Introduction

Access to clean fuels is vital for the development and wellbeing of any household (Bank, 2019; Day, Walker, & Simcock, 2016; IEA, 2011; Panda, 2017). Developing Countries like India still lag behind significantly in providing clean energy access to the population (Bank, 2016; ESMAP, 2020) where around 80% in rural and 25% in urban areas is dependent on biomass for cooking (GoI, 2013). Deprivation of clean and modern energy services makes it difficult for the population to improve their wellbeing and keeps them away from the new opportunities of the development (Pereira, Freitas, & da Silva, 2010). In these countries, most of the population is dependent on traditional biomass such as fuelwood, charcoal, and animal waste for their daily needs of cooking, lighting, and space heating. Globally 13% of the population lack access to electricity and 40% of the total population is still dependent on the traditional biomass for their cooking needs (Bank, 2019; IEA, 2011; Ritchie & Roser, 2019). In India, 51 per cent of the population could not access clean cooking fuel in 2018 when compared to 54 per cent in Pakistan, 28 per cent in China, 72 per cent in Sri Lanka and more than 80 per cent in Bangladesh (Bank, 2016; IEA, 2019). The energy situation in developed countries is very different than developing countries (Day et al., 2016) where billions of people are dependent on the traditional biomass for their daily needs which are having adverse effects on their health (Faizan & Thakur, 2019a, 2019b; Thomson, Snell, & Bouzarovski, 2017; WHO, 2018a, 2018b).

This lack of access to modern sources of energy services has been defined as energy poverty (Pereira, Freitas, & da Silva, 2011). It is mostly attributed to the people with low income, energy inefficiency, and no access or limited access to modern fuels (Chevalier & Ouédraogo, 2009; Thomson, Snell, et al., 2017). Energy poverty as an issue of concern got prominence in nineties when more than 80 percent of the population in the developing countries lacked access to sufficient and sustainable energy supply (Barnes & Floor, 1996; Reddy, 2000; Ritchie & Roser, 2019). Over the years, the situation has marginally improved, but the lack of access to clean fuels for cooking and lighting stills lies in billions (IEA, 2019).

Energy poverty is an issue which is growing in recognition across the global South (Khandker, Barnes, & Samad, 2010; Nagothu, 2016; Pachauri & Spreng, 2011) where majority of the developing and LDCs are situated. Since 2010 till 2018 India and China have provided access to 450 million people for clean cooking through programmes and policies but the sub-Saharan Africa poses a great challenge which provides a grim picture with only 17% of population having access to clean fuels for cooking (IEA, 2019).

Though, it is a worldwide accepted phenomenon that clean energy is vital for the betterment of humankind, there is no consensus on the concept and methodology which defines the energy poverty (Bensch, 2013; Culver, 2017; Khandker et al., 2010; Nagothu, 2016; Pachauri & Spreng, 2011). The concept of energy poverty is perceived differently in the global South and the North (Bouzarovski & Petrova, 2015; Day et al., 2016). The deprivation of basic energy needs and the access to clean and efficient energy for cooking is usually the central point in the global South, i.e. developing countries (Bouzarovski & Petrova, 2015; IEA & UNDP, 2010; Nagothu, 2016; Pachauri & Spreng, 2011); while as, affordability, where people cannot afford to satisfy their basic energy needs, is the primary focus in the North i.e. developed countries (Bouzarovski & Petrova, 2015; Okushima, 2017).

However, the notion of energy poverty is well accepted around the world but the difference in the context of energy poverty still exists in the North and global South. The definition of energy poverty is vital to understand the scale and nature of the problem and formulate strategies and policies to minimise the same (Moore, 2012). Energy poverty is also called as fuel poverty, and the United Kingdom was one of the first countries to talk about this issue as early as in the 1970s. But the discussions on energy poverty had concerns mainly about the affordability of energy, which was later, explained by Boardman (1991) in her book *'Fuel Poverty: From Cold Homes to Affordable Warmth'*. This work became roadmap which conceptualised energy poverty as *'the inability to afford adequate warmth because of the inefficiency of the home'*. Later, Hills (2012) developed *'Low-Cost High Income'* approach, which measures energy poverty and provides major policy implications for most of the European countries. According to 'The UK Fuel Poverty Strategy' "*A fuel poor household is one that cannot afford to keep adequately warm at a reasonable cost. The most widely accepted definition of a fuel poor household is one which needs to spend more than 10% of its income on all fuel use and to heat its home to an adequate standard of warmth. Generally, this is defined as 21ºC in the living* *room and 18ºC in the other occupied rooms - the temperatures recommended by the World Health Organisation (WHO)"*(BEIS, 2001). Over the years, this approach of energy poverty got accepted in other European countries like France and Ireland and was used in the UK until 2013.

Later, this was replaced by the 'Low Income High Costs' (LIHC) approach to measure energy poverty. According to LIHC, a household is fuel-poor if they have the required fuel costs which is above the median level; and if they spend that amount, they are left with the residual income which is below the official poverty line (Hills, 2012).

In other developed countries such as Ireland and Scotland, households are defined as energy poor if they spend more than 10% of their disposable income on energy costs (DCENR, 2011; Parliament, 2019). Similarly, is Slovakia *"Energy poverty under the law No. 250/2012 Coll. Of Laws is a status when average monthly expenditures of household on consumption of electricity, gas, heating and hot water production represent a substantial share of average monthly income of the household"*(Strakova, 2014)*. Also, in France "A person is considered fuel poor "if he/she encounters particular difficulties in his/her accommodation in terms of energy supply related to the satisfaction of elementary needs, this being due to the inadequacy of financial resources or housing conditions"*(Brunner, Mandl, & Thomson, 2018).

