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Measuring Energy Poverty: A Households Level Analysis of India

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Measuring Energy Poverty:
A Households Level Analysis of India[1]

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Abstract

Measurement of energy poverty has been a missing priority in energy research. There has been a lack of consensus on whether to consider energy as a resource or capacity, output or outcome, and quantity or service. The paper outlines the three approaches in literature to assess energy poverty: economic, engineering, and access-based. It critiques the economic and engineering approaches for the arbitrariness of cut-offs and the misplaced emphasis on energy quantity which is less meaningful. The study finds the access-based approach to be most suitable to the conventional notion of poverty and proposes a novel method based on deprivation in modern cooking and lighting fuels. The method introduces a transitional group between the energy-poor and energy-nonpoor and calculates the poverty gap based on the extent of inefficient fuel in the energy basket. The method is applied to rural and urban areas of different states and union territories of India by taking data from national sample survey. The study finds energy poverty in a household gets primarily dictated by deprivation in cooking, and a greater incidence of poverty in larger states. In contrast to the conventional measures, it argues for depth and severity of poverty to be computed only for those who are not energy-nonpoor as complement indicators to the poverty incidence, rather than as substitutes. Using this approach, the study shows though certain entities in India have less share of people who are not energy-nonpoor compared to certain others; but have a greater level of energy poverty compared to the other entities.

Key words: Energy-poor, Energy-nonpoor, Energy-transitional, Complementary poverty measures, Cooking and lighting energy services, Depth and severity of energy poverty.

JEL codes: Q4, I32

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1. Introduction

The importance of study on energy poverty comes from primarily three reasons. First, unlike income poverty,[4] there is no consensus on how to measure energy poverty (Branes *et al*., 2014; Halff *et al*., 2014). Measuring or sizing of the energy poverty problem is the essential first step in tackling it; Birol (2014) writes 'in life what gets measured gets managed'. The second important reason for study of energy poverty stems from the largeness of the problem. Depending on the definition, one-third to one-fourth of the humanity are energy-poor (Halff *et al*., 2014). The third reason is more fundamental and it has to do with the fact that access to energy is not only is an outcome of development, but also a mean to the same. Energy acts as an engine for production of goods and services and is a vital necessity for social progress, such as provisioning of health care, water and sanitation, education, and has a multiplier effect on the productivity of income-generating activities in agriculture, industry, and service sectors. (Modi *et al*., 2005; IAEA, 2008; Birol, 2014; Nathan and Raj, 2016). Access to affordable, sustainable, and reliable energy is critically important for poverty eradication, socio-economic transformation, and overall sustainable development (UN, 2013; Commonwealth Secretariat, 2014). Given the countless ways energy enhances the lives of the poor and enables development,[5] provision of modern energy services becomes a 'moral' imperative (Birol, 2014), and in this sense a poverty metric based on energy deprivation than income or wealth is more relevant for policy makers and implementers of development (Halff *et al*., 2014).

Irrespective of its importance, energy poverty has remained a missing global priority till recently. Highlighting the lack of attention to this by experts, Birol (2007; 2014) attributes energy poverty to the poverty of energy economists and its eradication is first a statistical battle. Barring some discrete individual efforts from the likes of Prof. A.K.N. Reddy of India or Prof. J. Goldemberg of Brazil, universal energy access was not on global agenda; it could not figure among the Millennium Development Goals (Halff et al., 2014). Only in 2002, International Energy Agency (IEA)'s World Energy Outlook Report assessed energy poverty for the first time. This missing

[4] Income poverty is 'usually based on measure of minimum consumption of food and non-food items necessary to sustain life' (Halff *et al*., 2014).

[5] Lighting extends the study hours of children and work hours for adults, modern cooking saves exposure to indoor air pollution, refrigeration can preserve food and medicine, energy can improve access to water, mobility, and information and communication, enhance quality of products and create employment opportunities and increases wages (Birol, 2014).

priority has received some recent amendments: In 2012, United Nations celebrated International Year for Sustainable Energy for All (UN, 2011). Subsequently, United Nations General Assembly declared 2014-2024 as decade of sustainable energy for all (UN, 2012). Also, energy was included as a goal among Sustainable Development Goals (SDGs); Goal 7 reads as: *Ensure access to affordable, reliable, sustainable, and modern energy for all* (UN, 2015).

One of the lagging factors in conceptualizing and measuring energy poverty has to do with the lack of consensus on situating energy in the course of development: whether to consider energy as a 'resource' or 'capacity', 'output' or 'outcome', and 'quantity' or 'service'. Energy in a conventional or physical sense is considered as a fuel or input resource, whereas under Sen's capability approach nomenclature,[6] it can be considered as an enabler or capacity– both from the perspective of households and society at large (Halff *et al*., 2014). To measure energy requirements, one can measure quantity of energy demand.[7] However, a more useful approach would be to measure energy services.[8] The same quantity of energy can provide different amount of services depending on the efficiency of the device.[9] Also energy can be measured in terms of output (for instance, access to electricity) or outcome (welfare gains because of the electricity access like increase in study hours for children) (Barnes *et al*., 2014).

