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Assessing the Relative Importance of Access and Affordability in Energy Poverty in India: A Guide for Future Energy Policies

Anver C. Sadath[1], Rajesh H. Acharya[2]*

[1]Department of Economics, Central University of Kerala, Kasaragod, Kerala, India, [2]School of Humanities, Social Sciences and Management, National Institute of Technology Karnataka, Mangaluru, Karnataka, India. *Email: rajeshacharyah@gmail.com

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ABSTRACT

We analyse the role of access and affordability in measuring energy poverty from a developing country context, particularly India. For this purpose, we use the Harvard Dataverse energy access database household-level data. We measure energy poverty based on subjective indicators such as the Multidimensional Energy Poverty Index (MEPI) and objective measures such as expenditure-based approaches. Empirical results show that India made substantial progress in reducing energy poverty based on all approaches, but we observe vast differences in the extent of energy poverty across different approaches. There is substantial variation in energy poverty among different socioeconomic groups and employment categories, reflecting the reality in the Indian context. Finally, we argue that access, affordability and socioeconomic variables are important determinants of energy poverty in the Indian context. Policymakers should consider these factors while designing policies to handle the problem effectively.

Keywords: Energy Poverty, Multidimensional Energy Poverty Index (MEPI), Subjective Indicators, Objective Indicators
JEL Classifications: O13, Q40, Q48

1. INTRODUCTION

The inability of households to avail reliable and adequate amounts of modern energy resources to satisfy their domestic needs is generally termed as energy/fuel poverty in the literature (Halkos and Gkampoura, 2021). According to (IEA et al., 2021), 759 million people lack access to electricity and 2.6 billion to clean cooking in 2019 and eradication of energy poverty is vital for achieving sustainable development. However, the concept of energy poverty eludes a universally acceptable approach in terms of its definition and measurement because of the complexity involved in conceptualizing and measuring it (Ntaintasis et al., 2019; Primc et al., 2021).

Difference in perceptions about the most important determinants of energy poverty is the fundamental source of the complexity (Pachauri and Spreng, 2011). That is why, while energy poverty in developing countries is linked with a lack of access and reliability of service, in developed countries, it is linked with a lack of affordability and efficiency (Primc et al., 2021). Further, questions such as whether the actual quantity of energy availed as an input or whether the services rendered by the energy sources as output/outcome matters also add to the complexity of conceptualizing and measuring energy (Barnes et al., 2011; 2014; Nathan and Hari, 2020). For example, LED bulbs can provide better lighting with lower electricity than incandescent bulbs. Likewise, in the case of space heating or cooling, the energy efficiency of the building also matters, as inefficient buildings will not be able to satisfy the inhabitants' needs despite having access and affordability. Finally, socioeconomic determinants of energy poverty vary across regions, countries and cultures and thus make the formulation of a single approach almost impossible (Abbas et al., 2020; Acharya and Sadath, 2019; Sadath and Acharya, 2017).

Therefore, energy poverty is regarded as a multidimensional problem determined by several factors such as lower income, higher energy prices, lack of access, housing conditions, quality and efficiency of the service, regional and climatic differences, and demographic composition of the population, gender, cast and culture (Betto et al., 2020; Bouzarovski and Petrova, 2015; Meyer et al., 2018; Nussbaumer et al., 2012; Sokołowski et al., 2020). Access to affordable and reliable modern energy services is indispensable for the welfare of the people (IEA, 2021; 2017). Therefore, accurately measuring energy poverty is crucial for policy formulation and implementation to expand access to energy services (Che et al., 2021; Pachauri and Spreng, 2011).

2. BACKGROUND

There is a widespread tendency in the literature to approach the problem of energy poverty in poor and developing countries from the angle of access and use of energy alone and thereby disregarding, often completely, the significance of affordability to access energy services as a major determinant of energy poverty (Khandker et al., 2012; Nussbaumer et al., 2012; Pachauri and Spreng, 2011). In other words, energy poverty is characterised as a supply-side problem, and thus, factors on the demand side, such as income, are almost neglected (Bazilian et al., 2010). Highlighting this problem, (Pachauri and Spreng, 2004) stated that "in addition to physical access, real access to energy services can be limited by the purchasing power of the household, the cost of energy and cost of energy-using equipment". Likewise, (Nussbaumer et al., 2012) clearly state that limited attention has been paid to the notion of affordability in the measurement of energy poverty in the literature; therefore, approaches focusing on demand-side elements are desirable. As shown by (Palit and Bandyopadhyay, 2017) from Indian villages, although villages are connected to the grid, the majority of households are not connected to the grid because they are very poor, highlighting the significance of affordability of households. The inability to pay electricity connection charges and monthly bills are the major reasons for households to stay unelectrified despite the village having a grid connection.

