proposed by Pachauri and Rao (2020), we draw from the same set of indicators to measure access to decent electric services, with some modifications. The original AF was a first attempt at improving on the MTF towards a more pragmatic national energy poverty measurement approach that could still capture heterogeneity at lower income levels. Our intention with this work is to propose a globally applicable set of indicators that more accurately reflect the original SDG 7.1 target wording. With this in mind, we further reduce the tiers in the MTF/original AF into a set of decent access thresholds. Evolving slightly from the original AF, we select the highest original AF tier (AF tier 3) for availability (≥ 16 hours per day) and affordability ($\leq 5\%$ of annual household expenditures), while setting the energy services target to AF tier 2 (access to lighting, phone charging and either TV, fridge or cooling). Sensitivity analysis setting the services target to AF tier 3 is included in the supplementary material (available online at stacks.iop.org/ERL/16/084048/mmedia). Overall, these thresholds describe a scenario where households can reasonably use electricity when it is desired, and can afford the supply necessary to power appliances delivering a decent living energy standard.

We then expand on the AF with new indicators that measure access to decent clean cooking solutions. The first indicator captures relative time spent using Biogas, Liquid Petroleum Gas, Electricity or Natural Gas (BLEN) cookstoves (at least 80% of total daily cooking time). This is designed to reflect widespread stove stacking and resulting pollution exposure, capturing actual household capabilities to translate clean cookstove access into clean cooking practices. We propose relative time-use rather than relative fuel consumption as a pragmatic solution to the challenge of homogenising heterogeneous measurement units and fuel calorific values across diverse country contexts. The underlying logic for this simplification is that more time spent using biomass stoves relative to BLEN stoves will lead to higher biomass fuel consumption and higher exposure to particulate matter. The second indicator relates to clean fuel availability

Table 1. Comparing the current framework (CF) for measuring progress towards SDG 7.1 with the alternative framework (AF).

Goal	Currently measured	Alternative framework
SDG 7.1.1	Grid OR Off-grid electricity access	<i>Services:</i> access to at least decent energy services ^a , AND <i>Availability:</i> electricity available for ≥ 16 hours per day, AND <i>Affordability:</i> electricity expenditures $\leq 5\%$ of median quintile expenditures ^b
SDG 7.1.2	Stated BLEN primary stove	<i>Timeuse:</i> $\geq 80\%$ of daily cooking time using BLEN stoves, AND <i>Availability:</i> BLEN fuels available for 10 months of the year, AND <i>Affordability:</i> fuel expenditures $\leq 5\%$ of median quintile expenditures ^c

^a Decent energy services are considered as access to at least light, phone, and either TV, fridge or cooling.

^b Annual electricity expenditures $\leq 5\%$ of median annual household expenditures by quintile.

^c Annual clean cooking fuel expenditures $\leq 5\%$ of median annual household expenditures by quintile.

(at least 10 months per year). This draws directly from the similar dimension for fuel availability in the MTF, using the tier 4 threshold.

For both cooking and electricity, we also attempt to address some of the concerns raised over an adequate measure of affordability, using the median annual (non-energy) expenditures within each quintile as the denominator when determining the relative share of actual expenditures on electricity and clean cooking fuels. While this does not adequately capture the freedoms and burdens of poorer households engaging in manual drudgery or subsistence farming, the use of quintiles and actual expenditures enables at least a naive estimation of an affordability threshold for energy consumption at each segment of the expenditures distribution, including for those households not reporting monetary expenditures. Furthermore, our analysis of affordability is cognisant of the case where a household is considered served by both SDG7.1.1 and SDG7.1.2, that is, has access to both modern electricity and clean cooking fuels. For these households, we sum the expenditures on electricity and cooking fuels and assess whether this is below 10% of the median annual (non-energy) expenditures within each quintile. We then assign the outcome to both electricity and clean cooking affordability dimensions within the AF.

An overview of the revised AF and comparison with the current SDG 7.1 indicators is provided in table 1. We want to emphasise here that our definition of thresholds is a first step and must be refined following further analysis of survey data, as discussed later in this work. Furthermore, national-level energy poverty assessments will in most cases continue to require a multi-tier approach as shown in the original AF / MTF, and this is in turn requires further discussion as to the contextually appropriate tier thresholds.

