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Measures of Energy Destitution: A New Complemented Methodology

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Abstract

Although the multidimensional energy poverty index (MEPI) gauges the extent and depth of energy poverty but overlooks gradations among energy-poor households that also have vital importance, as understanding degrees of energy poverty will lead to their reduction subsequently. This inability to differentiate the poor from the poorest urges to take a step further and design a new deep and complemented methodology, Measures of Energy Destitution: a subset of the MEPI and denoted with a superscript MEPI^{D}. All the parameters such as dimensions, indicators, and weights have remained unchanged except for deprivation cut-offs and poverty cut off- an intensity approach sets a stringent poverty cut-off, and a depth approach constitutes an extreme deprivation cut-off to discriminate between the energy-poor and the poorest (destitute). With the application of these novel approaches, we can calculate the extent, depth, and degrees of 'energy destitution' across the multiple dimensions of energy services. The results showed widespread energy destitution across the 59 selected countries. Consequently, it is helpful to assess the status of energy-destitute households and eradicate severe energy poverty by announcing various additional incentives, allocating resources, and providing special assistance to those who are at the bottom.

Keywords*:* Energy destitution; MEPI; Intensity approach; Depth approach; Policy implications; Asia, Africa

Introduction

Policy efforts and incentives to eradicate energy poverty may leave extreme energy-poor households behind because that requires some additional incentives and effective support programs. The inability to identify those who are at the bottom does not provide additional incentives and financial support to ameliorate the conditions of those who are susceptible to extreme

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energy poverty, who may have different characteristics as compared to moderate poor (Devereux 2003) and their deprivations may be more chronic deprivations comparatively (Harriss-White 2005; Alkire et al. 2015). Thus, it is an important question to ask whether energy poverty reduction has actually taken place among extreme energy-poor households or not. For that, the identification of those who are exposed to chronic forms of energy poverty is imperative. To achieve these objectives, this study proposes a new complemented methodological approach as a subset of the multidimensional energy poverty index (MEPI) to identify the households susceptible to extreme energy poverty setting more stringent and deep thresholds and examining the situation of the 'ultra-poor' (Hulme 2003; Hulme and Shepherd 2003) across the various modern household energy services.

The newly designed deep and complemented methodology, Measures of Energy Destitution, is denoted with a superscript $MEPI^{D}$, as it is a subset of the multidimensional energy poverty index (MEPI) and has a slightly different methodological approach comparatively. Though it uses the same parameters such as dimensions, indicators, and weights specified in the MEPI, deprivation cut-offs and poverty cut off are changed. A household can be identified as multidimensional energy destitute if the intensity of deprivations and deprivation scores exceed or are equal to a particular energy poverty threshold. It can be assessed by employing two approaches in this study. The first is to use a 'stringent' or higher cross-dimensional energy poverty cut off and the second approach applies 'deep/extreme' deprivation cut-off vectors to identify the dimension-wise poorest household (Lipton 1988; Alkire and Seth 2016). These parameters are assessed to identify the situation of extreme energy poverty or destitution across the selected countries of Asia. It measures the inequality level or gradations among the energy-poor households at the national, subnational, or regional levels. The term 'destitution' was coined from a multidimensional perspective for the identification of the poorest of the poor (Halder and Mosley 2004). Here, we will be using the word 'stringent' to refer to a subset of the multidimensional energy-poor households, which are strictly poorer than the subset we denote as 'moderately' poor. Thus, it is helpful to investigate the status of multidimensional energy destitution and subsequently, eradicate severe energy poverty by announcing different additional incentives, allocating resources, and providing special assistance to those who are at the bottom.

Literature review

As energy poverty is a complex and multi-faceted concept (González-Eguino 2015), different indicators were employed by the researchers to gauge, understand, and monitor energy poverty. The multidimensionality of the concept leads to capture its social, economic, and technical aspects adequately through a set of indicators (Rademaekers et al. 2014). Various researchers had proposed and discussed energy poverty measuring models with various simple and complex indicators. These indicators have their shortcomings and benefits and differ from each other based on measuring approaches and ultimate targets. Broadly speaking, all these indicators can be examined in two categories: unidimensional vs. multidimensional indicators.

Unidimensional indicators only measure the occurrence of energy poverty (headcount ratio) focusing on one aspect of deprivation such as 10%, MIS (minimum income standard), HEP (hidden energy poverty), AFCP (after fuel cost poverty), and LIHC (low-income high cost) indicators that take income or consumption against energy expenditures a standard parameter to distinguish deprived from non-deprived (Thomson and Bouzarovski 2018). The multidimensional indicators superseded unidimensional indicators because of their inability to measure the intensity (how much poor) of energy poverty along with the headcount ratio: prominently MEPI, a worldly recognized indicator to measure deprivations across the multiple dimensions of domestic energy services (Castaño-Rosa et al. 2019). Likewise, unidimensional indicators only use a single index to measure energy poverty whereas multidimensional indicators employ composite indices to understand, gauge, and monitor the multidimensionality of the concept and its potential implications (Patrick Nussbaumer et al. 2012). Thus, composite indices were developed to capture multiple attainments or multidimensionality to quantify and characterize the less tangible concepts in nature like sustainable development. In this way, it can be argued that composite indices give a useful statistical summary of particular issues, keeping in mind their limitations.