Pachauri and Spreng (2004) found that improved access to energy sources and adequate quantity of energy by making it affordable are needed elements for improving the well-being of the poor. (Khandker et al., 2012) found a negative relationship between energy expenditure and income of the households in the lower decile of income and income non-poor in rural areas of India are also energy poor. Further, underlying the significance of income and access, the study attributed the lower use of LPG in rural areas compared to electricity to both lack of income and access to LPG. Hence, energy poverty is much higher in rural areas than in urban areas. Similar findings are reported by (Srivastava et al., 2012) that most of the income-poor households are energy poor and most of the households from poor states like Bihar are energy poor indicating the strong link between income poverty and energy poverty in India. Consistent with this finding, (Alkon et al., 2016) also show a direct relationship between energy and income poverty especially in rural areas in India. (Abbas et al., 2020) clearly show that better socioeconomic status of the households mitigates the severity of energy poverty in South Asia. The finding of (Barnes et al., 2011) from Bangladesh that energy consumption of households below the 6th decile is insensitive to their respective income and widespread use of traditional energy sources at the lower decile of the income distribution seems to suggest the significance of income in determining the energy poverty along with the role of the access to modern energy services. A similar view was echoed by (Pachauri et al., 2004) who observed that households without access to modern energy services and thus, heavily depending upon biomass manifest the acute income poverty they are living in, and energy poor are, in general, income poor in India and energy expenditure increases with improvement in the standard of living. In another paper, (Pachauri, 2004) found that major reasons for variation in household energy requirements are household expenditure and income level.

However, existing demand-side approaches to measure energy poverty have widely used expenditure on energy services as a measure of energy poverty due to data constraints. However, energy expenditure has serious limitations in providing a true picture as it focuses on the energy purchased and hence excludes those who do not purchase energy services either because of lack of income or access or both and also disregards the importance of efficient technologies which would reduce the cost of energy services (Barnes et al., 2011; Srivastava et al., 2012).

Therefore, this paper argues with empirical evidence from India that access, and affordability are crucial determinants of energy poverty in poor and developing countries. To develop the case for the basic argument that both income and access matter, we take recourse to insights from existing theories of energy choice behaviour which shows that their economic status determines the energy choice of the households and thus, the energy transition of the households from dirty duels to modern fuels is determined by the level of income and economic status of the households (Chen et al., 2016; Heltberg, 2004; Hosier and Dowd, 1987; Leach, 1987). Of course, the energy transition of households from dirty fuels to modern fuels may not be as unidirectional as suggested by the energy ladder model as shown by vast literature that households use multiple energy resources involving both traditional and modern energy. The use of multiple energy resources, such as firewood and LPG, is also explained by the affordability of the households (Pachauri and Spreng, 2004). It appears that the lack of integration between the debate on determinants of energy choice and energy poverty has led to the almost one-sided approach to measuring energy poverty in literature. The importance of accounting for the role of affordability of households in determining energy poverty has become more significant today than ever before as the world is moving from fossil fuels to renewable energy resources. For example, the potential of renewable technologies like solar PV units in ameliorating energy poverty is widely appreciated where the economic affordability of households to purchase such technologies is crucial (Rao et al., 2009; Urmee et al., 2009; Venkateswaran et al., 2018; Zahnd and Kimber, 2009).

This paper contributes to the literature on energy poverty in three ways. First, appreciating the significance of supply and demand side factors in determining energy poverty, we propose a new multidimensional approach to measure energy poverty explicitly accounting for both access and affordability to avail energy services. Second, we expand the canvass of existing discourse on defining and measuring energy poverty by inculcating insights of energy choice theories in the discourse. Third, this paper aims to highlight that effective policy interventions to tackle energy poverty entail a systemic improvement in the living standards of the people so that poor households in particular, can not only access but also sustain their energy consumption. Finally, the measurement of energy poverty after accounting for the role of income along with access is more advantageous as it assesses the extent of energy deprivation and such an approach is consistent with examining energy poverty from the viewpoint of the capability approach to the development (Bazilian et al., 2010; Sen, 2001).

3. MEASURES OF ENERGY POVERTY IN LITERATURE

Researchers have adopted various definitions and measures depending on the context and the nature of the energy deprivation (Sokołowski et al., 2020). The extant literature used three methods to measure energy poverty. The first category of the method is called objective indicators using household energy expenditure. The second method is called subjective indicator based on the lived experience of households (Ntaintasis et al., 2019; Siksnelyte-Butkiene et al., 2021; Waddams Price et al., 2012). Finally, the last method is called composite methods which includes both objective and subjective indicators (Ahmed and Gasparatos, 2020; Nussbaumer et al., 2012).

3.1. Objective Indicators

Expenditure-based methods are prominent objective indicators of energy poverty in literature. They define it based on a household's expenditure on energy resources, income available after meeting energy expenditure and inadequate spending on energy services (Koen et al., 2016). The literature suggests Several thresholds under expenditure-based methods (Halkos and Gkampoura, 2021). For example, a household is classified as energy poor if the energy expenditure of the household is more than 10% (Boardman, 1991). This is in sharp contrast with income approach in which those households who cut energy expenditure due to lack of income would not be treated as energy poor (Aristondo and Onaindia, 2018). (Betto et al., 2020) call this phenomenon hidden energy poverty. However, households with high income and energy expenditure will be treated as energy poor (Papada and Kaliampakos, 2018).