The issue of energy poverty has been debated over the past two decades. However, there is no universal consensus on the measurement of the same. In addition to the approach mentioned above, there are several other approaches which are used in developing countries to measure energy poverty (Bensch, 2013; Foster, Tre, & Wodon, 2000; Khandker et al., 2010; Nagothu, 2016; Nussbaumer, Bazilian, & Modi, 2012; Pachauri & Spreng, 2004). For the purpose of understanding, these approaches can be put either in unidimensional category which have taken a single dimension, as energy use and energy access matrix by Pachauri and Spreng (2004), income threshold point below which household consume bare minimum energy by Khandker et al. (2010), or in multidimensional category which have taken more than one dimension to measure energy poverty like Multidimensional Energy Poverty Index developed by Nussbaumer et al. (2012), Nagothu (2016), and Correlation Sensitive Energy Poverty Index developed by Bensch (2013)). Most of these energy poverty measures have been critically assessed and discussed by Khandker et al. (2010) and Pachauri and Spreng (2004).

Uni-dimensional measures

One of the ways to define energy poverty is to measure the physical energy or expenditure, which specifies a minimum threshold at which households can be considered poor. These methods are deducted based on the minimum amount of energy needed to meet essential energy services. These were first used by Bravo, Mendoza, Legisa, Suárez, and Zyngierman (1983) and Krugmann and Goldemberg (1983). According to the calculations of Krugmann and Goldemberg (1983), in rural areas, the direct energy needs per capita per day varied from 10. 7 kWh in the hot climate to 43 kWh in the cold climate. Similarly, in the urban areas, the energy needs per capita per day varied from 6.87 kWh in hot climates to 18.37 kWh in cold climates. Also, Modi, McDade, Lallement, and Saghir (2005) examined various surveys from around the world, estimated that 1.61 kWh per capita per day is the minimum requirement of energy irrespective of the region.

Another uni-dimensional approach was proposed by Khandker et al. (2010) where they determined an energy threshold based on the estimations of end-use energy consumption. They define the threshold as the income decile where the energy consumption increases with the increase in income and below which a household consumes a bare minimum of energy for basic needs like cooking, lighting and space heating and should be considered as energy poor.

Expenditure-based poverty is well defined in various countries which defines energy poverty as the level of energy used by households below the given threshold expenditure of income poverty line. Foster et al. (2000) use the fuel poverty line which estimates the average energy consumption of households, where per capita energy consumption falls within plus or minus of 10% of the income poverty line. It is well established that poor households spend a higher percentage of their incomes on energy than the wealthier ones (Khandker et al., 2010).

Furthermore, Pachauri and Spreng (2004) have measured energy poverty by using a two-dimensional index based on access to types of energy and the amount of energy consumed. The approach allows drawing a poverty line based on access to the types of energy. They have defined three poverty lines for a household of 5 members, i.e. 1381 per month (pm), 1536 pm and 2590 pm for three types of access to useful energy; access to biomass and kerosene, electricity/biomass and/or kerosene and LPG/electricity, and kerosene respectively. While in energy consumption, if the amount of useful energy consumed by an individual in the household is equal to or less than 0.72 kWh per day, then, that household is considered as energy poor.

Multidimensional measures

Nussbaumer et al. (2012) composed an index of multidimensional energy poverty based on different indicators of the household energy needs. Later, Bensch (2013) developed Correlation Sensitive Energy Poverty Index (CSEPI) where instead of a dual cut off which was used in the earlier study, they identify a person as energy poor if he/she is poor in any of the dimensions. This method of identification is known as *union* method of identification where a person is said to be multidimensionally poor. Bensch (2013) adapted this method from Rippin (2011) which criticizes the OPHI method of poverty and developed the correlation sensitive poverty index. Mirza and Szirmai (2010) developed energy poverty index by taking into account the inconveniences faced by the rural people with different energy sources as well as the energy shortfalls to measure the degree of energy poverty among rural households in Pakistan. Another measure of energy poverty is Total Energy Access (TEA) which was developed by an NGO namely ‘Practical Action’ which took into consideration some other minimum service standards such as cooling, information and communications (ICTs) and earning a living apart from cooking, lighting, and space heating (PracticalAction, 2013). They recommended to recognise energy needs across home, work and community and the emphasis should not be only on supply of the energy but also the services they provide.

These above mentioned multidimensional energy poverty measures are important and emphasizes that energy is necessary for achieving wellbeing (Day et al., 2016). They comprehended the service gaps and prioritize actions at the household level, community level, and at the regional level. Composite indices reflect the problem of energy poverty in a better and subtle way (Bensch, 2013; O'Sullivan, Howden-Chapman, & Fougere, 2015). It provides a detailed picture of the situation within particular countries and captures the significant variations among geographical regions (Thomson, Bouzarovski, & Snell, 2017).

Composite indices are mostly the access-based approaches where they look into the access of desirable energy services. It delves into the affordability of the households by studying the use of certain energy services. When a household uses modern fuels, such as LPG, electricity, solar energy as their prime source of energy for cooking or lighting, it not only implies the physical access but, also, quality and reliability of the supply, access to market, and affordability of households for both the fuel and devices (Nathan & Hari, 2018).

Key elements which affect energy poverty are household income (per capita income), the cost of fuels and the type of energy consumed by the households which is affected by the energy efficiency of the fuels used. The studies conducted on developing countries especially on India have not considered all these elements together. All the elements are related to each other and affect the consumption of energy and income efficient modern fuels for their daily use, so it becomes inevitable to understand each element which contributes to the wellbeing of the household. Unavailability of efficient energy and technologies for cooking, lighting and space heating households with inability to pay deny the basic opportunities of health, education and various other opportunities to a household. By realizing the importance of these elements, we have created an index to understand the effect of all these elements on the outcome of energy poverty in this study. Energy poverty is multidimensional like general poverty; hence, this study has analysed the multidimensionality of energy poverty by developing the multidimensional scores of the households.

Data

Measuring energy poverty requires an extensive database of the household to provide a coherent response to the household energy situation. In this study, NSSO 68th quinquennial round of Household Consumer Expenditure (HCE) is utilized to empirically test the multidimensionality of energy poverty. HCE was designed to collect information on the consumption expenditure pattern along with other information of the households across the country, which is important to gauge the shifting priorities of the households in the use of cooking fuel.