Yet, with the methodological soundness of all the above-mentioned indicators, they were questioned on several grounds such as they overlooked the gradations/inequalities of energy poverty. Even efforts made by the MEPI were scarce and unable to distinguish the poorest from the moderately poor. Such distinguishes and gradations require setting different

cut-offs to identify the poorest, which is also one of the pivotal steps to be taken for the measurement of extreme energy poverty (Gouveia, Palma, and Simoes 2019). Thus, it is crucial to take a step ahead and design a new complemented approach to differentiate the ultra-poor from the moderate poor and extreme energy poverty from moderate energy poverty. The energy destitution approach, denoted with a superscript $MEPI^D$, as a subset of multidimensional energy poverty (MEPI) is proposed in this paper to understand the different degrees/inequalities of multidimensional energy poverty. The MEPI is designed to quantify 'acute' energy poverty (Sen 1976; Alkire, Kanagaratnam, and Suppa 2022; Admasu, Alkire, and Scharlin-pettee 2022) whereas the $MEPI^D$ is an indicator of measuring 'extreme/severe' multidimensional energy poverty.

Methods

This methodology is inspired by the work of Sabina Alkire, Adriana Conconi, Suman Seth, Jose Manuel Roche, and Ana Vaz on the measures of multidimensional poverty with the collaboration of the Oxford Poverty and Human Development Initiative (OPHI) (Patrick Nussbaumer et al. 2012; Abbas et al. 2020; Alkire, Kovesdi, and Scheja 2022). The methodology supersedes the multidimensional energy poverty index (MEPI), as it not only measures the intensity and headcount ratio of energy poverty but also the inequalities among multidimensional energy poverty that otherwise is overlooked completely. It enables us to understand the degrees of energy poverty and differentiates the poorest of the poor that can be very helpful to address the issue deeply, and ultimately leads to its reduction. It further paves the way to take necessary policy measures to remove energy destitution and addressing the conditions of those who are at the very bottom of the distribution.

Identifying the measures of energy destitute: a linked subset: To identify the energy destitute and differentiate it from the moderately poor, two parameters play their crucial roles to serve this purpose: deprivation cut off (z) and poverty cut off (k). All the other parameters such as dimensions, indicators, and weights specified in the MEPI have remained unchanged except for above mentioned two parameters. Deprivation cut-offs and cross-dimensional poverty cut off are made more stringent and deeper as compared to those of the MEPI. To obtain a more stringent cross-dimensional poverty cut off (k'), it should satisfy the condition $k' \geqslant k$ that requires a comparatively higher rate of simultaneous deprivations scores

across several dimensions. Here, the intensity approach is applied to make cross-dimensional poverty cut off (k) stricter and satisfy the condition (k' $\geqslant$ k) subsequently. The reports of the Oxford Poverty and Human Development Initiative (OPHI) proposed three cross-dimensional poverty cut-offs to examine the severity and degrees of energy poverty from vulnerability to extreme level. Energy 'vulnerability' can be simply measured by setting the poverty cut off k to 1/5 or 20% ($k \geqslant 20\%$). For example, if a household is deprived of more than one of the five dimensions of multidimensional energy poverty fixed and specified in the MEPI, that household will be considered 'vulnerable' regarding access to household energy services. Likewise, 'acute' energy poverty can be measured with 1/3 or 33% of cross-dimensional deprivations ($k \geqslant 33\%$) identifying simultaneous deprivation in two or more than two of the total dimensions.

The third proposed poverty cut off is 'severe' and the most stringent poverty cut off. It identifies 'extreme' energy poverty when poverty cut off k is set to 50% indicating the presence of deprivations in half of the total dimensions of basic energy services at the same time (Okushima 2017). As the MEPI uses an 'acute' energy poverty cut off, this study uses a 'severe' cross-dimensional poverty cut off as per the intensity approach to satisfy $k' \geqslant k$. For instance, a household can be identified as multidimensional energy destitute if the household is deprived of half of the dimensions of basic energy services that are ultimately higher and stringent than the threshold of acute energy poverty used in the MEPI.

Computing energy destitution with ordinal variables: deprivation cut-off vector: Another way to identify energy destitute is to choose 'strict/deeper' deprivation cut offs (z'), we use the depth approach to satisfy the condition $z' \leqslant z$. We obtain destitution deprivation cut off (zj^D) for all dimensions j lowering/deepening deprivation thresholds in communication, cooking, and ownership of household appliances than the deprivation cut off defined in the MEPI (Alkire and Foster 2011) as shown in Table 1. Ostensibly, the deprivation cut offs of the $MEPI^D$ for these dimensions are deeper than those defined in the MEPI. For instance, deprivation cut off is made deeper regarding the types of cooking fuels for the identification of cases for energy destitution. Dimensional energy destitution occurs when a household is only dependent on the consumption of wood or dung for cooking that is strict than the threshold set for the MEPI. Thus, these two approaches are combined to identify energy destitute or the ultra-poor and

to compute measures of multidimensional energy destitution ($MEPI^D$) in this study.