In this backdrop the importance of conceptualization and measurement of energy poverty cannot be over emphasized. This paper evaluates economic, engineering, and access-based approaches of assessing energy poverty. It argues that economic approach, which is based on income poverty, suffers from the arbitrariness of poverty line that divides the people discretely as poor and nonpoor; hence this approach may not be very reasonable. The engineering approach is a bottom-up and a more detailed way of assessing energy requirement based on household needs. However, this approach suffers from the limitation of availability of data, which is expected to be extremely dynamic. Also, there is a mismatch between energy quantity (that the engineering

[6] For details see introduction to capability approach in Stanford Encyclopedia of Philosophy (2011).
[7] An example of quantity of energy requirement is the IEA (2012) specification minimum requirement of 250 kWh and 500 kWh of electricity in rural and urban areas, respectively.
[8] Energy services are the services the energy devices provide such as lighting, heating for cooking, space heating, etc. (Modi et al., 2005; Kowsari and Zerriffi; 2011).
[9] An example of this is that using the same quantity of electricity, an incandescent bulb would give poorer lighting services compared to a compact fluorescent lamp.

approach generally focuses on) and energy service (that's the concern of households) on account of different efficiencies of energy devices for same service. Moreover, like economic approach, engineering approach is not free from the arbitrariness of cut-off.

The paper proposes an access-based method of computing energy poverty. It departs from the convention in two ways. First, it introduces transitional group(s) between the energy-poor and energy nonpoor. This way, it reduces the discreteness of the poverty line. As a second point of departure, the paper taking a cue from a recent exercise Nathan (2018), computes depth and severity of energy poverty only for energy-poor as against for entire population. Thereby, the paper presents depth and severity as complementary measures to incidence of poverty: incidence gives what share of population is energy-poor, whereas the depth and severity show how much is the energy poverty of the energy-poor. The paper provides an empirical illustration of the proposed methodology by considering energy poverty in different states of India for rural and urban areas.

The rest of the paper is organized as follows. Section 2 briefs the three approaches of measuring energy poverty. Section 3 outlines the new methodology proposed in this paper. Section 4 provides the empirical illustration. Section 5 provides concluding remarks.

2. Approaches of measuring energy poverty

2.1 Economic approach

The economic approach to energy poverty is linked with economic parameters. The most common of such approach is to map energy poverty to income (or expenditure) poverty (Pachauri *et al*., 2004). Under this approach, energy poverty line is considered as the average energy consumption of the households whose consumption expenditure is at same level as income poverty line (Foster *et al*., 2000; Pachauri *et al*., 2004).[10] The two other variants of economic approach are based on the energy budget share, i.e., share of household expenditure spent on energy fuels (Leach, 1987; Pachauri *et al*., 2004; DTI, 2005) and on the effective price, i.e., price paid by the household per unit of energy service availed (Leach, 1987; Foster *et al*.,

[10] For instance, in Foster *et al*. (2000) the average energy consumption of households falling within 10% range of official economic poverty line have been considered to determine energy or fuel poverty line.

2000; Pachauri *et al*., 2004). Due to lack of access to affordable modern energy services, poor tend to use more inefficient fuel or device by spending more time and effort in availing the same and ends up paying more price per unit of useful energy (Leach, 1987; Foster *et al*., 2000; Pachauri *et al*., 2004).[11] It is worthwhile to note that in 'poverty line' approach, an energy-poor lies below the cut-off, whereas in 'budget share' approach and 'effective price' approach, an energy-poor would lie above the cut-offs.

The economic approach has a few serious shortcomings. First and foremost, the economic parameters on which the energy poverty measurement is based, such as income or price are continuous variables and discrete cut-offs for identification of poor is arbitrary (Nathan, 2018). Watts (1968, p.325), in the context of income poverty line, quite succinctly wrote: "*Poverty is not really a discrete condition*. *One does not immediately acquire or shed the afflictions we associate with the notion of poverty by crossing any particular income line*." Hence, categorizing households adjacent to a cut-off on either side into two different groups, viz., energy-poor and energy-nonpoor is unreasonable given the similarities of their energy use (Nathan, 2018). For, instance, considering Govt. of UK definition, that identifies a household to be energy-poor when it has to spend more than 10% of its income on energy to heat its home to an adequate standard, categorizing two households spending a little less and a little more than the cut-off, *say* 9.9% and 10.1% of their income for the same purpose, as nonpoor and poor, respectively, is nothing but arbitrary. Also, by exclusive relying on income would make income poverty a proxy for energy poverty and vice-versa, thereby making energy poverty measure mostly redundant.

The other important shortcoming of economic approach is that the measure may not be indicative of the actual poverty situation. In the poverty line approach, lower energy consumption may be a result of use of higher efficient devices. Hence, as argued earlier, quantity of energy consumption is less meaningful.[12,13] Similarly, the larger budget share on energy need not be

[11] Useful energy is defined as "the energy effectively made available to the user in terms of the services delivered through end-user equipment" (Madureira, 2014).

[12] Conventionally the cut-offs are based on final energy, i.e., the energy delivered to the input devices a consumer uses (Madureira, 2014); hence do not consider for the efficiencies of the devices. One needs to consider useful energy, instead of final energy, to account for device efficiencies.