NSSO 68th round consisted of 101662 household samples which were allocated according to the census and weightage was given accordingly (GoI, 2013). A total of 59695 and 41967 household samples were drawn from rural and urban areas with an estimated population of 792116592 and 316854340, respectively. However, we have dropped those households from the analysis where source of energy for lighting and cooking i.e., 5 and 8 households respectively is missing. Also, we have dropped those household where energy consumption is zero i.e., 204 households. Therefore, a total of 101451 households were included in the final analysis.

Methodology

The primary goal of the paper is to measure the basic energy deprivations through different dimensions of access to modern energy sources, affordability, and ability to meet the most basic energy needs. While developing the multidimensional energy poverty index (MEPI) for India, we took insights from the framework of Nussbaumer et al. (2012). Their methodology is derived from the literature on multidimensional poverty measures of the Oxford Poverty and Human Development Initiative (OPHI) inspired by Amartya Sen's contribution to the discussion of deprivations and capabilities. The capability approach talks about functioning and capabilities of individuals. Functioning includes, being in good health and able to do work, while as, capabilities are the actual or the real opportunities to realize these functioning (Day et al., 2016). There are no set of capabilities defined by Amartya Sen but there is a consensus that a minimum level of wellbeing is related to functioning like, being healthy, educated, safe and socially inclusive (Nagothu, 2016). Smith and Seward (2009) make a distinction between basic and secondary capabilities as cited by Day et al. (2016). Basic capabilities cover every aspect of human wellbeing while secondary capabilities shape the actualization of basic capabilities (Smith & Seward, 2009).

In this study, we have included five different dimensions which have seven indicators such as cooking, lighting, access to minimum energy requirement (kWh), expenditure on energy consumption, and household amenities which has three indicators i.e. means of household appliances, entertainment/education, and communication.

These indicators provide the comprehensions to measure and understand the severity of the problem of energy poverty and to identify the trends, priorities, evaluation and monitors the energy progress of the country. The policy and the decision makers can accordingly intend to emphasize which indicator needs priority, though, the indicators are just the means and not the end.

Table 1: Dimensions, indicators, and respective variables with cut-offs, including relative weights (in parenthesis)

Dimension	**Indicators**	**Weights**	**Variable**	**Deprivation Cut-off (poor if..)**
Cooking	Modern Cooking fuel	(0.40)	The primary source of energy used by the households for cooking	Any fuel except LPG, electricity, natural gas, solar
Lighting	Access to electricity	(0.15)	The primary source of energy used by the households for lighting	Any fuel except electricity and LPG
Access to basic energy services	Quantity of energy consumption	(0.20)	Per Capita daily energy consumption	Per capita daily kWh consumption is less than the threshold (0.792) [1]
Consumption of energy services	Per cent of income spent to get energy services	(0.15)	Income spent to get energy services	Income spent on energy services is >10% [2]
Household amenities	Household appliance ownership	(0.033)	Has fridge/electric fan/AC/Cooler/Washing machine)	No
	Entertainment/education appliances ownership	(0.033)	Has a radio/TV/Tape recorder)	No
	Telecommunication	(0.033)	Has a mobile phone/landline	No

Explanation of the dimensions which are given in the table above:

Cooking and lighting dimensions

The variables used for these dimensions is the type of primary cooking and lighting fuel. They show the actual energy consumption patterns of the households. Cooking and lighting are the universal and regular services of a household than other services like transportation. An individual in a household is considered as deprived if the primary cooking fuel is not one of the modern cooking fuels (LPG, biogas, natural gas, electricity). In the lighting dimension, an

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[1] Towards a Perspective on Energy Demand and Supply in India in 2004-05', Report of the Advisory Board on Energy, Government of India (ABE, 1984)

[2] *Fuel Poverty: From Cold Homes to Affordable Warmth*. Bellhaven, London.(Boardman, 1991)

individual is considered as deprived if they don't use electricity or LPG as the primary source of lighting in their households.

$y_{ij} = 0$; if energy used for cooking is LPG, biogas, electricity and kerosene and energy used for lighting is electricity, LPG, biogas, and,

$y_{ij} = 1$; if energy used for cooking is any other fuel other than LPG, biogas, electricity and kerosene and energy used for lighting is any fuel other than electricity, LPG, biogas.

Access to basic energy services (all fuel types)

This dimension is, having access to the most basic energy services (cooking, lighting, and space heating) which is measured through the daily per capita consumption of household energy sources. A threshold amount of energy is based on the Report of the Advisory Board on Energy (ABE, 1984) cited in Pachauri and Spreng (2004) where they estimated that 0.792 kWh is the minimum useful energy required per capita per day for basic energy services and are adjusted for the household size scale of economies. An individual is considered deprived if the minimum useful energy required to consume fall short of 0.792 kWh.

Consumption of energy services

This dimension looks at whether individuals of the household spend more than 10% of its total consumption expenditure to access the basic energy services or not. Poor households may be spending most of their total consumption expenditure on inefficient fuels like biomass which are more costly than the efficient fuels and it deprives them of other basic goods and services needed to sustain life. In this dimension, an individual is considered deprived if the person belongs to the household spends more than 10% of total consumption expenditure on energy.

Services through household appliances, entertainment, and communication

This dimension looks whether an individual in the households have access to the services by the means of household appliances, entertainment, and communication. Whether household has ownership of any of the electronic goods like fridge, electric fan, A/C cooler, washing machine, TV, radio, telephone. An individual is deprived if the households to which individual belongs do not have access to any of these services.