Table 1: Multidimensional Energy Destitution ($MEPI^D$): Dimensions, Indicators and deprivation threshold

Dimension	**Indicator (Weight)**	**Deprivation threshold** *Deprived if…*
Cooking	Type of cooking fuel (0.2)	***MEPI***: a household uses cooking fuel besides electricity, natural gas, biogas, and kerosene ***Dest*****:** a household cooks with wood and dung
	Indoor smoke (0.15)	***MEPI & Dest*****:** a household has not a separate room for cooking (no chimney or hood)
Lighting	Electricity access (0.2)	***MEPI & Dest:*** a household has no electricity access
Telecommunication	Assets ownership (0.15)	***MEPI:*** a household does not possess more than a mobile phone or landline telephone ***Dest*****:** it does not even have a mobile phone
Entertainment/ Education	Possession of concerned means (0.15)	***MEPI*****:** a household does not own more than a radio, TV or computer ***Dest*****:** it has no asset listed above (radio, television, computer)

Household Appliances	Ownership of assets (0.15)	***MEPI*:** a household does not have more than a fridge, washing machine, or fan ***Dest*:** it has no asset above mentioned (refrigerator, washing machine, fan)

Methodological notes: construction of MEPI^{D}: The existing literature provides a comprehensive discussion about the methodological notes of the MEPI, here, we propose a subset of the MEPI to identify the extremely energy-poor households using a stringent dual cut off identification approach and term energy 'destitute' is used to distinguish from the 'moderate' energy poor. Therefore, we start with n that presents the population, i =1,2, 3…. n, across the dimensions, j = 1,2, 3 ... d, of household energy services and n×d describes the matrix achievement of the individuals and variables (Y= y_{ij}) under consideration. Where dimension d is fixed (j=5), and n can be extended to the positive numbers. Likewise, $y_{ij}>0$ presents an individual i achievement in any variable j. Weight w is intuitively equally distributed among the considered variables j with a total weight $\sum_{j=1}^{d} wj = 1$ and $w_j \geqslant 0$ can be the achievements of any individual in any variable. We also take deprivation matrix g of the elements ij. Following, $g_{ij}>0$, if an individual i is deprived of variables j whereas $g_{ij} \leqslant 0$ denotes no deprivation across the row vector.

The row vectors describe the individual's i achievements in different variables *j* whereas column vectors present the distribution counts of variables among the individuals i. For example, if any household is deprived of a dimension d as per the deprivation threshold, the assigned weight (1/6 or 0.16) of that variable/dimension will be added to the row vector. We also construct a column vector Ci^{D} to accumulate the achievements of individuals across the dimensions. If any household is deprived of all dimensions, the aggregate weight of achievements of the household will be 1 and oppositely 0 in case of no deprivation in any dimension. For every variable j, zj^{D} denotes the destitution deprivation cut off, where $zj^{D} \geqslant 0$ presents the possible degrees of achievement, $zj^{D} \leqslant 0$ indicates no deprivation in any variable j, and $zj^{D}>0$ otherwise. Note that, to compute z_j^{D},

the depth approach is applied with stricter or lower cut offs than zj of the MEPI and it satisfies $z_j^D \leqslant zj$ for all variables j. For example, the possession of no assets leads to deprivation instead of owning a single means of entertainment/education or other household appliances.

Similarly, a strict poverty cut off $k' \geqslant k$ is taken to identify energy destitute and individual's high and intensive deprivations across the dimensions. If an individual's destitution counts (c_i^D) exceeds the stringent or higher poverty cut off threshold that is set to 50% ($k \geqslant .48$) as per allocated weights in the study, the household is considered the poorest of the poor or multidimensional energy destitute. According to the measures of energy destitution, the intensity approach is applied to acquire $k' > k$ stricter poverty cut off. If the destitution counts ci^D exceeds the stringent poverty cut off k', the household is multidimensionally energy destitute and $ci^D < k$ otherwise. Finally, $c_i^D > k$ is set to 1 to construct the censored matrix of multidimensional energy destitution $c_i k^D$, and $c_i^D < k$ is set to 0 for not being multidimensionally energy destitute. Now, we have explained all the pertinent hidden indices and notes of the methodology. Eventually, we can measure the headcount ratio (HD) of energy destitute households by computing and using the following equation (1):

$$H^D = q^D/\mathrm{n} \tag{1}$$

Where q^D presents the number of energy destitute households (truncated through a constructed censored column vector $c_i k^D$) and n presents the total number of populations. Now, we can also calculate the intensity (AD) of energy destitution employing equation (2):

$$A^D = \sum_{j=1}^{d} C_i^D(k) \Big/ q^D \tag{2}$$

Where, $C_i^D(k)$ denotes the total destitution counts (Ci^D) of the multidimensional energy destitute households and q^D presents the number of energy destitute households. Lastly, we can calculate multidimensional energy destitution ($MEPI^D$) as a product of intensity (A^D) and headcount ratio (H^D) of energy destitution using equation (3):

$$MEPI^D = H^D + A^D \tag{3}$$

Identification of multidimensional energy-poor vs. destitute: As per the differential identification of energy-poor and destitute is concerned, the households deprived of two or more dimensions of domestic energy services are identified as multidimensional energy poor. Whereas, if the household is deprived of more than three dimensions of the household energy services, that household is considered multidimensional energy destitute. As mentioned before, the poverty cut off k for the MEPI is set to 0.32, therefore, simultaneous deprivation in two indicators out of the total six exceeds the fixed threshold to identify the moderate energy poor. Similarly, the destitution cut off kD is fixed at 0.48 for the $MEPI^D$, so, contemporaneous destitution in three or more indicators surpassed this threshold. Subsequently, this identification presents an intuitively fine difference between both approaches bearing in mind their ultimate targets.