(Hills, 2012) developed a Low-Income High-Costs (LIHC) approach to overcome the limitations of an expenditure-based approach. The expenditure method stipulates that a household's income should be below the official poverty threshold and energy expenditure should be above the average expenditure of the population. However, this approach fails to account for the increase in energy service prices and the state's intervention (Siksnelyte-Butkiene et al., 2021). Twice the Median Indicators (2M) includes four indicators: Double the median or mean of household expenditure on energy and double the median share or mean share of household expenditure on energy (Schuessler, 2014; Siksnelyte-Butkiene et al., 2021). Households are in energy poverty if they spend more than double the median share of its income on energy (Castaño-Rosa et al., 2019). The minimum Income Standard developed by (Moore, 2012) defines energy poverty as a situation in which a household's available income after meeting their energy and housing expenditure is lower than the minimum income that allows it to have what it needs in order to have the opportunities and choices necessary to participate in society (Castaño-Rosa et al., 2019).

3.2. Subjective Indicators

Subjective measures classify the household as energy poor if they are unable to avail basic energy services (Awaworyi Churchill et al., 2020). As per this approach, the experiences of households regarding energy services such as lighting, cooking and warmth would be elicited through primary surveys (Thomson et al., 2017). The ability to capture wider elements such as household experiences and their perceived impacts of being in energy poverty is a significant advantage of subjective methods (Herrero, 2017; Koen et al., 2016). However, a significant limitation of this approach is that households may not identify themselves as energy-poor despite being unable to avail required energy services (Ntaintasis et al., 2019).

3.3. Multidimensional Composite Indicators

Table 1 provides a description of multidimensional indicators of energy poverty.

4. DATA AND METHODOLOGY

The study uses the Harvard Dataverse energy access database conducted in two rounds in 2015 and 2018. The survey is conducted in rural areas of states such as Jharkhand, Uttar Pradesh, Bihar, Madhya Pradesh, Odisha, and West Bengal. Among the states covered, bearing West Bengal, all states are known for acute energy poverty and lower level of development. The database has rich information on the economic activity of the households, lighting and electricity situation and satisfaction, cooking situation and satisfaction, and policy preferences for enhancing access and affordability to various modern energy resources. Coverage of rural areas makes the survey particularly useful for assessing the success of various government energy access programs at different levels.

We measure energy poverty based on both objective and subjective indicators. Under objective indicators, we use the expenditure method. However, unlike the extant literature, we use total consumption expenditure instead of income due to the non-availability of data. Following Alkon et al. (2016), we calculate the ratio of monthly energy expenditure to total expenditure to measure the energy cost burden as follows:

$$Energy\,Cost\,Burden_i = \frac{Energy\,Expenditure_i}{Total\,Expenditure_i} \quad (1)$$

The value of the energy cost burden will be in the range of 0-1. A higher value indicates a higher energy cost burden on the household. An increase (decrease) in energy cost burden could be due to an increase (decrease) in expenditure on energy resources or a fall (rise) in total spending. An increase in energy expenditure could be due to an increase in the prices of energy resources or a

Table 1: Multidimensional indicators of energy poverty from extant literature

Author (s)	Region/country	Dimensions/indicators	Major finding
Ntaintasis et al., 2019	Greece	Unable to keep homes warm and pay utility bills and inefficient buildings.	37-43.5% energy poverty in Attica region.
Karpinska and Śmiech, 2020	Poland	Housing inadequacy, heating regime, and household characteristics	23.7% hidden energy poverty and it is linked to income poverty to an extent.
Gupta et al., 2020	India	Possession of electrical appliances, monthly per capita expenditure, indoor air pollution, per capita consumption of LPG and electricity and access	Widespread prevalence of energy poverty was reported.
Khanna et al., 2019	South and Southeast Asia	Access to electricity, clean cooking fuel and technology, total energy supply and consumption.	Cambodia and Thailand are most and least energy poor countries, respectively, in the study.
Nathan and Hari, 2020	India	Access to electricity, LPG and use of biomass.	High energy poverty in Bihar and Uttar Pradesh and lack of clean cooking fuel is the major deprivation.
Sokołowski et al., 2020	Poland	Less income, inability pay bills, higher costs, lack of warm in house and energy inefficient house.	10% of households in Poland suffer from multidimensional energy poverty
Qurat-ul-Ann and Mirza, 2021	Pakistan	Household, demographic, and geographical characteristics	Households with foreign remittance and increased income experienced a decrease in energy poverty.
Abbas et al., 2020	South Asia	Lighting, cooking, household appliances, indoor air pollution, entertainment/education and communication.	Improving the household's socioeconomic status will reduce energy poverty.
Ssennono et al., 2021	Uganda	Electricity access, cooking solutions and appliances	66% of Ugandans are multidimensionally energy-poor
Zhang et al., 2021	China	Access to clean cooking fuel, travel, household appliances, education and entertainment.	Multidimensional energy poverty deteriorates the physical and mental health of rural and urban residents, respectively.
Rafi et al., 2021	India	Access to clean cooking, lighting fuel, household appliances, communication and entertainment.	Energy poverty negatively impacts children's health and education.
Zhang et al., 2019	China	Health, Access, Energy expenditure/total income, annual income, annual energy consumption, etc.	Negative impact of energy poverty on health.
Crentsil et al., 2019	Ghana	Lighting, cooking, indoor pollution etc.	Prevalence of high energy poverty.
Meyer et al., 2018	Belgium	Affordability, self-restriction of energy below needs and feeling of energy poverty	21.3% energy poverty in Belgium.
Okushima, 2017	Japan	energy cost, income energy efficiency of housing	an increase in energy poverty since 2000.
Mendoza et al., 2019	Philippines	Lighting, cooking, appliances and communication means	A high correlation between MEPI and income poverty.
Castaño-Rosa et al., 2019	EU	Geography, income and quality of dwelling	Several factors influencing day-to-day activities are not considered. It may result in incomplete analysis if it is used in an isolated manner.
Nussbaumer et al., 2012	Africa	Cooking, lighting, appliances and telecommunications means	Energy poverty varies across countries