[13] We acknowledge that improvement in energy-efficiency does not lead proportionate decrease in energy consumption because of rebound effect (Gillingham *et al*., 2014).

because of energy poverty, rather may be due to luxurious and wasteful consumption or larger household size (Foster, 2000). And a higher effective price per unit energy may indicate that the household's consumption is at a higher level: for instance, per unit electricity price is greater at higher consumption slabs (Bijli Bachao, 2018).

2.2 Engineering approach

The engineering approach of assessing energy poverty is basically a bottom-up approach that estimates directly the energy requirement of households based on normative basic needs of different energy services and specifications of different energy carriers (calorific value of fuels) and energy appliances (size, efficiency, etc.) used to get those services (Pachauri *et al*. 2004; Goozee, 2017). For instance, using this approach, assuming safe, clean, and efficient cooking with liquified petroleum gas (LPG) or LPG-like fuel, and electricity for lighting, space comfort, food preservation, and entertainment, Reddy (1999) estimated that the basic final energy requirements was 100 watts per capita.[14] This approach has the flexibility of finding energy thresholds for different needs in different geographical and socio-cultural settings.[15] For literature on different past initiatives based on engineering method, see, Pachauri *et al*. (2004) and Swan and Ugursal (2009), among others.

The engineering approach has several limitations. This method is computationally intensive requiring complex and inter-related data on household dwelling units, occupants, fuels, and appliances (Swan and Ugursal, 2009; Goozee, 2017). In addition, the basic needs are subjective to the consumers and also can vary with season, region, and climate (Pachauri *et al*., 2004). Hence, these data are extremely dynamic and availability of such data always remains an issue. Also, comprehensive and expensive surveys conducted to collect such data can become obsolete with changing technologies, preferences, and practices. The engineering approach also suffers from the limitation of cut-offs, and in this sense, is not free from arbitrariness. Also, in the engineering approach, the focus is on quantity of energy, which is not a very useful parameter as

[14] Expressing energy requirements in watts/capita is an alternative unit. For example, the IEA (2012) monthly requirement of 250 kWh electricity for a rural household can be expressed as: 250*1000/(30*24*5)=69 watts per capita assuming 30 days for month and five for the size of the households.

[15] For these advantages, Pachauri *et al*. (2004) terms this measure to be robust.

discussed earlier. Last, but not the least, engineering approach fails to account for individual socio-economic characteristics or consumer behavior (Goozee, 2017).

2.3 Access-based approach

The access-based approach of measuring energy poverty is based on whether the household has access to desirable energy services. The IEA uses access-based approach to assess worldwide energy poverty by calculating number of people lacking access to electricity and modern cooking fuel. Though this approach is a straight forward one of identifying households with and without access to energy services, it is presented in literature, as in case of Pachauri *et al*. (2004), as a complicated method with difficulty in data finding. It is so as the definition of access in these literature is limited to physical access. For instance, in case of households' access to electricity, data on physical coverage of electricity need to be supplemented with market prices of electricity and electrical equipment, households purchasing capacity, quality of supply, etc. (Pachauri and Spreng, 2004; Pachauri *et al*., 2004).

A way to overcome this is to define access in such a way that includes utilization aspect of energy services. When a household uses certain energy services, it automatically accounts for affordability and all other factors that makes the use possible. In this way one overcomes the data limitation as some of these data on utilization of energy services are readily available. For instance, in the Indian context, the national sample surveys (NSS) data include households primary source of energy for cooking and lighting (NSSO, 2013). When a household uses modern fuel, such as LPG or electricity, as prime source of energy for cooking, it implies not only physical access, but also, quality and reliability of supply, access to market, and affordability of households for both the fuel and device.

It is important to note that energy poverty based on households' primary source for certain energy services better fits to the notion of poverty line. When a household substitutes an inefficient fuel by an efficient one as the prime energy source for certain purpose (such as from kerosene to electricity for lighting) there is a definite jump in the energy ladder.[16] Hence, this

[16] Energy ladder concept corresponds to a series of fuel substitution in a household for different purpose as the economic situation of the household changes (Hosier and Dowd, 1987; Kowsari and Zerriffi, 2011).

suits better to the discreteness requirement in categorizing people as poor and nonpoor. Given the merit of the approach, we use the same to propose a new method to assess energy poverty.

3. A new method

3.1 Focus on cooking and lighting energy services

This paper proposes a new method of computing energy poverty based on access-based approach. We define energy poverty on the basis on an individual's access to modern forms of energy. We have taken into account two major aspects of household energy use: cooking and lighting. The rationale for focusing on these two energy use comes from at least four reasons. First, cooking and lighting is of great importance in households' energy basket, especially for developing countries (Reddy and Nathan, 2013; ADB, 2017). Among the different energy needs of a household, cooking and lighting are most universal and regular services, compared to other services like space heating and transportation (Wickramasinghe, 2005; de la Rue du Can *et al*., 2009; Greentech, 2010; WHO, 2014). Being the most basic, the first, and the foremost energy use, cooking and lighting constitute not only the main share in household energy consumption, but also a substantial component in household expenses, particularly for low-income families (Reddy, 2004; CAREPI, 2009; Reddy and Nathan, 2009; Nicholson, 2012).