Relevant partial indices of MEPI and $MEPI_D$ and their relationship: Here, we discuss some further indices and their subsequent relationship with each other. There is an intuitive relationship between the headcount ratio of energy poverty (H) and destitution (HD), as all energy destitute households are already poor (moderate). The headcount ratio of energy destitution (HD) refers to a subset of energy-poor households who experiences additional extreme deprivations in multiple dimensions and HD/H is the shared ratio of that energy-poor who are identified as destitute. This mutual relationship is further explained in Figure 1.

Let suppose, the area OBCD is the total population n, vertical axis presents the deprivation cut off z on the left and poverty cut off k on the right side. The population is divided into two groups by deprivation cut off z, deprived (in two indicators at least) and non-deprived whereas the poverty cut off k splits the deprived into two further groups, 1) whose cross-dimensional deprivation counts equal or exceed poverty cut off k, and 2) whose simultaneous deprivation counts do not exceed the poverty cut off k. These two parameters together identify the observations of multidimensionally energy-poor, which is defined in the above area demarcated by a horizontal line zk (see in Figure 1): this proportion presents headcount ratio H of multidimensional energy poor (moderate poor).

The stringent deprivation cut off (that is actually the destitution cut off) zD and poverty cut off kD then differentiate the energy destitute among the multidimensional energy poor. The ratio of multidimensionally ener y destitute HD is defined by this proportion of the above area separated by a

horizontal line of zD and poverty cut off kD on the right side (see in Figure 1). Hence, moderately multidimensional energy poor are those who are poor but not energy destitute.

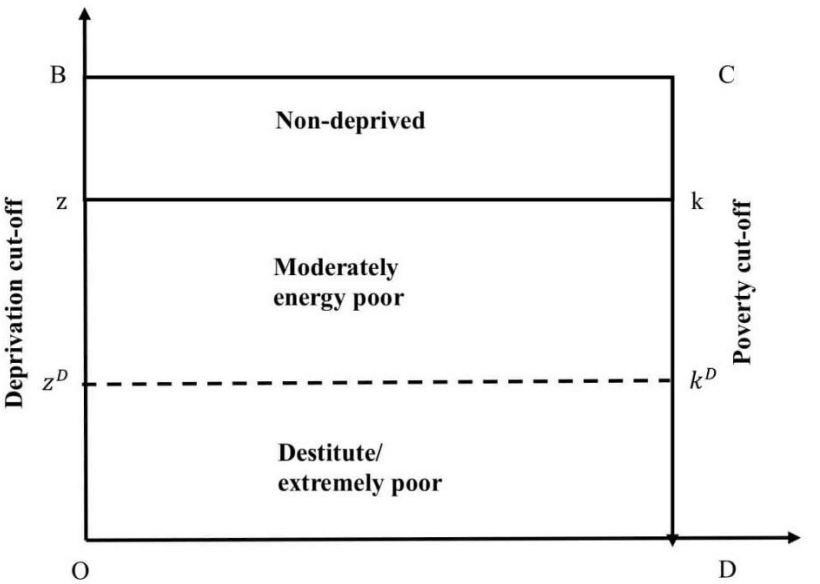

Figure 1: Decomposition of partial indices into '*moderate*' multidimensional energy poverty and '*destitution*'

This demonstrates a rigorous, comprehensible, and understandable comparative relationship between multidimensional energy poverty (MEPI) and destitution ($MEPI^D$). It also explains the new measures of energy destitution which utilize similar dimensional parameters, indicators, and weights but extreme poverty cut off kD and lower/deeper deprivation cut offs zD to compute the subset (extreme/severe) of the MEPI. Finally, this comprehensive description is quite applicable to grade multidimensional energy poverty, to differentiate the poor from destitute, and to compute the measures of multidimensional energy destitution.

Data availability

This study uses primary household survey data of 20 Asian and 39 Sub-Saharan African countries acquired from the USAID (United States Agency for International Development). The agency gathers the data in association

with the national institutes of involved countries and disseminates the information worldwide. The survey data, Standard DHS-VII, provides a complete demographic and health profile of the households and household possessions. In this regard, the data have all the necessary variables needed to all indicators of household multidimensional energy poverty and has theoretical as well as practical policy implications aimed to reduce energy poverty nationally, regionally, and globally. The survey data can be obtained from the agency after registering to its portal and making a formal request with a research proposal (USAID 2019).