greater extent of the use of modern energy resources. An increase in total expenditure may be taken as an indication of the increase in income.

Under multidimensional indicators, we construct Multidimensional Energy Poverty Index (MEPI) based on three broad approaches. Table 2 presents MEPI dimensions, indicator/s under each dimension, and their weights. The first measure is a pure access-based approach in which a MEPI is constructed based on households' access to electricity for lighting and Liquefied Petroleum Gas (LPG) for cooking. Both lighting and cooking have 50% weight. A household with access to electricity or LPG will be coded as zero else, one. In the second stage, it will be multiplied by the weight assigned. Finally, the sum of the product of calculated numbers in the first and second stages will give us MEPI based on the access.

Second, we construct a MEPI based on access and asset ownership, which requires using modern energy resources like electricity. Studies like Ssennono et al. (2021) and Rafi et al. (2021) follow this approach. In this approach, the lighting dimension has two indicators, viz., access to electricity and ownership of assets that require electricity use. Both these sub-dimensions have further equal weight, i.e., 25% each. The remaining 50% weight is allocated to cooking dimension. Asset ownership is considered as a proxy for the extent of use and reliability of energy services.

Table 2: Multidimensional energy poverty index dimensions, indicators, and weights

MEPI	Dimension (%)	Indicator (weight)	Deprivation
Access based	Lighting (50)	Access to electricity (50%)	Not having access to electricity
	Cooking (50)	Access to LPG (50%)	Not having access to LPG
Access and assets based	Lighting (50)	Access to electricity (25%)	Not having access to electricity
		Access to electrical appliances (25%)	Not owning electrical appliances
	Cooking (50)	Access to LPG (50%)	Not having access to LPG
Access and biomass use based	Lighting (33.33)	Access to electricity (33.33%)	Not having access to electricity
	Cooking (33.33)	Access to LPG (16.66%)	Not having access to electricity
		Stove type (16.66%)	Using a traditional stove without Chimney
	Biomass (33.33)	Firewood	Using firewood for cooking
		Dung cake	Using dung cake for cooking
		Crop residue	Using crop residue for cooking
		Coal/charcoal	Using coal/charcoal for cooking
		Kerosene	Using kerosene for lighting and cooking

The third approach is to measure energy poverty with MEPI based on access and use of biomass or traditional fuel like firewood, dung cake, crop residue, coal/charcoal, kerosene, etc. Studies like Sadath and Acharya (2017) and Nathan and Hari (2020) used this approach. Specifically, we follow Sadath and Acharya (2017) approach in the MEPI construction. Unlike Nathan and Hari (2020), which classify households into five categories based on energy poverty, the approach of Sadath and Acharya (2017) adopt classifying households into deciles and, as a result, does not result in loss of information due to smaller number of energy poverty groups. For example, finer details about a specific segment of energy-poor households will be lost if there are smaller groups. There are three dimensions, viz. lighting, cooking, and use of biomass with an equal weight of 33.33%. The lighting dimension has a single indicator, i.e., access to electricity. The cooking dimension consists of two indicators in the form of access to LPG and the type of stove used. A modern and efficient stove with a better exhaust facility versus a traditional stove without exhaust. Both indicators have an equal weight of 16.66, which takes the total weight of the cooking dimension to 33.33. Finally, biomass use has five indicators: Firewood, dung cake, crop residue, coal/charcoal, and kerosene for cooking, heating or lighting purposes. In a country like India, where there is greater use of biomass despite having access to modern energy resources either due to lack of affordability of modern energy resources or as a matter of practice and tradition, this measure is capable of capturing such dimensions of energy choice.