Mathematical model

The mathematical outline of the measure as defined by Nussbaumer et al. (2012) for MEPI is described below:

Assuming a population of *n* being evaluated for energy poverty across *d* variables, an *n*×*d* matrix of achievements of *i* individuals for *j* variables can be written as;

$$Y = y_{ij}$$

where;

j are dimensions of cooking, lighting, minimum access of energy, expenditure on energy consumption and household amenities and y_{ij} *are the achievements of the individual in j dimensions.*

$y_{ij} > 0$ denotes the individual *i's* achievements in the dimension j*;* thus, each row vector $y_{ij} = y_{i1}y_{i2} \dots \dots .., y_{in}$ represents the individuals *i's* achievements in the different dimensions, and each column vector $y_j = y_{1j}, y_{2j} \dots \dots .., y_{nj}$ gives the distribution of achievements in the dimensions across individuals. Each dimension *j* has an assigned weight w_j where the sum of the weights is equal to 1:

$$\sum\nolimits_{j=1}^{d} w_j = 1$$

A deprivation cut-off z_j in dimension *j* identifies whether an individual *i* is deprived or not in the dimension *j* based on the achievements. For example, in the dimension of cooking if a household is using biomass (firewood, coke, coal, charcoal etc) as energy source than the individuals living in that household are deprived in cooking dimension. Hence, using biomass as energy for cooking means individual is deprived in cooking dimension. A deprivation matrix $g = g_{ij}$ provides the deprivation of individuals for a given dimension. If the individual is deprived in the dimension or if $y_{ij} < z_j$ then g_{ij} is equal to w_j while as if $y_{ij} \geq z_j$ then $g_{ij}$is equal to zero.

After this, a column vector is constructed;

$$ci \sum_{j=1}^{d} g_{ij}$$

where the i^{th} entry represents the sum of weighted deprivations suffered by a person *i* across all the dimensions *j*.

An individual is multidimensionally energy poor by defining a final cut-off, $k > 0$ and applying it across column vector and consider a person as energy poor if her weighted deprivation count ci exceed k. Therefore $ci(k)$ is set to 0 when $ci \leq k$ and equals ci when $ci > k$. Thus $c\ (k)$ represents the censored vector of deprivation counts.

Finally, headcount ratio H is calculated by $\mathrm{H} = {}^{q}\!/_{n}$ which represents the proportion of the population that are considered energy poor, where q is the number of energy-poor ($ci > \mathrm{k}$) and n the total population, and shows the incidence of multidimensional energy poverty. Further the intensity of the multidimensional energy poverty is calculated by $A = \sum_{i=1}^{n} {}^{ci(\mathrm{k})}\!/_{q}$ which is the average of the censored weighted deprivation counts $ci(\mathrm{k})$.

Multidimensional energy poverty is then defined by the multiplication of head count ratio (H) and average of the censored weighted deprivation (A) and hence;

$MEPI = H \times A.$

However, in the OPHI measure for poverty measurement the intensity is defined as the poverty gap between the average shortfall from that of the poverty line. However, it is not possible in this methodology as variables are categorical (either a household is using biomass or LPG for cooking). Hence, in this methodology intensity is measured as the average sum of weighted deprivation of those who are determined as poor. It shows that intensity measure counts, in how many dimensions on average the energy poor are deprived. If those who are already energy-poor become poor in additional dimensions the intensity increases and not the headcount, hence MEPI score increases.

Weights

It is a fact that the lack of access to modern energy sources in cooking and lighting is the major source of indoor air pollution which has a detrimental effect on health (Faizan & Thakur, 2019a, 2019b; Gaye, 2007; WHO, 2018b). Thus, this is an important dimension when looking into energy poverty measurement. The access to cooking fuel, as the only indicator, has been used to calculate the dimension of cooking as there is no data available on the level of pollution in a household.

Lighting is also an important dimension which has been given high importance in the MEPI by measuring through access to electricity which has an important role in the development of any nation.

The dimension of minimum energy required for basic energy services is an important dimension to measure energy poverty. It gives us the insights whether a person is able to utilize minimum energy required to achieve basic services of energy. We take the minimum amount of energy calculated by ABE (1984) i.e., 0.792 kWh for our analysis in this study as this report was prepared by the task force assigned by the Government of India. Advisory Board on Energy (ABE) has calculated 0.792 kWh per capita per day as the minimum amount of energy needed to achieve basic services of cooking, lighting, and space heating. However, Pachauri and Spreng (2004) in their research have provided a deprivation threshold of the amount of consumption of energy at 0.72 kWh.

Expenditure on energy services is an important aspect to understand energy poverty as it shows the expenditure on energy to achieve basic energy services. Poor households cannot afford to spend more but their spending on energy is a big share of total consumption expenditure because of that they must forego other services of wellbeing. Hence, this is also an important dimension to measure energy poverty.

Energy services through different household appliances for other services like space heating/cooling, entertainment and communication provides insight into the efficiency and the sustainability of the energy supplies to the households.

All these five dimensions have been assigned the weights based on their importance in providing energy services to the households and the wellbeing they carry. The importance of all the dimensions and the weights assigned were derived from the existing literature (ABE, 1984; Boardman, 1991; Faizan & Thakur, 2019a, 2019b; Nussbaumer et al., 2012; Pachauri & Spreng, 2004; WHO, 2018a). In this study, the dimensions of cooking, lighting, access to basic energy consumption, expenditure on energy consumption and access to household amenities (household appliances, entertainment and communication) have been assigned weights of 0.4, 0.15, 0.2, 0.15 and 0.10 respectively. The multidimensional cut-off, *k*, is set to 0.40, which means, an individual is multidimensionally deprived either if they do not use modern cooking fuels, or either they do not use electricity and have access to basic minimum energy consumption or the expenditure on the energy consumption is more than 10%. Also, a person is deprived if she does not have access to basic minimum energy services, she is spending more on the energy and have lack of access to services through household appliances, entertainment, and communication. Both, the weights, and multidimensional cut-off have been assigned based on the importance of the dimension. The dimension of cooking has been assigned the highest weight due its importance in the outcome of health and education.

Constructing the per capita daily energy consumption

The consumption of each of the fuels that the household consumes is added together to construct the variable. In the survey, total consumption quantity of each fuel for a household is reported in different units. The quantity per unit of each fuel was converted to kWh, then the efficiency of the fuel as suggested in SGC (2012) and UNSC (2018) has been applied to find the useful energy consumption of each fuel. After converting different fuels consumption into the same unit, they have been added to get each household’s total energy consumption for the last 30 days. This total was then converted into daily per capita consumption of the household. Table 2 provides the energy content and energy efficiency of different fuels which has been used to construct the per capita daily energy consumption (kWh).