Results and discussion

Figure 2 gives a summary of the whole discussion regarding the situation of energy destitute. In the Asian continent, the countries of South and Southeast Asia were found to have more deprived households mainly, which did not have access to clean and efficient energy fuels including Bangladesh, Cambodia, Myanmar, Nepal, and Afghanistan: Almost 40% of households in Myanmar, 35% in Cambodia, 30% in Afghanistan, 29% in Yemen, 27% in India and Nepal, 26% in Bangladesh, and 23% of households in the Philippines are susceptible to extreme energy poverty. Whereas this percentage rises to 52%, 48%, 44%, 35%, 35.5%, 40%, 44%, and 33% in terms of moderate household multidimensional energy poverty in the aforementioned countries respectively. Likewise, these are the countries with lower rates of household access to clean energy fuels for cooking and electricity.

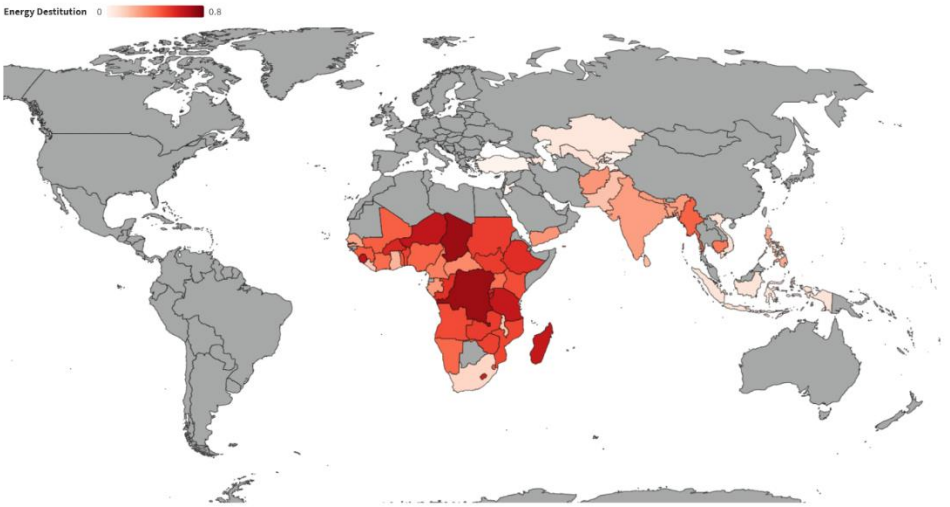

Figure 2: Results of multidimensional energy destitution in selected countries of Asia and Africa

In contrast to the situation of energy poverty in Asian countries, the African states face considerable precariousness in affordability and accessibility of basic energy services. Hardly a few nations have successfully provided electricity access to more than 50% of the households nationwide such as Cameron, Comoros, Eswatini, Gabon, Ghana, S. Tome & Principe, Senegal, and South Africa. The situation to access modern energy fuels for household consumption is even worse, exposing most of the population to the adverse health impacts of using inefficient and contaminated energy fuels. In addition, more than 50% of the households of most African countries are rated as multidimensionally energy poor. Only South Africa is an African country with the lowest cases of multidimensional energy poverty that is less than 15% of the total population. The empirical findings imply significant policy implications directed to energy poverty reduction. The governments must formulate policies particularly focused on the provision of basic energy services, especially universal electrification and clean cooking fuels. Further, policy measures should be taken to elevate the overall socioeconomic status of the households that will considerably be helpful to reduce any type of energy poverty (Abbas, Li, et al. 2020: Liu et al. 2022), moderate or severe and unidimensional or multidimensional, and mitigate the adverse health implications of multidimensional energy poverty ultimately (Liu et al. 2022), especially for women (Nadimi and Tokimatsu 2018), gender discrimination and forced human displacement

Figure 3 describes the deprivation rates across the household energy services for the selected countries of Asia. Most countries are deprived of household appliances indicating that they are unable to afford modern household appliances for cooling, washing, refrigeration, entertainment, and education. South and Southeast Asia have higher rates of unaffordability as compared to other regions of Asia. In contrast, over half of the households in Nepal, Yemen, Uzbekistan, and Kazakhstan are susceptible to indoor air pollution due to cooking in the living room rather than the kitchen and lack of proper ventilation systems such as chimney or hood.