The second rationale comes from the fact that lack of access to modern energy source in cooking and lighting is the major source of indoor air pollution causing detrimental effect on health, mainly for women, leading to premature deaths (Lighting Africa, 2011; Patange *et al*., 2015; WHO, 2014; González-Eguino, 2015). The third important reason for considering cooking and lighting is that data for these energy uses are available worldwide. Globally, International Energy Agency, keeps track of people deprived of electricity and modern cooking fuel through its world energy outlook reports since 2002 (IEA, 2002). Lastly, given its far reaching implications, energy poverty measurement based on household's primary energy source for cooking and lighting would help in targeting the anti-poverty programmes as well programmes specific to reducing energy deprivation in households (TERI, 2008; Nagothu, 2016).

3.2 Study area

The present analysis focuses on India, which is a home to largest number of people without access to electricity or modern cooking fuel in the world (IEA, 2017). As per the latest Census of India (2011), approximately two-thirds of households use either firewood, crop residue, dung cake, or charcoal for cooking, and approximately one-third of households are deprived of electricity. As per the IEA (2012a) definition of modern energy,[17] by 2015, India housed 834 million people without clean cooking fuel facilities, and by 2016, 239 million people without electricity (IEA, 2017).

We have considered India's 35 entities—28 states and seven union territories (UTs).[18] We have also considered urban and rural energy poverty separately. We have done so as nature of energy transition from traditional fuels to modern fuels in urban and rural areas of developing countries are different (Kowsari and Zerriffi; 2011). Urban areas are characterized with a transition of 'energy ladder' (that signifies with increase in income, households progress to superior fuels with continuous abandonment of inferior fuels), whereas rural areas are characterized with a transition of 'energy stacking' (that signifies a 'partial switch' or accumulation of energy options so that household adopting the modern fuel can fall back to traditional fuel at the time of crisis) (Kowsari and Zerriffi; 2011).[19]

3.3 Definition of energy poverty and data source

Following the access approach and considering the utilization of modern energy sources for two basic needs of cooking and lighting, we propose the following definitions of energy poverty.

Energy-poor: An energy-poor is one who belongs to the household which does not use modern fuels as the prime source of energy either for cooking or lighting. Among the energy-poor, those

[17] The IEA (2012) defines modern energy with respect to electricity a minimum consumption of 250 kWh in rural area and 500 kWh in urban area and with respect to clean cooking fuel use of biogas system, liquefied petroleum gas (LPG) stoves and advanced biomass cookstoves.

[18] India currently has 29 states and seven union territories; however, this study uses data prior to the formation of the newest state, i.e., Telangana, which was formed out of state of Andhra Pradesh on 2nd June 2014 (India Today, 2014). Hence, in this study, Andhra Pradesh state represents the erstwhile territory that included Telangana.

[19] The crisis can be either because of supply failure or price fluctuation of modern energy. For detail discussion on the energy transition in developing economies, see Kowsari and Zerriffi (2011).

who belong to the households that are deprived of modern fuels in both cooking and lighting are considered as *extreme energy-poor*.

Energy-nonpoor: Energy nonpoor is one who belongs to the household which uses modern fuels as the prime source of energy for both cooking and lighting, and has no dependency on any energy inefficient fuels for any purpose whatsoever.

Energy-transitional: Energy-transitional is one who belongs to a household which uses modern fuels as the prime source of energy for both cooking and lighting, but has dependency on energy inefficient fuels for some purpose.

For estimating energy poverty, we use NSS 68th Round (NSSO, 2013) Schedule 1.0 data from household consumption expenditure carried out during July 2011 to June 2012. The calculations are based on the unit level (household level) data on primary sources of energy for cooking and lighting and consumption of different fuel in household during the last 30 days (NSSO, 2013).[20] The different primary source of energy for cooking are: coke, coal, charcoal, firewood and chips, LPG, biogas (*gobar* gas), dung cake, kerosene, electricity, and others; and that for lighting are: kerosene, oils other than kerosene, gas, candle, electricity, and others (NSSO, 2013). Of these, LPG, electricity, and biogas are considered as modern sources of energy for cooking. Similarly, electricity has been considered as the modern energy source for lighting.

The depth of energy poverty will be indicated by the extent of dependency of household on inefficient fuels. We propose to measure the extent of dependency by the share of total household energy consumption catered through inefficient fuels. The fuels that are considered inefficient are: coal, coke, charcoal, firewood and chips, dung cake, and kerosene. The calorific values assumed for different fuels are given in Appendix Table A1.

[20] The data on primary source of energy for cooking and lighting are item no. 16 and 17 in the Table 3, i.e., Household characteristics table of Schedule 1.0 (NSSO, 2013). The data on households' consumption of different fuels during the last 30 days are from Table 6 of the same schedule (NSSO, 2013).