Table 2: Energy content and energy efficiency of the different fuels used for cooking

Energy	Unit	Energy Content (MJ/Kg)	Efficiency (%)	Useful Energy (kWh/Unit)
LPG	Kg	47.3	60	7.88
Coke	Kg	28.2	15	1.17
Kerosene	L	43.8	45	5.47
Charcoal	Kg	29.5	25	2.05
Firewood	Kg	15.6	20	0.87
Biogas	Kg	20	60	3.33
Coal	Kg	25.8	25	1.79
Electricity	kWh	-	75	0.75

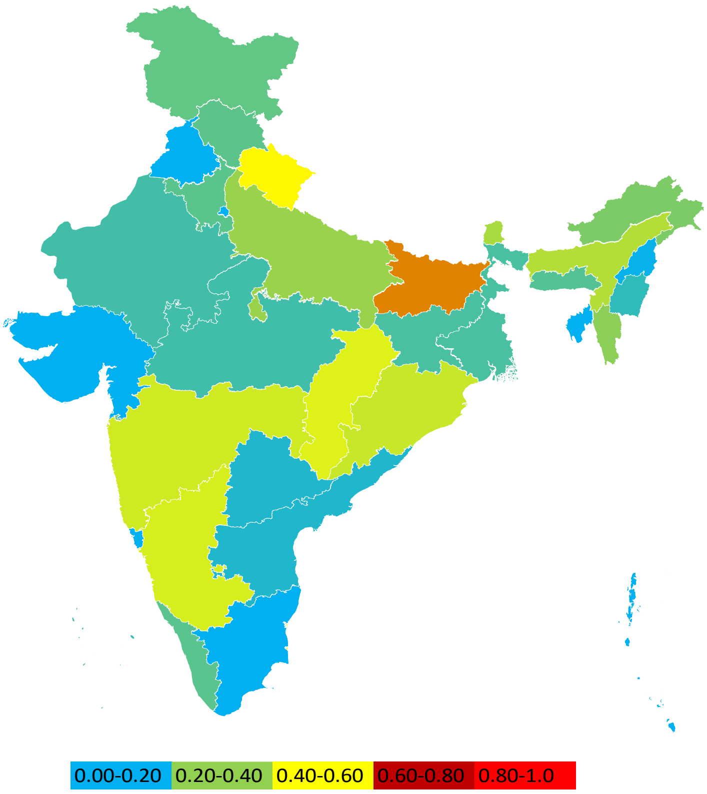
Dung Cake	Kg	14.5	16	0.64
NOTE: MJ= Mega Joule, Kg= Kilogram, L= Litre				

Source: LPG, Coke, Kerosene, Charcoal, Firewood, Coal, Dung Cake: UNSC (2018); Biogas SGC (2012)

Results

The results have been estimated for all 35 Indian states and union territories while setting the multidimensional energy poverty cut-off *k* to 0.40. Figure 1 shows the MEPI scores of all the states, where states with blue colour depicts least MEPI score form 0.00-0.20 and dark red represents highest MEPI score of 0.80-1.00. Table 3 below gives an overview of the scores of energy poverty for different states in which a higher MEPI score shows higher energy poverty. The MEPI score at the national level is 0.43, the percentage of energy poor is 68 percent and the average intensity of deprivation among energy poor is 0.63. The 8 Empowered Action Group (EAG) states like Bihar, Jharkhand, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Odisha and Rajasthan except Uttarakhand have higher scores of MEPI, which means they have higher energy poverty. Bihar has the highest MEPI score of 0.70 and the percentage of population dependent on the inefficient fuels for cooking and lighting is highest in this state (Fig. 2 & Fig. 3). No other state has MEPI score of 0.70 but the states like Uttar Pradesh, Odisha, Chhattisgarh, Jharkhand, Madhya Pradesh, West Bengal, Assam, and Rajasthan have significantly high MEPI scores than the national average and the score varies between 0.44 to 0.61. These states have significantly higher percent of population dependent on the inefficient fuels cooking and lighting as shown in Fig 2 and Fig 3.

Fig 1: MEPI scores across various states in India



Source: Based on the author's calculations from NSS 68th round.

Table 3 provides a complete scenario of the scores of MEPI along with the headcount poverty, intensity of the deprivation, and Human Development Index (HDI) scores of the respective states. HDI is the measure of average achievement in the key dimensions of the human development viz-a-viz a long and healthy life, being knowledgeable and have a decent standard of living. Access to clean and modern fuels enhances the wellbeing in a household and hence, improves the human development. Hence, it is imperative to understand the relationship between the MEPI and HDI as it shows how important it is to disengage the people from using biomass and other unclean fuels. As it is evident from the Table 3 and Figure 6 that there is inverse relationship between the MEPI and HDI. More a state is using clean fuels, high is the HDI score in the state.

Table 3: Detailed results for all states: Headcount ratio and intensity of energy poverty, and the composite MEPI, as well as HDI.