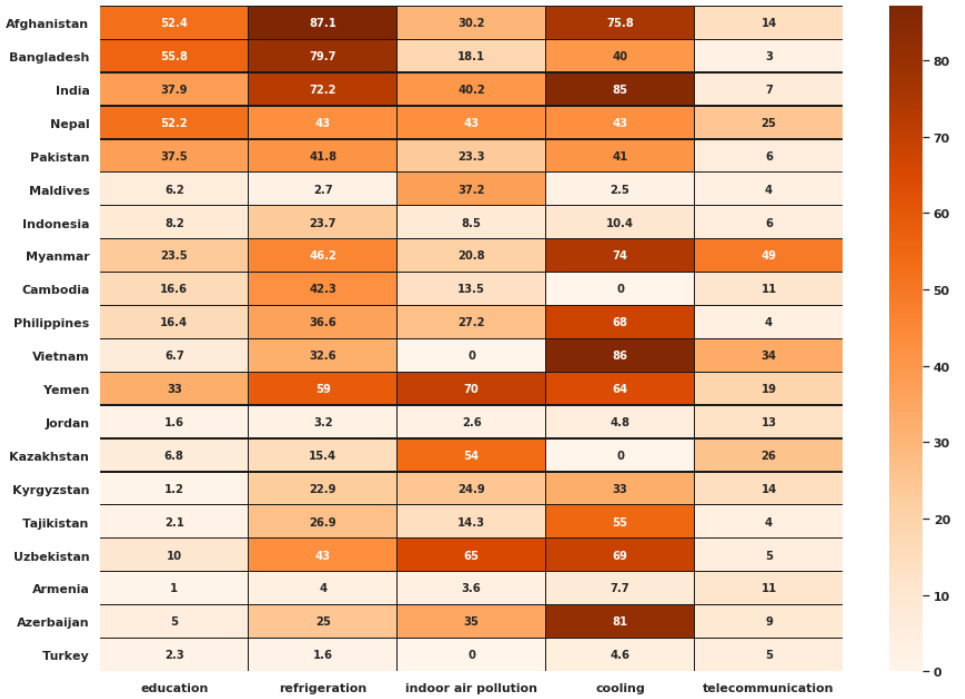

Figure 3: Dimension wise results of deprivation rates for Asian countries

Likewise, Figure 4 presents the deprivation rates in every dimension of energy service specified in the index for each African country. The results again demonstrated that the population in African countries were mostly deprived of assets of cooling or washing and refrigeration that were the main factors along with the inability to afford modern cookstoves and lighting to cause such a high percentage of multidimensional energy

destitution in Africa. Only a few countries such as South Africa, Eswatini, and Namibia had comparatively very lower deprivation rates overall in each energy facility.

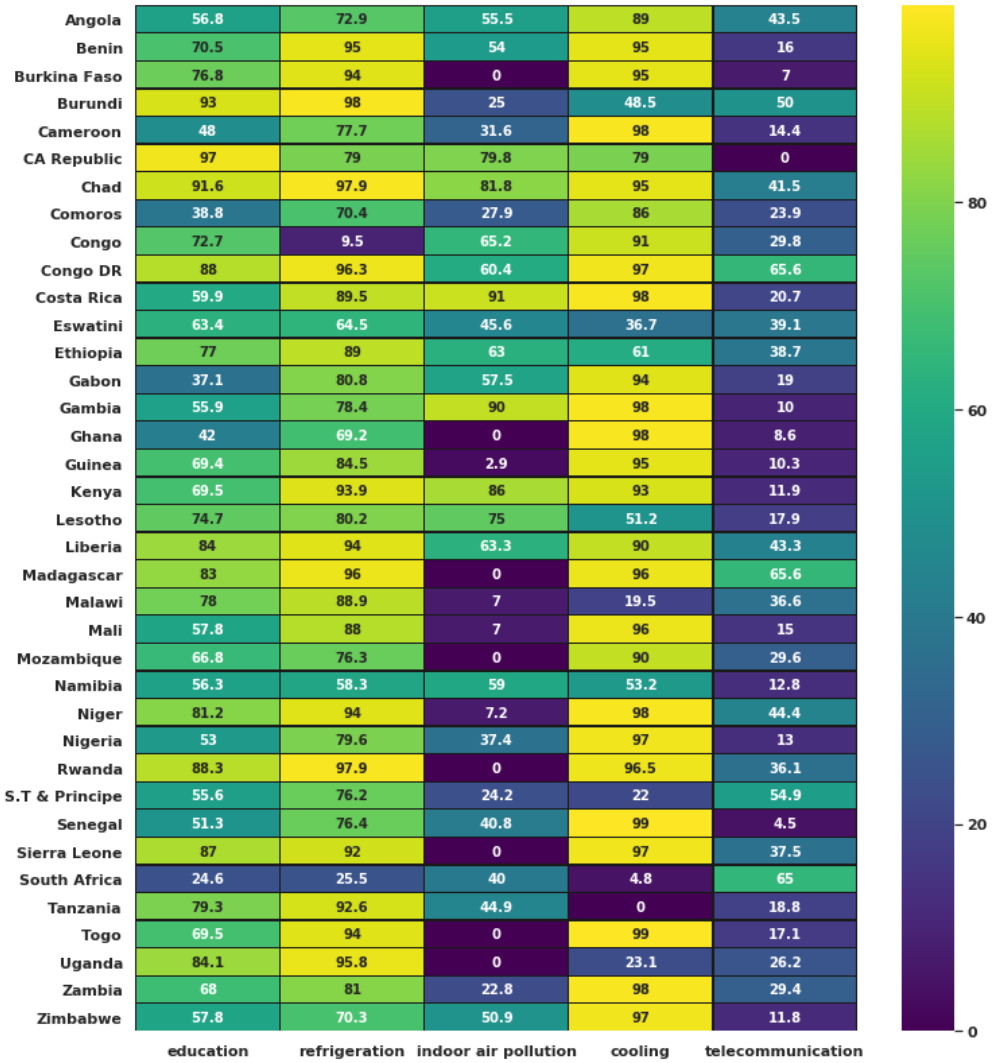

Figure 4: Results of deprivation rates in each dimension across the African countries