We apply the AF across ten countries using household survey data gathered under the World Bank's Energy Sector Management Assistance Program (ESMAP) Multi-tier Framework for Measuring

Energy Access (MTF) surveys. As of writing, nationally representative survey data is available for Rwanda, Ethiopia, Cambodia, Myanmar, Honduras, Nepal, Kenya, Niger, Sao Tome and Principe and Zambia (Dave et al 2018, Koo et al 2018, 2019, Padam et al 2018, Brutinel et al 2019, Pinto et al 2019, 2020, Brutinel 2020, Luzi 2020, Luzi et al 2020).

The survey data across all ten countries is generated using similar surveys, though contextual differences and improvements between earlier (2018) and later (2020) surveys are evident. Cross-country comparison thus requires extensive data cleaning and processing to produce a homogeneous data set, though missing value issues at different levels of severity remain. Table 2 describes the total number of households satisfying SDG 7.1 in each country, and the corresponding complete cases across relevant AF dimensions for this sub-population, which ideally should be 100%. MTF surveys in Rwanda and Sao Tome & Principe did not include questions regarding household expenditures, and thus limit the application of the affordability indicator. Details on how the survey data sets were homogenised and used to derive the AF dimensions are provided in the appendices. A replication archive containing all raw MTF survey data and R programming language scripts necessary to recreate the final analysis data set is available here (<https://doi.org/10.7910/DVN/DP2V5I>).

Alongside our main descriptive analysis, we also examine whether there are any systematic patterns in the characteristics of households that lack service in different AF dimensions even though they are considered 'served' by the current SDG 7.1 indicators. To do so, we use regression analysis to test the relationships between income (using expenditures as a proxy) and the multi-dimensional supply characteristics defined by the AF. While this is by no means indicative of any causal relationship, trends identified could potentially motivate a deeper analysis of inequities hidden by binary indicators. We conduct our analysis using the following linear

Table 2. Summary table describing the total number of households considered to satisfy SDG 7.1 as per the current framework, and the total complete cases for each individual AF dimension for these households following data cleaning and processing.

	Rwanda	Ethiopia	Cambodia	Myanmar	Honduras	Nepal	Kenya	Niger	STP	Zambia
Total households	3295	4317	3301	3420	2815	6000	4285	4006	2135	3537
SDG7.1.1 households	1734	3224	3165	3175	2395	5608	2915	2019	1160	1413
Energy services completeness	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Supply availability completeness	88%	97%	97%	99%	100%	100%	95%	94%	89%	92%
Supply affordability completeness	0%	79%	94%	67%	67%	79%	87%	92%	0%	32%
SDG7.1.2 households	26	564	1905	1218	1325	2200	909	476	28	443
Stove time-use completeness	100%	98%	96%	99%	96%	100%	57%	100%	93%	100%
Fuel availability completeness	92%	93%	98%	100%	80%	100%	96%	96%	89%	100%
Fuel affordability completeness	0%	84%	94%	37%	67%	97%	76%	70%	0%	28%

probability model applied to the the pool of households considered served by the current SDG 7.1 indicators:

$$\begin{aligned} \text{AFdimension}_i = & \beta_1 \text{ExpenditureQuintile}_i \\ & + \vartheta_i \text{Country} \times \text{Rural} \\ & \times \text{Admin2} + \varepsilon_i \end{aligned} \quad (1)$$

where AFdimension is a binary outcome variable reflecting that the electricity supply provided to household_{*i*} satisfies one of the individual AF dimensions, depending on the model. ExpenditureQuintile is a vector of dummy variables indicating which expenditure quintile the household belongs to, omitting the bottom quintile. We include Country × Rural × AdminLevel2 fixed-effects, adjusting as far as possible for time-invariant differences across and within the surveyed countries. ε represents the error term and robust standard errors are clustered at the primary sampling unit level.