State	Head Count	Intensity	MEPI	HDI[3]
A&N Islands	0.31	0.49	0.15	-
Andhra Pradesh	0.50	0.49	0.24	0.47
Arunachal Pradesh	0.59	0.63	0.37	-
Assam	0.76	0.61	0.46	0.44
Bihar	0.90	0.78	0.70	0.37
Chandigarh	0.09	0.65	0.06	-
Chhattisgarh	0.89	0.61	0.54	0.36
Dadra & Nagar Haveli	0.61	0.56	0.34	-
Daman & Diu	0.17	0.55	0.09	-
Goa	0.15	0.47	0.07	0.62
Gujarat	0.58	0.55	0.32	0.53
Haryana	0.57	0.57	0.33	0.55
Himachal Pradesh	0.69	0.48	0.33	0.65
J&K	0.59	0.50	0.30	0.53
Jharkhand	0.87	0.60	0.52	0.38
Karnataka	0.62	0.52	0.32	0.52
Kerala	0.62	0.45	0.28	0.79
Lakshadweep	0.67	0.43	0.29	-
Madhya Pradesh	0.78	0.65	0.51	0.38
Maharashtra	0.46	0.58	0.27	0.57
Manipur	0.54	0.58	0.31	-
Meghalaya	0.76	0.51	0.39	-
Mizoram	0.37	0.57	0.21	-
Nagaland	0.34	0.49	0.17	-
NCT of Delhi	0.10	0.52	0.05	0.75
North East (excluding Assam)	0.65	0.52	0.34	0.57
Odisha	0.89	0.62	0.55	0.36
Puducherry	0.13	0.45	0.06	-
Punjab	0.49	0.59	0.29	0.61
Rajasthan	0.76	0.58	0.44	0.43
Sikkim	0.38	0.52	0.20	-
Tamil Nadu	0.39	0.48	0.19	0.57
Tripura	0.86	0.48	0.41	-
Uttar Pradesh	0.82	0.74	0.61	0.38
Uttarakhand	0.59	0.50	0.30	0.49
West Bengal	0.78	0.64	0.50	0.49
India	0.68	0.63	0.43	0.61

Source: Based on the author's calculations from NSS 68th round

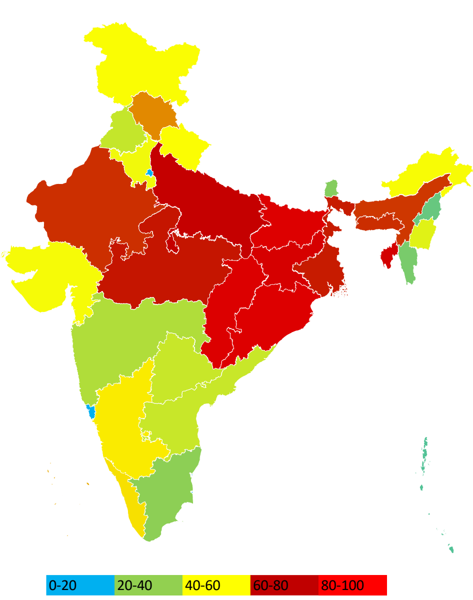
[3] UNDP (2009) http://hdr.undp.org/sites/default/files/reports/269/hdr_2009_en_complete.pdf

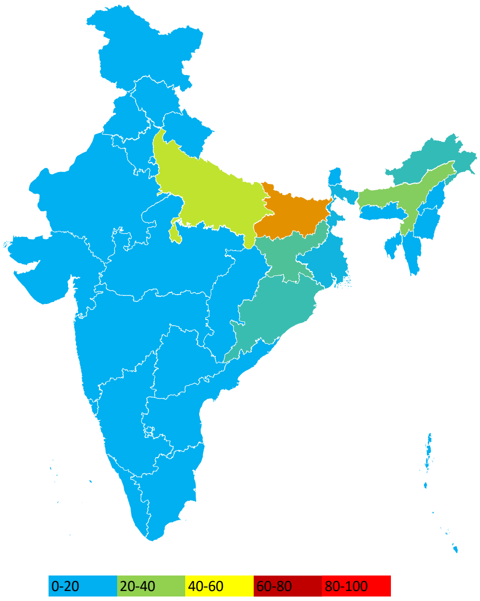
Figure 2 shows the percentage of population without access to clean fuels for cooking. Blue colour depicts the higher access to clean fuels while as dark red depicts least access to clean fuels for cooking. The states of Bihar, Odisha, Chhattisgarh, Jharkhand, Tripura, Uttar Pradesh have more than 80 percent of the population dependent on inefficient fuels for cooking. This is also reflected in the higher MEPI scores in these states. On the other hand, several other states including few South Indian states like Kerala and Karnataka have more than 60 percent of the population dependent on the inefficient fuels for the cooking. Most of the states have more than 30 percent dependence on inefficient fuels for cooking except Union Territories of Daman & Diu, Puducherry, NCT of Delhi, Chandigarh, and the state of Goa.

Figure 3 shows the percentage of population without access to clean fuels for lighting. Blue colour depicts the higher access to clean fuels while dark red represents least access to clean fuels for lighting. Bihar is the only state which has almost 70 percent dependent on inefficient fuels for lighting, while, Uttar Pradesh has almost 50 percent population dependent on inefficient fuels for lighting. Most of the other states have less than 20 percent of population dependent on inefficient fuels for lighting.

In Figure 4, percentage pf population which lacks access to minimum energy consumption is shown. In this dimension, again Bihar has the highest percent of population which lacks access to the basic minimum energy of 0.792 kWh. It is followed by Uttar Pradesh and Madhya Pradesh. Figure 5 shows the percentage of population which consumes more than 10 percent of expenditure on energy consumption out of their total consumption expenditure. In this dimension, Odisha has the highest percent of population which consumes more than 10 percent of their expenditure on energy consumption. It is followed by the states of Madhya Pradesh, Punjab, Arunachal Pradesh, and Chhattisgarh.

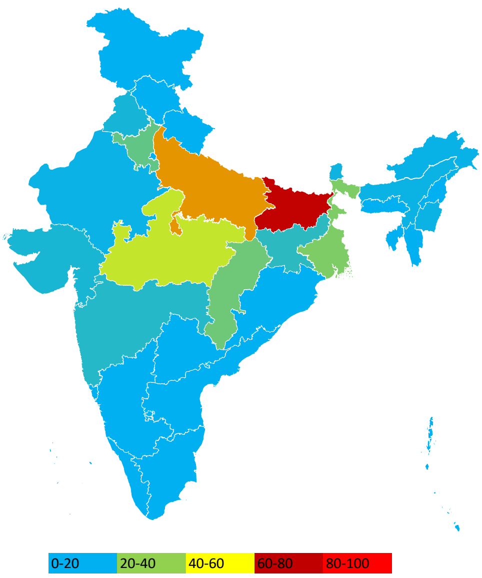
Fig 2: Lack of access to clean fuel for cooking ***Fig 3: Lack of access to clean fuel for lighting***