We estimate pooled regression model to identify the determinants of the energy cost burden, energy expenditure, and MEPI based on access and biomass. The equation for energy cost burden is specified as follows:

$$Energy\ Cost\ Burden_i = \beta_0+\beta_1 Lighting\ Index_i+\beta_2 Cooking\ Index_i+\beta_3 Biomass\ Index_i+\beta_4 Household\ Size_i+\beta_5 Land\ Ownership_i+\beta_6 Ln(Non-Energy\ Expenditure)_i+\beta_7 Education\ Dummy_i+\beta_8 Decission\ Making\ Dummy_i+\beta_9 Access\ to\ Media\ Dummy_i+\beta_{10} Occupation\ Dummy_i+\beta_{11} Caste\ Group\ Dummy_i \quad (2)$$

where $Energy\ Cost\ Burden_i$ is estimated from equation (1). $Lighting\ Index_i$ and $Cooking\ Index_i$ measure the access to modern energy resources, whereas *Biomass* measures the prevalence of the use of biomass. $Household\ Size_i$ and $Land\ Ownership_i$ are continuous variables measuring the number of households and the amount of land in acres, respectively. $Ln(Non-Energy\ Expenditure)_i$ is natural log of household expenditure on all products, excluding energy expenditure. It is considered as a proxy for income since the income information is not directly available. $Education\ Dummy_i$ is a dummy variable that takes value of 1 if a household member has education above the 10th standard and 0 for the education of 10th standard or less. takes a $Decission\ Making\ Dummy_i$ value of 1 if the decision-making is in the hands of women or both men and women and 0 if only men make it, whereas $Access\ to\ Media\ Dummy_i$ takes the value of 1 for having access to either Radio or Television and 0 otherwise. $Occupation\ Dummy_i$ takes value of 1 if the household occupation is a salaried job or business and 0 for all other occupations. Finaly, $Caste\ Group\ Dummy_i$ takes value of 1 if the household belongs to Scheduled Caste (SC), Scheduled Tribe (ST) and Other Backward Classes (OBC) and 0 for other caste groups.

Our second model is estimating the determinants of energy expenditure. The equation is specified as follows:

$$Ln(Non-Energy\ Expenditure)_i = \beta_0+\beta_1 Lighting\ Index_i+\beta_2 Cooking\ Index_i+\beta_3 Biomass\ Index_i+\beta_4 Household\ Size_i+\beta_5 Land\ Ownership_i+\beta_6 Ln(Non-Energy\ Expenditure)_i+\beta_7 Education\ Dummy_i+\beta_8 Decission\ Making\ Dummy_i+\beta_9 Access\ to\ Media\ Dummy_i+\beta_{10} Occupation\ Dummy_i+\beta_{11} Caste\ Group\ Dummy_i \quad (3)$$

where the dependent variable is the natural log of energy expenditure, and the independent variables are same as in equation (2)

The third model measures determinants of MEPI based on access, access & assets, and access & biomass. The equation is specified as follows:

$$MEPI_i = \beta_0+\beta_1 Energy\ Cost\ Burden_i+\beta_2 Ln(Non-Energy\ Expenditure)_i+\beta_3 Land\ Ownership_i+\beta_4 Household\ Size_i+\beta_5 Education\ Dummy_i+\beta_6 Decission\ Making\ Dummy_i+\beta_7 Access\ to\ Media\ Dummy_i+\beta_8 Occupation\ Dummy_i+\beta_9 Caste\ Group\ Dummy_i \quad (4)$$

where $MEPI_i$ is MEPI based on access, access & assets, and access & biomass. We had to drop lighting index, cooking index and biomass index variables as they are used in constructing the dependent variable. We have added *Energy Cost Burden*$_i$ as an independent variable to measure its impact on MEPI. All other variables are the same as described for equation (2).

5. EMPIRICAL RESULTS

The empirical results of the study are presented in this section.

Table 3 presents the summary statistics of different measures of energy poverty used in the study. The mean value of MEPI based on access is highest in 2015, whereas MEPI based on access & biomass is highest in 2018. The mean value of energy expenditure to total expenditure ratio is very close to 13%. All measures of energy poverty point towards improvement in reducing energy poverty. However, the magnitude of improvement is vastly different. The standard deviation of MEPI based on access and access & assets are high compared to standard deviation of MEPI based on access & biomass. The improvement in reducing energy poverty is high in the case of MEPI based on access and access & assets are high compared to standard deviation of MEPI based on access & biomass. This can be attributed to households continuing to use biomass even after getting access to cleaner energy alternatives. The lowest standard deviation is recorded in the case of energy expenditure to total expenditure ratio. The table also reports 25, 75, 95 and 99 percentile values for all energy poverty measures. There is greater scope for classifying households based on MEPI based on access & biomass and energy expenditure to total expenditure ratio. A steady increase in both measures at higher percentiles shows that there is a higher correlation between these two measures.

Table 4 presents a detailed account of MEPI based on access & biomass and corresponding energy expenditure to total expenditure ratio. We classify the households into total 10 energy poverty groups, one representing lowest energy poverty and 10 representing the highest. For e.g., households with MEPI value of <10 are grouped under one, whereas value of 90 and above are grouped under 10. Across these groups we present the average MEPI, percent of households and the cumulative per cent of households starting from poorest. About 95% of households had an MEPI score of more than 33.33% in 2015 reduces to about 75% in 2018 indicating substantial improvement. Further, the percent of households above group five reduced substantially in 2018 in comparison with 2015. Energy expenditure to total expenditure ratio shows an interesting trend. It is higher in the middle groups