In the proposed method, we calculate the average depth of energy poverty by taking the sum of shares of household energy consumption catered through inefficient fuels for those who are not energy-nonpoor (i.e., energy-poor and energy-transitional together) and dividing the same by their total number. Similarly, in the calculation of the average severity of energy poverty, which considers square of shares of household energy consumption catered through inefficient fuels and thereby accounts for distribution. For severity too, we take total number of those who are not energy-nonpoor in the denominator. This is a departure from the conventional poverty measure where depth and severity is calculated for the total population considering zero contribution from the nonpoor (Nathan 2018).

3.4 Novelty of the method

The novelty of the method is on two counts. First, it introduces a transitional group between the energy-poor and energy-nonpoor. As one moves from energy-poor to energy-transitional the household sheds dependency on any inefficient fuel as its prime source for cooking or lighting. As one moves from energy-transitional to energy-nonpoor the household further sheds dependency on any kind of inefficient fuel for any purpose whatsoever. Within the poor, the method proposes an extreme energy-poor group who uses inefficient fuels as the prime source for both cooking and lighting needs. The boundary lines among the different groups indicate shifts from inefficient fuels to efficient ones for different energy needs of the households. Unlike the economic poverty line (that is based on certain income) or the engineering approach (that is based on certain energy quantity), the cut-offs in this method are not on continuous variable.[21] Rather they indicate a definite jump with household shifting from inefficient to efficient one. Hence, this method suits better to the practical requirement in categorizing people into different groups without being as arbitrary as the economic or engineering approach. Moreover, the method reduces the discreteness by having more than just two groups: poor and nonpoor.

The second novelty of the method is that, following Nathan (2018), it proposes to calculate depth and severity of energy poverty only for those who are not energy-nonpoor. By this, the depth and severity truly reflect the state of those who contribute to these parameters, as opposed to diluting

[21] Income and modern energy quantity are continuous variables; so cut offs on those variables to categorize people as poor and nonpoor is arbitrary.

the average values of depth and severity by inclusion of nonpoor. So, while the head count ratio (HCR) or the incidence of energy-poverty would indicate what share of population is not energy-nonpoor (or what is state of energy poverty of the entire population in a crude sense), the proposed method of calculating depth and severity would complement HCR by indicating how much is the energy poverty of those who are not energy-nonpoor. Conventional measures of depth and severity measures that considers total population, improve over HCR by giving weights to each person based on the distance from the cut-off, as in HCR all those who are not energy-nonpoor are given equal and full weight. In this sense, the proposed method being inspired by Nathan (2018), presents depth and severity as complementary measures to incidence of energy poverty instead of merely substituting it with better measures.

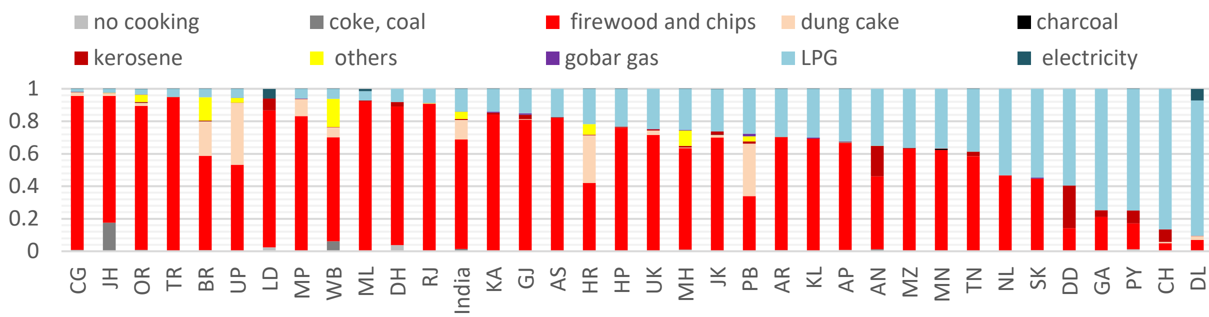
4. Results and discussion

4.1 Incidence of energy poverty in rural India

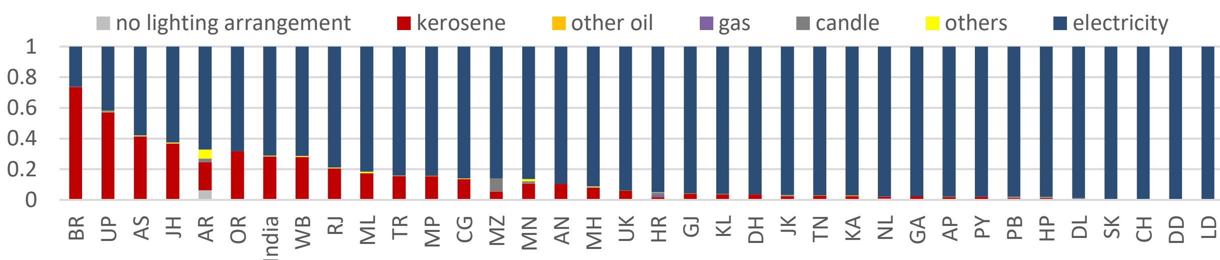
Figures 1(a) and 1(b) give for different entities of India, the share of rural population using different fuels as prime source of cooking and lighting, respectively. Overall in India, close to four-fifths of the population in rural areas used firewood and chips or dung cake as their prime source of cooking (NSSO, 2013). Kerosene, which was promoted as a relatively clean fuel for cooking (Misra *et al*., 2005; Reddy and Nathan, 2011a; 2011b; Rehman *et al*., 2012), could not make a dent with only 0.6% people in rural India relying on kerosene for cooking (NSSO, 2013). However, kerosene is a significant fuel for lighting with 28% of rural population reporting as their primary source such purpose (NSSO, 2013). In rural areas, the perception of freely available firewood on one hand and low access to electricity on the other hand has resulted in continued reliance on biomass—firewood, dung, crop residue, etc. for cooking, while the subsidized kerosene is used for inefficient lighting and diverted for other adulterated use, indicating a ‘classic case of failure of policy’.[22] Also, it is worth noting that biomass as cooking fuel and kerosene as lighting fuel are responsible for indoor air pollution and associated health hazards (Misra *et al*., 2005; Lam *et al*., 2016).[23]