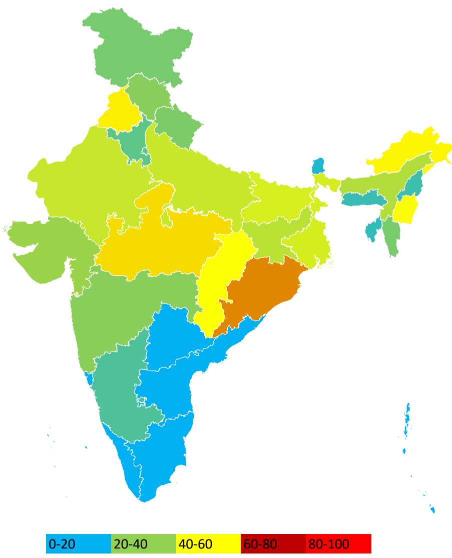




Source: Based on the author's calculations from NSS 68th round ***Source: Based on the author's calculations from NSS 68th round***

Fig 4: Lack of access to minimum energy consumption ***Fig 5: Consumption of energy more than 10%***



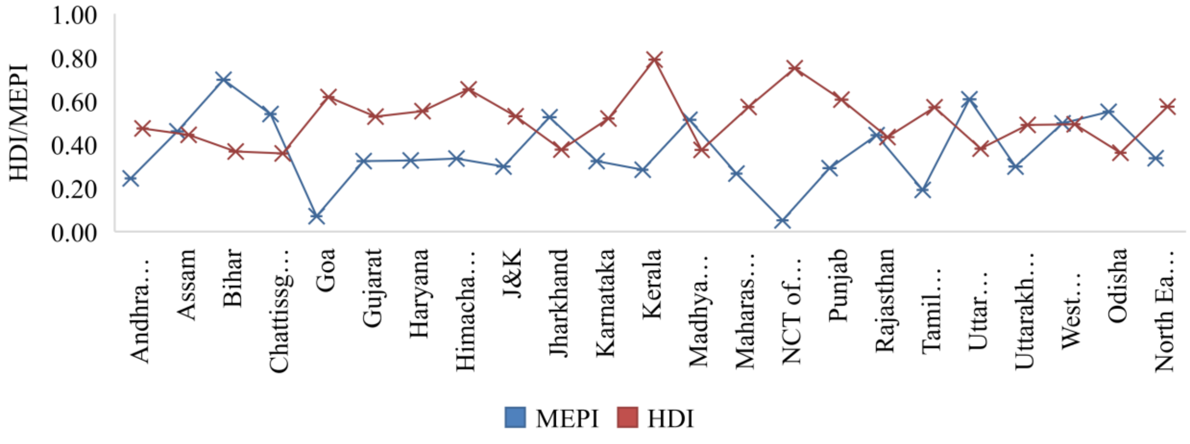


Source: Based on the author's calculations from NSS 68th round. ***Source: Based on the author's calculations from NSS 68th round.***

In Figure 6, we have depicted the relationship between MEPI and HDI of different states. It shows that states with high HDI have low MEPI scores, which means that if the state has high

HDI, the energy poverty in the state is low. For e.g., the HDI of Bihar is low and it is reflected in the MEPI scores, showing highest energy poverty.

Fig 6: Comparison of HDI and MEPI across states



Source: Based on the author's calculations from NSS 68th round ; UNDP (2009)

Discussion

Atkinson and Bourguignon (1982) as cited in Okushima (2016) emphasized that poverty cannot be comprehensively represented by the single dimension but the multidimensional index provides a convincing picture of the level of energy poverty. It is important to develop an index which can be easily computed and flexible enough to be used in various contexts (Nussbaumer et al., 2012).

Almost 70 percent of the population in India is still using inefficient fuels for cooking as their primary source of energy, while, nearly 22 percent are still lacks electricty as their primary source of energy for lighting. The lack of access to clean fuels for cooking is one of the main reasons for most of the states to have highest MEPI scores. Bihar and Uttar Pradesh are at the top among all these states. Easy availability of firewood epecially in rural areas and lack of access to electricity is one of the important factors responsible for over dependence on biomass for cooking and use of kerosene and other oils for inefficient lightig purposes (Nathan & Hari, 2018). Majority of the Indian states have more than 30 percent of the population dependent on biomass for cooking and shows that it is the most important dimension which should be prioritized for the policy implications. Bihar and Uttar Pradesh along with the states of Odisha, chhattisgarh, Jharkhand, Madhya Pradesh, West Bengal, Assam, Rajasthan are states which should be prioritized by the policy makers as these are the states where energy poverty or MEPI is above the national energy poverty. Moreover, using inefficient fuels for cooking and lights has negative effects on the health (Faizan & Thakur, 2019a, 2019b; WHO, 2018a).

The dimension of minimum access to energy consumption provides the useful insights regarding the consumption of fuels. If a household consumes inefficient fuel, the useful energy per unit of that fuel is very less with respective to clean and efficient fuel after considering efficiency factor. It reveals that a household consuming inefficient fuel is not only consuming less of the useful energy but it also exposes the members to the hazardous gaseous emmissions which are harmful for the health (Faizan & Thakur, 2019a, 2019b).

Also, the dimesnion of 10 percent which provides the affordabilty of the households for the fuels. If a household is consuming more than 10 percent of their expenditure for accessing energy, it may lead to less expenditure on accessing health and educational services. Reducing expenditure on health and education have their own negative effects which may lead to poor health and poor skills and less employments opportunities. Hence, all these dimensions are important to comprehend the importance of the aspects of energy poverty.

Energy poverty is a serious concern especially in the developing countries but the concept and definition are yet to be defined which can be measured and compared universally. There is a clear and universal understanding of the general poverty, but for energy poverty, it has not been developed yet which can have universal understanding. Thus this paper aims to make energy poverty an academic as well as a policy issue in India. This study takes into account the key elements which affect energy poverty like household consumption, cost of the fuels and the efficiency of the energy fuels consumed by the households. Though, researchers have tried to understand and measure energy poverty, this study considers some other important dimensions which were not studied by earlier researchers in their studies.