Table 3: Summary statistics of different measures of energy poverty

Statistic	2015				2018			
	MEPI-access	MEPI-access and assets	MEPI-access and biomass	Energy to expenditure ratio (%)	MEPI-access	MEPI-access and assets	MEPI- access and biomass	Energy to expenditure ratio (%)
Mean	66.27	61.26	62.44	13.27	34.15	29.89	42.86	9.92
Percentile 25	50.00	50.00	41.67	5.17	0.00	0.00	25.00	3.25
Percentile 75	100.00	100.00	83.33	17.13	50.00	50.00	58.33	12.41
Percentile 95	100.00	100.00	91.66	37.60	100.00	75.00	83.33	30.96
Percentile 99	100.00	100.00	91.66	61.20	100.00	75.00	91.66	60.40
Standard deviation	35.61	33.36	22.46	12.16	35.11	29.51	22.97	11.21

Table 4: Decile wise multidimensional energy poverty index (access and biomass) and energy poverty to total expenditure ratio

Year	Decile	MEPI- access and biomass	Household percent	Cumulative percent	Energy to expenditure ratio (%)
2015	1	0.52	2.45	100.00	13.56
	2	16.67	1.03	97.55	11.62
	3	25.00	2.94	96.52	15.47
	4	33.33	6.27	93.58	16.67
	5	46.22	28.82	87.31	12.72
	6	58.33	6.63	58.48	14.46
	7	66.66	4.22	51.85	17.13
	8	75.00	11.83	47.64	8.58
	9	83.33	27.70	35.81	14.04
	10	92.22	8.10	8.10	13.20
2018	1	0.18	7.99	100.00	5.85
	2	16.67	7.41	92.01	5.97
	3	25.00	11.04	84.60	8.05
	4	33.33	16.26	73.56	11.87
	5	46.28	32.16	57.30	11.01
	6	58.33	5.93	25.13	11.26
	7	66.66	4.14	19.20	9.84
	8	75.00	5.05	15.06	8.19
	9	83.33	7.64	10.01	10.62
	10	91.78	2.37	2.37	14.57

in comparison with the low and very high energy poverty groups. This could be because low-energy poor groups have higher income and expenditure, whereas poor groups rely more on biomass, which is either free or cheap to purchase. However, the middle groups have access to modern energy resources and also use biomass. They spend more on energy resources as per cent of total expenditure due to lesser income and expenditure.

Tables 5 and 6 present the MEPI based on access and, access and assets respectively. Since these two measures are based on access to electricity and LPG, there are three groups in Table 5 and five groups in Table 6, which have an additional measure in the form of ownership of assets. Both MEPI based on access and access and assets show improvement in reducing energy poverty from 2015 to 2018.

Further, the energy expenditure to total expenditure ratio reduces as energy poverty increases. This is because MEPI based on access and access and assets fail to effectively classify energy non-poor, energy poor and extremely energy poor. From a policy perspective, MEPI based on access and biomass provides finer details than MEPI based on access and access and assets. Therefore, from a developing country standpoint, it is necessary to have an explicit representation to the use of biomass along with access to cleaner energy resources as a lot of households use both cleaner energy resources and biomass for the same purposes.

Table 7 presents different measures of energy poverty across different caste groups. This is necessary in a country like India where socioeconomic progress is highly linked to the caste group to which the household belongs. As expected, the households belonging to Scheduled Caste (SC) and Scheduled Tribe (ST) groups have higher energy poverty followed by Other Backward Classes (OBC). Households belonging to the General category have the lowest energy poverty. There is a reduction in energy poverty from 2015 to 2018 but the magnitude of reduction is lowest in the case of MEPI based on access & biomass.

Table 8 presents the difference in energy poverty levels across different occupation groups. Energy poverty based on MEPI is high for groups practising agriculture on leased land, casual agriculture labour and daily wage labourers. On the other hand,

Table 5: Decile wise multidimensional energy poverty index (access based) and energy poverty to total expenditure ratio

Year	Decile	MEPI- access	Household percent	Cumulative percent	Energy to expenditure ratio (%)
2015	1	0.00	14.38	100.00	16.16
	5	50.00	38.70	85.62	13.26
	10	100.00	46.92	46.92	12.40
2018	1	0.00	45.51	45.51	9.20
	5	50.00	40.66	40.66	10.58
	10	100.00	13.82	13.82	10.32

Table 6: Decile wise multidimensional energy poverty index (access and assets based) and energy poverty to total expenditure ratio

Year	Decile	MEPI-access and assets	Percent	Cumulative percent	Energy to expenditure ratio (%)
2015	1	0.00	13.93	100.00	16.29
	3	25.00	5.29	86.07	16.62
	5	50.00	32.13	80.78	12.72
	8	75.00	19.12	48.65	13.64
	10	100.00	29.53	29.53	11.62
2018	1	0.00	43.65	100.00	9.20
	3	25.00	10.59	56.35	8.37
	5	50.00	28.96	45.76	11.25
	8	75.00	16.13	16.80	10.32
	10	100.00	0.67	0.67	13.73

Table 7: Caste wise multidimensional energy poverty index and energy poverty to total expenditure ratio