3. Access measurement comparing existing binary indicators with the AF

The results of applying the AF across ten countries surveyed under the World Bank MTF survey are depicted in figure 1, which compares measurement of progress towards SDG 7.1 using the current indicators against the AF. Access measured by the current indicators are shown by the wider bars and the share of these households that also satisfy each AF dimension are shown by the thinner inset bars. Data quality issues notwithstanding (especially for energy affordability, see section 2), this comparison indicates that we are further from modern, reliable and affordable access to energy for all than the current SDG 7.1 indicators would suggest. The deficit is evidently heterogeneous across the individual dimensions of the AF, with greater deficits in certain dimensions depending on the country in question.

For SDG 7.1.1 (electricity), affordability appears to be the most widespread constraint, with at best 93% (Ethiopia) and at worst 29% (Niger) of SDG 7.1.1 households allocating less than 5% of their annual expenditures towards electricity consumption. We find the most variance in household utilisation of decent energy services, which varies from 100% (Nepal) to just 37% (Ethiopia) of electrified households. Finally, decent supply availability is provided to at best 92% (Honduras) and at worst 51% (Ethiopia) of those households considered to have access by the existing SDG 7.1.1 indicator.

Although progress towards SDG 7.1.2 (clean cooking) is far poorer, deficits in individual AF dimensions provide further evidence of major bottlenecks to improved access. Once again, we find that affordability appears to be the most widespread constraint, with at best 82% (Cambodia) and at worst just 25% (Zambia) of SDG 7.1.2 households allocating less than 5% of the annual expenditures on cooking fuels. We also find that stove stacking, that is, continued use of solid-fuel cookstoves despite stating primary reliance on a BLEN stove is also evident, with at best 100% (Honduras) and at worst 41% (Cambodia) of SDG 7.1.2 households using their BLEN stove(s) for at least 80% of typical daily cooking time. It should be noted that the survey data for Honduras did not capture stove stacking, see the supplementary materials. Finally, fuel availability does not appear to be a major constraint in any of the countries surveyed among households considered to have clean cooking access according to the current SDG 7.1.2 indicator, with the vast majority of households having access to clean cooking fuels for at least 10 months of the year.

We now compare these findings with aggregates of corresponding dimensions from the MTF ESMAP reports described in tables 3 and 4. The intention here is twofold. Firstly, we demonstrate accurate reproduction of the reported aggregates in terms