Further, Figure 5 and Figure 6 depicted that natural gas and firewood were the two most used domestic fuels for cooking in both Asia and Africa. When contaminated cooking fuels such as firewood, crops, straws, coal, charcoal,

and animal dung are used to prepare meals in poorly ventilated kitchens or enclosed rooms, it causes indoor air smoking. Several existing studies empirically conclude that indoor air pollution causes various health issues including respiratory diseases, lung cancer, cardiovascular problems, pregnancy, sterilization, and fertility, etc. (Abbas, Xu, et al. 2020). Jordan, Armenia, the Maldives, Uzbekistan, Kazakhstan, and Yemen had the highest reliance on efficient energy fuel like natural gas across the Asian states.

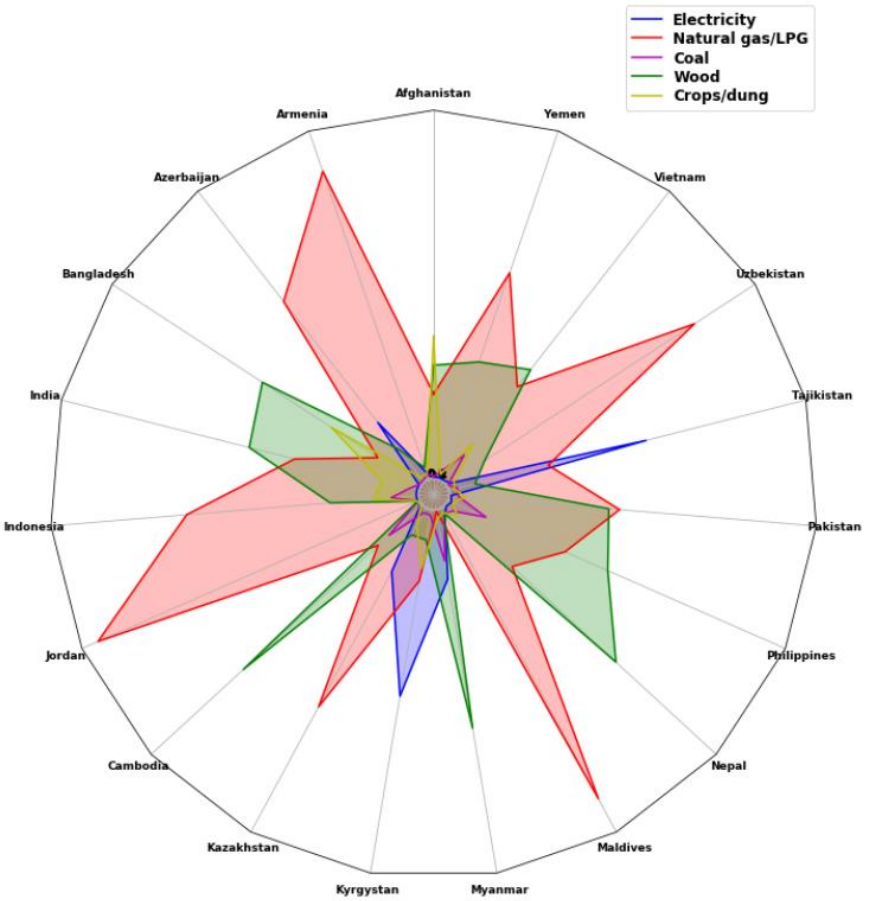

Figure 5: Rates of prominently used cooking fuels across Asian countries

Yet, firewood remained the second most used cooking fuel in the above-mentioned states and the first most common in Cambodia, Nepal,

Bangladesh, Myanmar, and India where more than 50% of the population was still dependent on it. However, firewood remained mostly used as a primary source of cooking fuel across the Sub-Sharan African countries, as visualized in Figure 6. Coal/charcoal was used as the second most common and natural gas as the third most commonly used energy fuel to cook food and get warmth at the household level.