Year	Caste	MEPI-access	MEPI- access and assets	MEPI- access and biomass	Energy to expenditure ratio (%)	Household percent
2015	SC	73.93	68.93	66.62	13.55	18.32
	ST	72.44	67.53	62.90	9.23	10.04
	OBC	68.18	63.00	64.41	14.07	47.67
	Gen	54.04	49.31	55.14	13.17	23.96
	Others	0	0	0	0	0
2018	SC	36.57	31.60	45.16	10.25	19.41
	ST	43.45	40.46	45.54	9.13	10.86
	OBC	35.46	30.81	44.43	10.09	46.70
	Gen	25.10	21.62	36.49	9.66	23.02
	Others	0.00	0.00	25.00	15.00	0.01

households with salaried jobs or having their own business have lower energy poverty. There is no major variation in the level of energy expenditure to total expenditure ratio due to not classifying households based on energy poverty within a particular employment group. Once again, the reduction in energy poverty shown by MEPI based on Access and biomass is lowest compared to the MEPI based on access and access and assets.

To assess the role of access to energy resources, income and other factors on energy poverty, we estimate a total of five regressions. Table 9 presents the determinants of energy expenditure and energy expenditure to total expenditure ratio and Table 10 presents different multidimensional energy poverty indicators of energy poverty. The explanatory variables are measures of access to different energy resources, a proxy for income, assets, and other socioeconomic variables. As seen in Table 9, both lighting and LPG index have a negative impact on the dependent variables, indicating that access to energy resources is crucial in deciding energy poverty. The biomass index has a positive impact and significant impact on the dependent variable. It indicates that households with lesser income are likely to use biomass, leading to higher energy expenditure and a higher ratio of energy to total expenditure. It highlights the importance of income in deciding energy poverty. As expected, household size and land ownership lead to higher energy poverty, whereas non-energy expenditure, a proxy for income, leads to lesser energy poverty. Concerning other socioeconomic determinants, households with higher education, access to media, and salaried and business professions lead to higher energy poverty. This is in sharp contrast with the expectation. Finally, households belonging to socially marginalised and backward groups lead to lesser energy poverty. This also contradicts the popular perception.

We present the determinants of multidimensional energy poverty measures based on access, access and assets, and access and biomass use as seen in (Sadath and Acharya, 2017) in Table 10. Both energy to total expenditure ratio and non-energy expenditure have a negative and significant relationship with all measures of multidimensional energy poverty. It confirms the role of income in explaining energy poverty. Land ownership has a negative relationship with energy poverty but the relationship is significant in access and access and assets measures only. As expected, household size has a positive relationship with energy poverty. Concerning other socioeconomic variables, households with higher education, access to media, salaried and business professions, and households with a female head lead to lesser energy poverty. Finally, households belonging to socially marginalised and backward groups have higher energy poverty.

A comparison of the results in Tables 9 and 10 reveals some interesting findings. First, both access and income are essential in explaining energy poverty in the Indian context. Second, socioeconomic variables are equally important determinants of energy poverty. Third, multidimensional energy poverty indicators seem to capture energy poverty better than the expenditure-based approaches. For example, a household may have a lesser energy expenditure to total expenditure ratio because it is dependent on biomass, which is cheap or available for free. It is reflected in the contrary findings of some of the socioeconomic variable results in Table 9. Therefore, we argue that income, access and socioeconomic variables are important to explain energy poverty and multidimensional indicators along the lines of (Sadath andf Acharya, 2017) are better indicators for measuring energy poverty. Further, we feel that there should be an explicit representation to biomass use in measuring energy poverty as it captures the complexity of the energy poverty problem in the Indian context. Measures based on only access or access and assets do not capture the phenomenon of energy stacking, which is quite common in developing countries.

Table 8: Occupation wise multidimensional energy poverty index and energy poverty to total expenditure ratio

Year	Occupation	MEPI- access	MEPI- access and assets	MEPI- Sadath and Acharya	Energy to expenditure ratio (%)	Household percent
2015	Agriculture on own land	65.40	59.90	63.20	13.81	46.09
	Cultivation on leased land	80.26	74.49	70.60	12.92	4.55
	Casual agricultural labor	78.62	75.46	68.49	11.39	3.14
	Salaried job	42.63	37.34	48.87	12.17	5.63
	Cattle rearing	65.12	61.05	61.63	16.05	0.50
	Own business	50.34	46.04	51.32	13.75	8.63
	Daily laborer	74.32	69.81	65.95	12.73	29.84
	Others	46.74	41.67	48.19	13.07	1.61
2018	Agriculture on own land	34.25	29.92	44.45	10.52	36.64
	Cultivation on leased land	40.65	35.40	49.73	11.78	3.42
	Casual agricultural labor	45.17	38.87	51.05	10.61	2.62
	Salaried job	19.22	16.16	31.84	7.18	6.77
	Cattle rearing	42.73	36.36	49.09	12.51	0.61
	Own business	21.98	19.08	31.64	8.58	9.95
	daily laborer	38.56	34.06	45.18	9.82	38.34
	Others	30.33	26.00	37.22	12.47	1.65