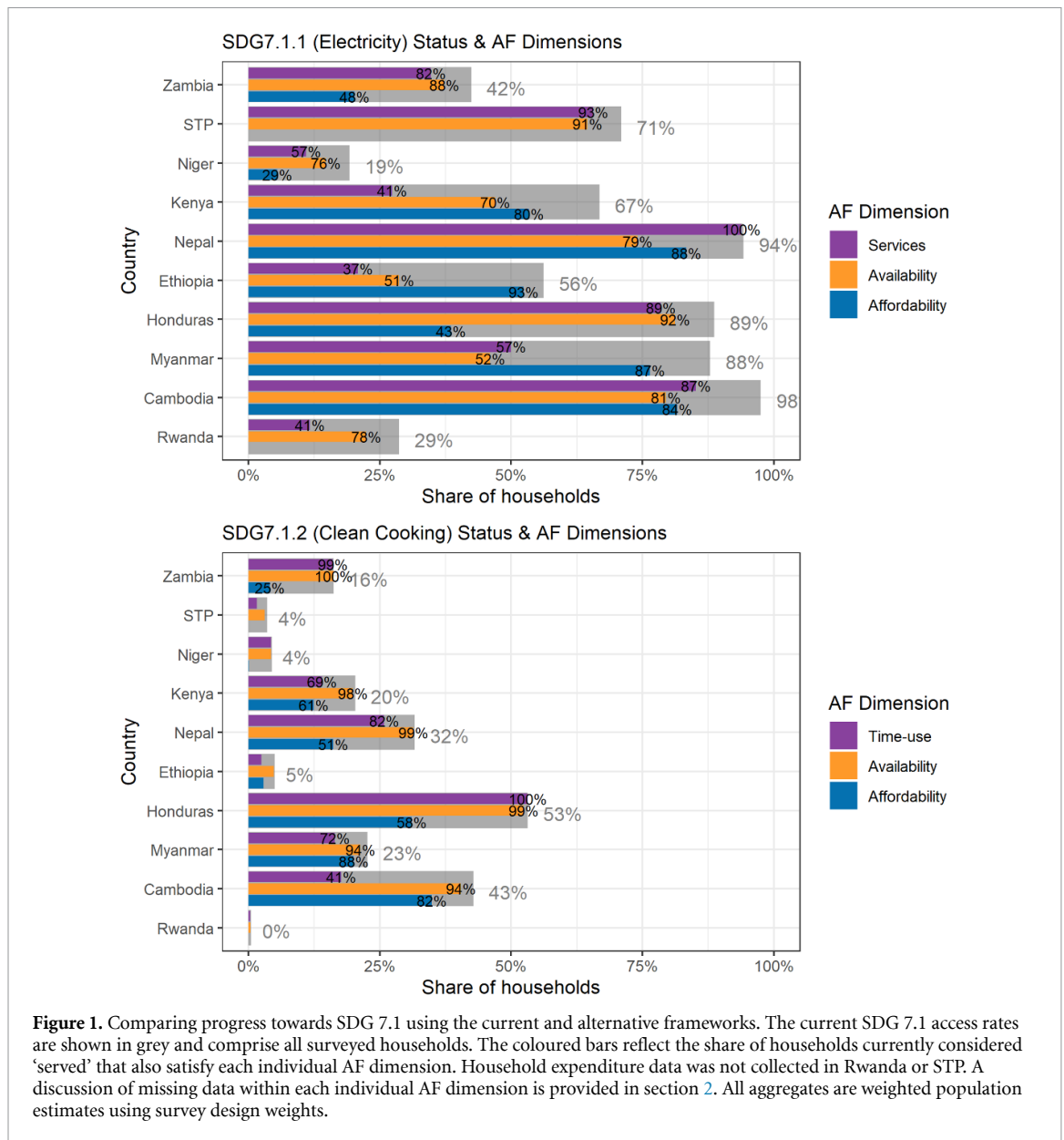


Figure 1. Comparing progress towards SDG 7.1 using the current and alternative frameworks. The current SDG 7.1 access rates are shown in grey and comprise all surveyed households. The coloured bars reflect the share of households currently considered ‘served’ that also satisfy each individual AF dimension. Household expenditure data was not collected in Rwanda or STP. A discussion of missing data within each individual AF dimension is provided in section 2. All aggregates are weighted population estimates using survey design weights.

Table 3. Multi-dimensional supply aggregates retrieved from the ESMAP MTF reports. Aggregates are weighted population estimates and those with subscript Report refer to aggregates taken directly from the MTF report. Grid and OG refers to those households stating Grid or Off-grid electricity usage. Availability and Affordability aggregates reflect only those households with access to electricity. Availability refers to at least MTF tier 4 (16 hours day time, 4 hours night time), and Affordability refers to at least MTF tier 4 (nominal annual consumption of 365kWh from the national grid costing less than 5% of annual household expenditures). Data sources: (Dave et al 2018, Koo et al 2018, 2019, Padam et al 2018, Brutinel et al 2019, Pinto et al 2019, 2020, Brutinel 2020, Luzi 2020, Luzi et al 2020).

Country	Grid	Grid_Report	OG	OG_Report	Availability	Availability_Report	Affordability	Affordability_Report
Zambia	38%	38%	4%	5%	88%	87%	48%	84%
STP	70%	69%	2%	2%	90%	92%	0%	—
Niger	16%	16%	4%	4%	76%	85%	28%	58%
Kenya	38%	39%	30%	26%	70%	70%	80%	98%
Nepal	72%	72%	22%	23%	78%	78%	88%	100%
Ethiopia	34%	33%	22%	24%	52%	51%	94%	100%
Honduras	84%	84%	4%	4%	92%	92%	44%	96%
Myanmar	38%	39%	48%	48%	52%	51%	88%	100%
Cambodia	72%	72%	26%	26%	82%	75%	84%	91%
Rwanda	24%	24%	6%	5%	78%	77%	0%	—

of primary fuel usage, which should be identical in the absence of data issues. Secondly, we compare the share of households with access to electricity or clean

cooking fuels achieving at least MTF tier 4 for availability and affordability as per the MTF definition and decent supply as per the AF definition. We select