[22] The subsidy policy on kerosene is misdirected as the objective of provision of clean cooking fuel is not met, and as the same is misappropriated as the subsidized kerosene is diverted as adulterated diesel because of the price difference (Misra *et al*., 2005; NCAER, 2005; Rehman *et al*., 2005; 2012; Gangopadhyay, *et al*., 2005; Reddy *et al*., 2009; Zhang, 2009; IISD, 2010; 2017).

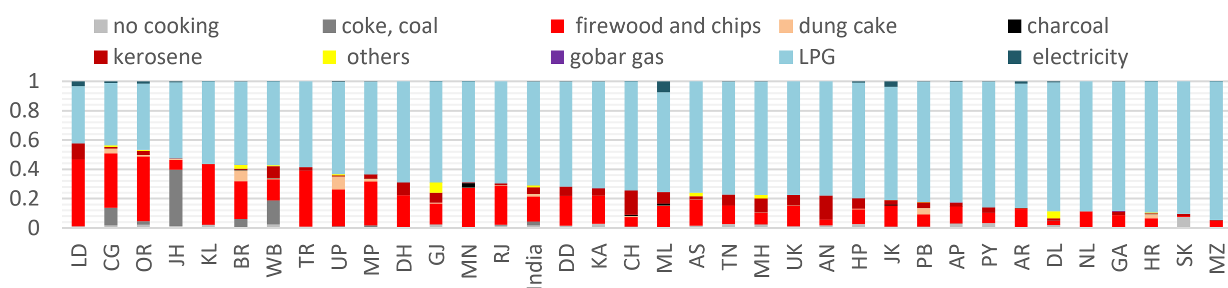
[23] The kerosene adulterated transportation fuel also adds to local air pollution (Misra *et al*., 2005; Mills, 2017).