We have gone beyond the analysis of the results by checking the robustness of the methodology and the results. For this, we did the following tests to check the sensitivity of the weights.

Sensitivity Analysis

Dimensional Weights

To compute a composite index by aggregating dimensions requires a set of weights for the dimension. The weights used for all the dimensions have been discussed above. Due to the uncertainty involved, a test is performed where weights are changed to test the robustness of the results.

In the test, only weights were changed to isolate the effect of the changes. The multidimensional cut off *k* has been set to 0.40 in the original model which shows that if an individual lacks access to the clean cooking fuels is energy poor. For the testing of the weights, the dimensional cut of *k* was varied between 0.30 to 0.50. The change in the energy poverty cut off does not lead to significant changes in the states rankings.

From Table 4 and Table 5, it is evident that there is a positive correlation between the rankings of the different MEPI outcomes which is significant at 5 per cent level.

Table 4: Spearman Rank Correlation test of MEPI for change in multidimensional cut-off

K	**0.30**	**0.40**	**0.50**
0.30	1		
0.40	0.9994*	1	
0.50	0.9392*	0.9381*	1

Source: Based on the author's calculations from NSS 68th round.

Table 5: Kendall Rank Correlation test of MEPI for change in multidimensional cut-off

k	**0.30**	**0.40**	**0.50**
0.30	1		
0.40	0.9933*	1	
0.50	0.8218*	0.8151*	1

Source: Based on the author's calculations from NSS 68th round.

In Table 6, we see the effects of changing multidimensional deprivation cut-off *k* in the rankings and the MEPI scores of all the states and it reveals there are marginal changes in the MEPI score while varying the values of *k* but there are negligible changes in the ranking of the state.

Table 6: Effects of multidimensional energy deprivation cut-off change on the distribution of states in deciles

MEPI Deciles*	*Varying cut-off (k)**		
	0.30	**0.40**	**0.50**
0.0-0.10	Delhi, Puducherry, Chandigarh, Goa, Daman & Diu	Delhi, Chandigarh, Puducherry, Goa, Daman & Diu	Puducherry, Goa, Delhi, Chandigarh, Lakshadweep, Daman & Diu, A&N Islands, Nagaland, Tamil Nadu, Kerala
0.10-0.20	A&N Islands, Nagaland, Tamil Nadu, Sikkim	A&N Islands, Nagaland, Tamil Nadu, Sikkim	Andhra Pradesh, Sikkim, Mizoram, Uttarakhand, J&K, Himachal Pradesh, Tripura
0.20-0.30	Mizoram, Andhra Pradesh, Maharashtra, Kerala, Lakshadweep, Punjab, Uttarakhand, J&K	Mizoram, Andhra Pradesh, Maharashtra, Kerala, Lakshadweep, Punjab, J&K, Uttarakhand	Karnataka, Maharashtra, Meghalaya, Haryana, Punjab, Gujarat, Manipur, Dadra & Nagar Haveli
0.30-0.40	Manipur, Karnataka, Gujarat, Haryana, Himachal Pradesh, Dadra & Nagar Haveli, Arunachal Pradesh, Meghalaya	Manipur, Karnataka, Gujarat, Haryana, Himachal Pradesh, Dadra & Nagar Haveli, Arunachal Pradesh, Meghalaya	Arunachal Pradesh, Rajasthan
0.40-0.50	Tripura, Rajasthan, Assam, West Bengal	Tripura, Rajasthan, Assam, West Bengal	Assam, Jharkhand, West Bengal, Chhattisgarh, Madhya Pradesh, Odisha
0.50-0.60	Madhya Pradesh, Jharkhand, Chhattisgarh, Odisha	Madhya Pradesh, Jharkhand, Chhattisgarh, Odisha	Uttar Pradesh
0.60-0.70	Uttar Pradesh, Bihar	Uttar Pradesh, Bihar	Bihar
0.70-0.80	-	-	-
0.80-0.90	-	-	-
0.90-1.00	-	-	-

Source: Based on the author's calculations from NSS 68th round * MEPI scores lies between 0 and 1 and hence MEPI deciles 0.00-0.10 is the final MEPI score which lies between 0.00 and 0.10.

Conclusion

Accessabilty and affordability of clean energy sources in any household is essential given the hazards of using biomass on health and environment. With the growing population and increased demand for energy in day to day life, we attempted to assess the energy poverty in India using household consumption expenditure data and analyzed it by using multidimensional energy poverty index. The results reveal that energy poverty is prevalent in India especially in the EAG states of Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan, Chattissgarh, and Jharkhand. The headcount energy poverty in majority of the states is more than 50 percent which shows that the households are higly reliant on biomass for their daily energy needs. Also, the results reveal that the MEPI is inversely proportional to HDI, which shows that reducing the energy poverty could improve the human development of the individuals. Results further reveal that in majority of the states, people are spending more than 10 percent of their income on household energy irrespective of the type of energy which shows the intensity of the burden of the same. These results corroborate that energy poverty is a multidimensional phenomena and needs to be evaluated using comprhensive approach such as MEPI. The insights from this study can provide policymakers with the possibility of choosing a group of population which needs intervention and be targeted in specific policies. This index can also be used to monitor and evaluate public policies regarding energy poverty. For example, the decline in the index score will be perceived as a decline in energy poverty in general. It will identify the dimension in which the given policy is effective. Further, this index can be used for making comparisons between the households in a country but also with other countries. This study holds importance as energy poverty has not been measured as comprehensively in India and this methodology throws light on the importance of each indicator in different dimentions to understand the level of the energy poverty. This study lays a basis for further development of the energy poverty indicators to improve the access to clean and modern energy services.

Data availability

The data which supports the plots and analysis within this paper and other finding of this study are available from the government of India and also with the authors upon reasonable request.

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