Table 4. Multi-dimensional supply aggregates retrieved from the ESMAP MTF reports. Aggregates are weighted population estimates and those with subscript Report refer to aggregates taken directly from the MTF report. BLEN refers to those households stating they use a primary clean cookstove. Timeuse refers to the AF definition of clean cookstove usage. Availability and Affordability aggregates reflect only those households stating access to clean cooking. Availability refers to at least MTF tier 4 (10 months of the year), and Affordability refers to at least MTF tier 4 (annual fuel expenditures less than 5% of annual household expenditures). Data sources: (Dave et al 2018, Koo et al 2018, 2019, Padam et al 2018, Brutinel et al 2019, Pinto et al 2019, 2020, Brutinel 2020, Luzi 2020, Luzi et al 2020).

Country	BLEN	BLEN _{Report}	Availability	Availability _{Report}	Affordability	Affordability _{Report}
Zambia	16%	17%	100%	97%	26%	75%
STP	4%	1%	86%	—	0%	—
Niger	4%	5%	98%	93%	2%	93%
Kenya	20%	16%	98%	—	60%	79%
Nepal	32%	28%	100%	99%	50%	86%
Ethiopia	4%	4%	98%	96%	58%	72%
Honduras	54%	36%	98%	99%	58%	85%
Myanmar	22%	24%	94%	—	88%	81%
Cambodia	42%	33%	94%	84%	82%	94%
Rwanda	0%	0%	94%	—	0%	—

these two variables and tiers from the MTF as they are the closest to the dimensions and thresholds defined within the AF. Comparison of the actual use of these energy sources (either energy services or cooking time-use) is not possible as this is not consistently discussed within the MTF reports.

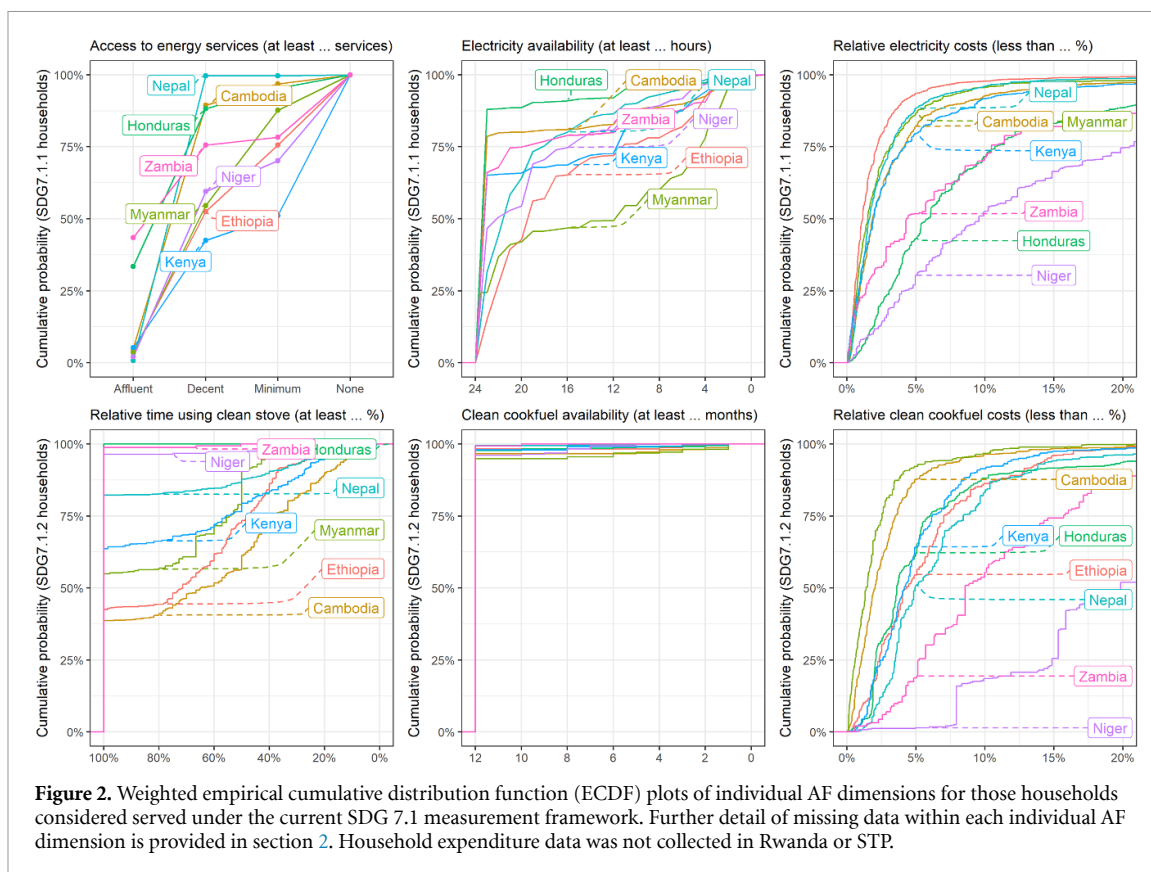
The availability dimension broadly aligns with that reported in our application of the AF as expected, given that the definition of decent availability is identical to at least tier 4 availability within the MTF for both electricity and cooking. Nonetheless, differences in these aggregates are indicative of discrepancies between the raw MTF datasets and corresponding reports, underlining the importance of transparent data processing and preparation as we attempt to do in this work (see replication archive). The affordability attribute diverges quite significantly due to the difference in how this is defined between the two frameworks. Evidently, the definition within the AF is stricter and indicates that while a basic level of energy consumption as tested in the MTF may be affordable (see Bhatia and Angelou (2015)), the actual energy expenditures of households commonly exceed the 5% expenditure threshold accepted as defining affordable energy access.