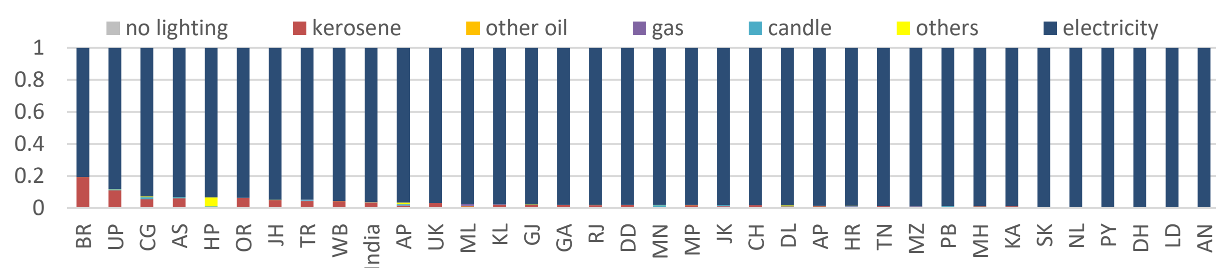
(a) Cooking in rural areas



(b) Lighting in rural areas



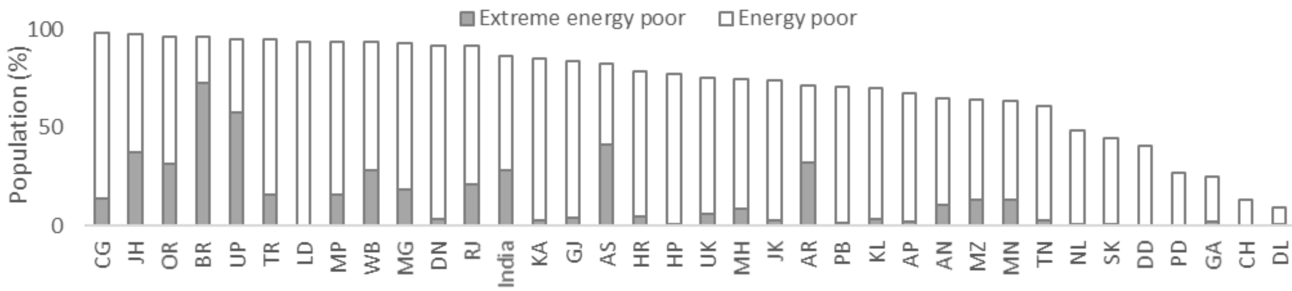
(c) Cooking in urban areas



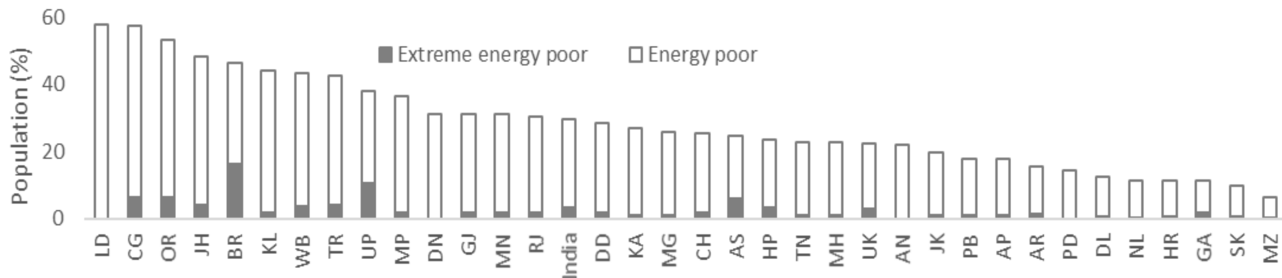
(d) Lighting in urban areas

Note: The full name of abbreviation of states are: AN: Andaman and Nicobar Islands, AP: Andhra Pradesh, AR: Arunachal Pradesh, AS: Assam, BR: Bihar, CG: Chhattisgarh, CH: Chandigarh, DD: Daman and Diu, DL: Delhi, DN: Dadra & Nagar Haveli, GA: Goa, GJ: Gujarat, HP: Himachal Pradesh, HR: Haryana, JH: Jharkhand, JK: Jammu & Kashmir, KA: Karnataka, KL: Kerala, MG: Meghalaya, LD: Lakshadweep, MH: Maharashtra, MN: Manipur, MP: Madhya Pradesh, MZ: Mizoram, NL: Nagaland, OR: Orissa, PB: Punjab, PD: Pondicherry, RJ: Rajasthan, SK: Sikkim, TN: Tamil Nadu, TR: Tripura, UK: Uttarakhand, UP: Uttar Pradesh, WB: West Bengal

Fig. 1 Share of population using different fuels as prime source of energy for cooking and lighting in rural and urban areas of different states of India.



(a) Rural



(b) Urban

Notes: Energy-poor are deprived of modern source of energy as the prime source for either cooking or lighting service. Extreme energy-poor are part of the energy-poor who are deprived in both services.

The full name of abbreviation of states are: AN: Andaman and Nicobar Islands, AP: Andhra Pradesh, AR: Arunachal Pradesh, AS: Assam, BR: Bihar, CG: Chhattisgarh, CH: Chandigarh, DD: Daman and Diu, DL: Delhi, DN: Dadra & Nagar Haveli, GA: Goa, GJ: Gujarat, HP: Himachal Pradesh, HR: Haryana, JH: Jharkhand, JK: Jammu & Kashmir, KA: Karnataka, KL: Kerala, MG: Meghalaya, LD: Lakshadweep, MH: Maharashtra, MN: Manipur, MP: Madhya Pradesh, MZ: Mizoram, NL: Nagaland, OR: Orissa, PB: Punjab, PD: Pondicherry, RJ: Rajasthan, SK: Sikkim, TN: Tamil Nadu, TR: Tripura, UK: Uttarakhand, UP: Uttar Pradesh, WB: West Bengal

Fig. 2 Share of energy-poor and within the poor the extreme energy-poor in rural and urban area of India and its different entities.

Table A2 gives incidence of energy poverty in rural areas of different entities of India. Among the 35 entities, 12: 10 states and two UTs—Chhattisgarh, Jharkhand, Odisha, Tripura, Bihar, Uttar Pradesh, Lakshadweep, Madhya Pradesh, West Bengal, Meghalaya, D & N Haveli, and Rajasthan—have more than 90% population deprived of modern fuels as prime source of energy for cooking. These twelve entities are also the ones which have a greater share rural population deprived of modern cooking fuels than the national average, which is at 85.8%. Delhi is the only entity with less than 10% rural population deprived of modern cooking fuel. It is followed by Chandigarh with corresponding figure of 13.4%. All other entities have at least one-fourth of rural population deprived of modern cooking fuels. In terms of lighting, seven entities: six states and one UT: Bihar, Uttar Pradesh, Assam, Jharkhand, Arunachal Pradesh, Odisha, and West

Bengal—have more than 25% population deprived of electricity as prime source of energy for lighting. Again, these seven entities are also the ones which have a greater share rural population deprived of electricity than the national average, which is at 28.8%. Of these, Bihar and Uttar Pradesh, with respective corresponding figure of 73.9% and 58.2%, are the only entities with more than half of rural population deprived of electricity. Contrarily, three entities, namely Chandigarh, Daman & Diu, and Lakshadweep have the distinction of having cent percent rural population using electricity as their prime source of lighting.