Table 9: Determinants of expenditure-based energy poverty measures

Variables	Energy to total expenditure ratio (energy cost burden)		Ln (energy expenditure)	
	Standardised beta	VIF	Standardised beta	VIF
Constant	(98.40)*		(62.08)*	
Lighting index	−0.07* (−8.40)	1.20	−0.08* (−7.60)	1.19
LPG index	−0.20* (−22.34)	1.36	−0.31* (−27.48)	1.36
Biofuel index	0.16* (19.59)	1.07	0.27* (27.01)	1.07
Household size	0.16* (19.35)	1.16	0.17* (16.69)	1.15
Land ownership (in acres)	0.04* (4.29)	1.16	0.04* (3.68)	1.16
Ln (non-energy expenditure)	−0.78* (−93.01)	1.21	−0.08* (−7.38)	1.19
Education dummy (1=Above 10th, 0=10th and Below)	0.04* (5.04)	1.12	0.04* (3.88)	1.12
Decission maker dummy (1=Female and Both, 0=Male or Others)	−0.03* (−4.02)	1.09	−0.05* (−4.88)	1.09
Access to media dummy (1=Yes, 0=No)	0.08* (8.52)	1.36	0.11* (9.80)	1.36
Occupation status dummy (1=Salaried and Business, 0=Others)	0.06* (6.96)	1.10	0.06* (6.04)	1.10
Caste group dummy (1=SC, ST, and OBC, 0=Others)	−0.02* (−3.03)	1.07	−0.04* (−3.73)	1.07
R square	0.557		0.283	

Above table contains standardized beta, values in () are t statistics, *and **indicate 1% and 5% level significance, respectively

Table 10: Determinants of multidimensional energy poverty index-based measures

Variables	MEPI- access		MEPI- access and assets		MEPI- access and biomass	
	Beta	VIF	VIF	VIF	Beta	VIF
Constant	(70.46)		(76.13)		(88.89)	
Energy to total expenditure ratio	−0.15* (−13.93)	1.27	−0.16* (−15.99)	1.27	−0.06* (−5.67)	1.27
Non-energy expenditure	−0.18* (−15.26)	1.52	−0.17* (−15.42)	1.52	−0.13* (−10.27)	1.52
Land ownership (in acres)	−0.07* (−7.10)	1.13	−0.07* (−7.56)	1.13	−0.01 (−0.65)	1.13
Household size	0.07* (6.63)	1.15	0.04* (3.73)	1.15	0.08* (7.02)	1.15
Education dummy (1=Above 10th, 0=10th and Below)	−0.07* (−7.37)	1.09	−0.09* (−9.08)	1.10	−0.06* (−5.51)	1.10
Decission maker dummy (1=Female and Both, 0=Male or Others)	−0.07 (−0.67)	1.01	−0.02** (−2.07)	1.09	−0.005 (−0.49)	1.09
Access to media dummy (1=Yes, 0=No)	−0.38* (−36.93)	1.16	−0.44* (−44.29)	1.16	−0.37* (−33.63)	1.16
Occupation status dummy (1=salaried and business, 0=Others)	−0.11* (−11.06)	1.07	−0.11* (−11.63)	1.08	−0.13* (−12.07)	1.08
Caste group dummy (1=SC, ST, and OBC, 0=Others)	0.08* (8.282)	1.05	0.09* (9.27)	1.05	0.09* (8.31)	1.05
R Square	0.305		0.374		0.236	

Above table contains standardised beta, values in () are t statistics, and *and **indicate 1% and 5% level significance, respectively

6. CONCLUSION

The significance of access and affordability to modern energy resources is well-understood in academic and policy circles alike. Access to reliable and affordable modern energy resources helps households to choose a life that they yearn for and the lack of access to these energy resources acts as an unfreedom. Therefore, it is essential to measure energy poverty accurately and understand the factors responsible for it. In this regard, we attempted to measure energy poverty based on objective indicators like expenditure-based approaches and subjective indicators like the MEPI based on different dimensions. We use the Harward dataverse energy access database.

Empirical results of the study show that India substantially reduced energy poverty during the study period. However, there is a vast difference in the extent and reduction of energy poverty given by different measures. MEPI based on access and biomass use records lowest decline in energy poverty among all measures. Socioeconomic variables like caste, employment, etc., influence energy poverty. Regression results confirm that access, affordability and socioeconomic variables are important determinants of energy poverty. Finally, we argue that the expenditure-based measures fail to capture energy poverty in the Indian context due to the complexity of energy choice of Indian households and the market for energy resources, especially biomass. Therefore, it is necessary to measure energy poverty not only from the point of view of access but also from the point of view of the use of biomass. In this regard, MEPI based on access and biomass is well equipped to show the trends in energy poverty over the years in the case of countries of the global south in general and India in particular. Expenditure-based methods perform poorly in comparison with MEPI.

The results of this study have implications for future policies. Both access and affordability are important determinants of energy poverty in the Indian context. Landless farmers, labourers, and households belonging to socially marginalized groups are worst affected by energy poverty. Therefore, it is necessary to strengthen access to modern energy resources and ensure affordability through targeted subsidization to vulnerable groups. Promoting education and access to media can go a long way in reducing energy poverty.

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