Overall, while this comparison points towards unresolved data quality issues (as discussed in section 2), it is clear that even when using the reported MTF aggregates, a sizeable subset of households that would be considered served under the current SDG 7.1 indicators do not have access to affordable or reliable access to modern energy sources.

Our selection of thresholds in the AF draws from prior work (see (Bhatia and Angelou 2015), Rao and Min (2017) and Pachauri and Rao (2020)), to enable a pragmatic multi-dimensional assessment of progress towards SDG 7 reflecting the actual wording of the goal. Nevertheless, the thresholds that we have selected for each dimension will certainly invite debate as to what constitutes decent energy access at the global and country levels. To support this discussion, we provide further empirical evidence from the

countries surveyed under the MTF. Figure 2 describes the cumulative share of households considered served under the current SDG 7.1 indicators (y -axis) that are also likely to reach a given threshold for each AF dimension (x -axis). These plots are agnostic to pre-determined thresholds and describe the actual distribution of each AF dimension among the SDG 7.1.1 (electricity) and SDG 7.1.2 (clean cooking) populations within each country. We include a separate visualisation of the affordability attribute for those households considered served by both SDG7.1.1 and SDG7.1.2 in the supplementary materials, as it is not possible to distinguish between these households (where the affordability threshold increases to 10% as described earlier) and others in the visualisation shown here.

These visualisations serve to inform the debate as to what an appropriate threshold for each dimension may be, and how this would change the population considered served across each AF dimension. Notably, the data does not suggest the presence of a natural threshold for any of the AF dimensions. Rather, we can draw two main conclusions. Firstly, it is likely that normative criteria need to be developed to establish global-level thresholds for what constitutes decent access under the framework for SDG7.1. This determination could build on the literature describing basic ‘needs’ as we have done, and may also benefit from a deliberative process across multiple countries to develop equitable and acceptable targets informing global agenda setting. Secondly, the distributions suggest that further prioritisation of households below whatever threshold is set is necessary at the country-level, as for example attempted by the tiers within the original AF / MTF. The work we present here is primarily concerned with the former, namely the definition and measurement of global progress towards SDG 7. Efforts to improve country-level measurement motivated by this work should begin with an assessment of the original AF / MTF and associated critical literature (see Bhatia and Angelou (2015), Trace (2015), Pelz et al (2018)).