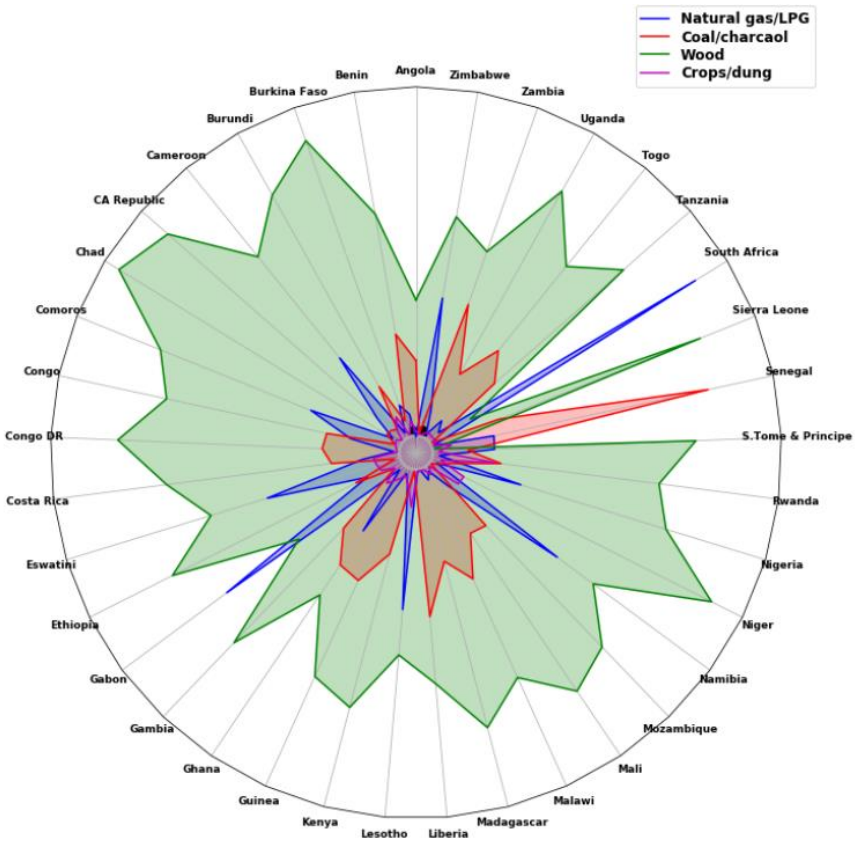

Figure 6: Rates of commonly used cooking fuels in Africa

Figure 7 presents that the households exposed to energy destitution were at the bottom throughout the countries, as hypothesized. It also corroborates the hypothesis that the $MEPI^D$ as a subset of the MEPI filters and differentiates the moderate energy-poor cases from the extreme energy poor-they are at the very bottom of the energy poverty line, seek the special attention of the stakeholders, and require additional incentives and financial supportive measures, especially directed policy options.

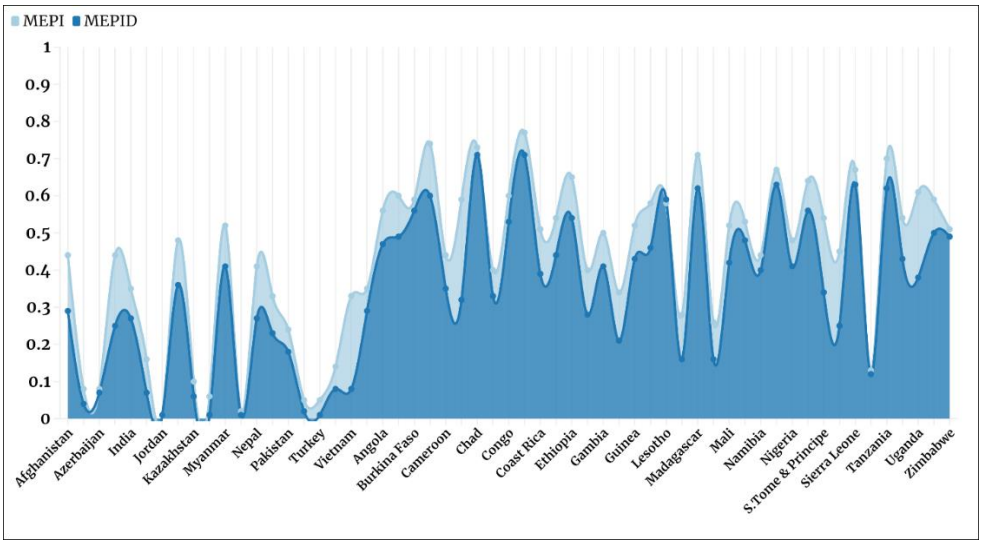

Figure 7: Projection of distribution of MEPI and MEPI^{D} across the countries.

Concluding remarks

The study proposed a new complemented methodology to gauge and monitor extreme energy poverty with a multidimensional approach. It has extended and superseded the methodological work of Patrick Nussbaumer regarding the measurement of multidimensional energy poverty using the MEPI (Patrick Nussbaumer et al. 2012) . The MEPI^{D} grades inequalities among energy-poor households that are also vitally important and overlooked by the MEPI previously. The novel methodological approach not only measures the severe forms of simultaneous deprivations across the multiple dimensions of household energy services but also provides policy insight to address the conditions of those who are at the very bottom by announcing some additional incentives, allocating resources, and financing assistance programs. It is only possible after identification that who is at the bottom and faces severe forms of energy poverty and how they are different from moderately energy poor in deprivation levels and characteristics wise. This identification required setting quite different thresholds to reflect more chronic deprivations.

The current methodology MEPI^{D}, a subset of the MEPI, empirically answered the above questions and tried to come up with the solution that could ultimately lead to the reduction of the chronic or severe forms of

multidimensional energy poverty at the household level that might otherwise be overlooked and neglected. Lastly, the robust findings disclosed that high energy destitution occurred due to household inaccessibility of electricity and clean cookstoves primarily. The results suggest that the fundamental focus of the stakeholders should be providing universal access to lighting by building and expanding transmission lines and electric infrastructure and connecting the far and remote areas of the country. Also, the networks of gas pipelines must be established and extended to rural households as well. Achieving success of implementation in these policy directions will substantially and considerably lead to the reduction of multidimensional energy poverty nationally, regionally, and globally.

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