4. Inequities in access and associated factors

We further motivate our central argument by now describing inequities hidden by the current binary indicators. To do this, we apply a linear probability model linking total expenditures as a proxy for income with the likelihood that households considered served by the current indicators also achieve each individual AF dimension. The hypothesis we test is whether the current indicators systematically count lower-income population sub-groups as served although they fail to receive affordable or reliable modern energy services as defined within the AF.

Ordinary least squares estimates describing the likelihood to achieve each AF dimension are presented in tables 5 and 6. The coefficients are estimates of the percentage-point change (to interpret, use $\beta \times 100$) in the probability of satisfying each individual AF dimension associated with a step-change in income (using the expenditure quintile as a proxy for income). Further descriptive analysis of access levels by expenditure quintile are provided in the supplementary materials.

The results suggest that inequities in decent electricity access among households considered electrified by a modern source (SDG 7.1.1) are associated with household income (expenditure quintile). Conditional on having electricity access, the likelihood a

household has access to decent energy services and supply availability increases for households in the upper expenditure quintiles. In contrast, conditional on having access to a clean cookstove as per the current binary indicators (SDG 7.1.2), we find no systematic association between income (expenditure quintile) and the likelihood to have decent clean cookstove time-use and clean fuel availability. We do note that this might be due to the fact that access to clean cooking in most of these countries is significantly lower than electricity access. Our analysis may thus be confounded by the fact that even higher income households lack access, thus muting the potential systematic differences across income quintiles for these dimensions.

Supply affordability appears to be more sharply associated with income for clean cooking fuels than electricity supply. This is likely to be related to the widespread usage of block tariffs for electricity supply. Block tariffs provide lower-income households that consume lower net amounts of energy with a cheaper flat rate in order to combat the naturally regressive nature of fuel affordability where consumption and corresponding costs rise less quickly than corresponding rising incomes as wealth increases. This tariff structure is broadly unavailable for clean cooking fuels and thus is quite likely a driver of the inequalities across expenditure quintiles we observe.

Table 5. Ordinary least squares estimates of linear probability models linking individual dimensions of electricity access with household income, for those households considered served under the current SDG 7.1.1 aggregate. Household expenditure data was not collected in Rwanda or STP.

Dependent variables: Model:	Decent services (1)	Decent availability (2)	Decent affordability (3)
<i>Variables</i>			
ExpenditureQuintile2	0.074*** (0.015)	0.022 (0.024)	0.080*** (0.020)
ExpenditureQuintile3	0.105*** (0.019)	0.070*** (0.022)	0.131*** (0.021)
ExpenditureQuintile4	0.162*** (0.019)	0.084*** (0.024)	0.194*** (0.021)
ExpenditureQuintile5	0.231*** (0.021)	0.109*** (0.023)	0.278*** (0.021)
<i>Fixed-effects</i>			
Country×Rural×AdminLevel2	Yes	Yes	Yes
<i>Fit statistics</i>			
Observations	23 896	23 292	18 489
R ²	0.56 939	0.56 416	0.28 376
Within R ²	0.03 588	0.01 012	0.02 870

One-way (PSU) standard-errors in parentheses

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 6. Ordinary least squares estimates of linear probability models linking individual dimensions of clean cooking access with household income, for those households considered served under the current SDG 7.1.2 aggregate. Household expenditure data was not collected in Rwanda or STP.

Dependent variables: Model:	Decent time-use (1)	Decent availability (2)	Decent affordability (3)
<i>Variables</i>			
ExpenditureQuintile2	-0.072* (0.040)	0.003 (0.022)	0.186*** (0.041)
ExpenditureQuintile3	-0.102*** (0.038)	0.015 (0.022)	0.228*** (0.036)
ExpenditureQuintile4	-0.084** (0.033)	0.016 (0.018)	0.519*** (0.032)
ExpenditureQuintile5	-0.062* (0.032)	0.014 (0.018)	0.723*** (0.032)
<i>Fixed-effects</i>			
Country×Rural×AdminLevel2	Yes	Yes	Yes
<i>Fit statistics</i>			
Observations	8485	8631	6879
R ²	0.40 569	0.15 119	0.41 888
Within R ²	0.01 078	1.37 × 10 ⁻⁵	0.16 189

One-way (PSU) standard-errors in parentheses

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

5. Discussion

Increased international attention and efforts towards advancing access to modern energy services globally has certainly resulted in significant progress in extending connections to electricity and clean cooking. Official indicators to track the SDG 7.1 targets paint an optimistic picture of how much progress has been made over the last few years. However, this stands at odds to contemporary assessments that look beyond mere connections to modern energy sources (Dave et al 2018, Koo et al 2018, 2019, Padam et al 2018, Brutinel et al 2019, Falchetta et al 2019, Pinto et al 2019, 2020, Brutinel 2020, Luzi 2020, Luzi et al 2020). In this work, we present an AF for broadening

the current narrow focus in the SDG 7 indicators to track critical dimensions of energy provisioning and household capabilities that link more closely with how energy services can enhance well-being. We apply this new AF across ten countries to measure energy access and provide empirical evidence of how the current indicators underestimate energy poverty and neglect decent access.

Our application of the AF clearly illustrates that households officially counted as having access to modern energy sources, in many instances, still benefit only from minimal energy services, receive unreliable energy supply, and struggle with being able to afford energy services they need to enjoy a decent standard of living. Moreover, our descriptive

regression analysis reveals that poorer households (using expenditures as a proxy for income) are over-represented in this group. We argue therefore that the current indicators for measuring progress towards SDG7.1 are insufficient in signaling who benefits from access to modern energy services, whether certain population groups or regions are of particular concern, or indeed whether policy needs to be targeted at energy suppliers or end-users or both. The narrow indicators used in measuring global progress towards SDG7.1 reflect narrow ambitions, masking the difficult reality that we are further from the goal of being able to provide affordable, reliable and modern energy for all than currently reported, and that poorer population sub-groups are more often provided sub-standard access.

The study has some limitations that point clearly to avenues for future work. We limit our analysis to those dimensions we feel are relevant at the global level in alignment with the SDG 7.1 target wording. Similar empirical analysis and deliberation to determine context-specific thresholds across other dimensions captured within the MTF surveys could support the improvement of country-level targets including other important dimensions related to safety and quality. Even at the global level, our definition and application of the AF is an impulse to motivate further discussion, and by no means the final iteration. For instance, the AF definition of affordability does not capture the capital outlays required to purchase energy end-using appliances and equipment or how irregular cash inflows might effect ability to pay for specific households.

We use the MTF surveys that are specifically designed to capture aspects of energy choice and use. While this makes them fairly comprehensive, it is not clear how widely and regularly these can be administered. Furthermore, as we discuss in section 2, the MTF survey datasets require extensive processing and cleaning in order to homogenise the different survey structures in each country. This process is outlined in our replication archive and transparently identifies missing data with varying levels of severity across each country surveyed (see table 2). While for both electricity and clean cooking, availability and use dimensions appear to be well reported (excepted for stove time-use in Kenya, where only 57% of SDG7.1.2 households responded), affordability appears to be generally poorly reported across the MTF datasets. At the same time, the discrepancies between the raw MTF survey data aggregates and MTF reports underlines the need for standardisation and integration into a consistent data structure as is currently being conducted within ESMAP. In parallel to these efforts, appending additional questions to regularly repeated surveys such as the DHS, LSMS, MICS etc that can help capture these dimensions should be explored. Such initiatives are already being discussed by the WHO in partnership with the agencies that carry out

these surveys (WHO 2019). Finally, other sources of data such as those from Earth observations, citizen science etc can also supplement surveys for tracking modern energy access.

In summary, the proposed AF, introduced in this work, is an example of how the current indicators for measuring progress towards SDG 7.1 can be strengthened with the inclusion of measures for actual energy services utilisation and quality, which reflect the actual developmental and well-being improvements that energy access can unlock. Such improvements are critical to meet the UN's ambitious 'leave no one behind' agenda. It can also pave the way for agenda setting and policy development that recognises and addresses broad inequities in household capabilities to use modern energy towards achieving a decent living standard.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: <https://doi.org/10.7910/DVN/DP2V5I>.

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