Overall in rural India, 86.2% people are energy-poor. Among all the 35 entities of India, 12 have more than 90% rural population energy-poor. These are the same entities which have more than 90% rural population deprived of modern energy as prime source for cooking. The five states with more than 95% share of population energy-poor in rural areas are: Chhattisgarh, Jharkhand, Odisha, Bihar, and Uttar Pradesh. Bihar has the dubious distinction of an entity with 72.5% rural population as extreme energy-poor, i.e., deprived of modern energy as prime source for both cooking and lighting. Uttar Pradesh follows Bihar with the corresponding figure of 57.5%. Contrarily, fiver entities: four UTs and one state, namely, Chandigarh, Pondicherry, Sikkim, Daman & Diu, and Lakshadweep have no rural population who can be categorized as extreme energy-poor. The top two entities in terms of energy-nonpoor in rural area are Delhi and Chandigarh with respective population shares of nonpoor of 87.8% and 71.5%.[24] The other three entities with more than one-fourth rural population energy-nonpoor are: Pondicherry (36.2%), Goa (27.6%), and A & N Isalans (26.3%).

4.2 Incidence of energy poverty in urban India

Figures 1(c) and 1(d) respectively represent the share of urban population using different fuels as prime source of cooking and lighting. Unlike in rural India, urban areas are characterized with greater use of modern fuels. Overall in India, more than 70% population use LPG as their prime cooking fuel (NSSO, 2013). Firewood and chips and dung cake which dominate the rural scene accounts for approximately 19% urbanites prime source for coking (NSSO, 2013). The use of

[24] Chandigarh and Delhi are the most urbanized entities in India with having only 7.2% and 7.9% of population in rural areas, respectively (NSSO, 2013). Rest all entities have at least one-third population in rural areas (NSSO, 2013).

such inefficient fuels is prevalent among slum dwellers (Ahmad, 2014), who constitute 17.4% of urban population (Census of India, 2011).[25] These fuels coupled with poorly built congested and overcrowded tenements with bad ventilation cause indoor air pollution and adversely affect the health of women and children (Saksena *et al*., 2003). Kerosene, a relatively less polluting fuel than biomass for cooking, is used by 4.5% population as prime source for cooking in urban area. In terms of lighting, electricity is the predominant means with 96.3% population using it as the prime source. Kerosene is used by 3.3% as the prime source for the same purpose.

Table A3 gives the incidence of poverty in urban areas of different entities of India. Fourteen of the 35 entities: 12 states and two UTs—Lakshadweep, Chhattisgarh, Orissa, Jharkhand, Kerala, Bihar, West Bengal, Tripura, Uttar Pradesh, Madhya Pradesh, D & N Haveli, Gujarat, Manipur, and Rajasthan—have more than 30% population deprived of modern source of cooking. These are also the same entities having greater share of people deprived of modern cooking fuel than the national average which is at 29.1%. The two entities with less than 10% urban population deprived of modern cooking fuel are two northeastern states: Mizoram (5.6%) and Sikkim (9.7%). In terms of lighting, eight entities: Bihar, Uttar Pradesh, Chhattisgarh, Assam, Himachal Pradesh, Orissa, Jharkhand, and Tripura have more than 5% urban population deprived of electricity. These eight entities, along with West Bengal, are the ones with greater share urban population deprived of electricity than the national average, which is at 3.7%. Like in the case of rural areas, the only two entities, with more than 10% population deprived of modern lighting in urban area are Bihar (19.4%) and Uttar Pradesh (11.6%). Contrarily, three UTs: A & N Islands, D & N Haveli, and Lakshadweep have cent percent population using electricity as their prime source for cooking. The three other entities which have 0.5% or lower share of urban population deprived of electricity are: Pondicherry, Nagaland, and Sikkim.

Overall, 29.5% people are energy-poor in urban India. Figure 2(b) gives the share of energy-poor for different entities of India. Among the entities of India, 14 entities turn out to be ones having more than 30% urban population as energy-poor. These are the same entities which have more

[25] As per the Census definition, slum is an area notified or recognized as so by the state government or identified to be an area with “at least 300 populations or about 60-70 households of poorly built congested tenements, in unhygienic environment usually with inadequate infrastructure and lacking in proper sanitary and drinking water facilities.” (GoI, 2010).

than 30% population deprived of modern source of cooking. Of these entities, Lakshadweep, Chhattisgarh, and Orissa have more than half of urbanites as energy-poor. In terms of extreme energy-poor, likewise in rural area, Bihar leads the rest with a share of 16.1% followed by Uttar Pradesh with a corresponding figure of 10.4%. Contrarily, four entities: all UTs, namely, A & N Islands, D & N Haveli, Lakshadweep, and Pondicherry have no urbanites who can be categorized as extreme energy-poor. The top three entities in terms of energy-nonpoor in urban area are Delhi, Sikkim, and Haryana. These three entities have more than four fifths urban population who are energy-nonpoor. The other two entities with more than two-thirds urban population energy-nonpoor are: Chandigarh (69.4%) and Punjab (69.3%).

4.3 General observations on incidence of energy poverty

From the incidence of energy poverty in rural and urban areas India and its different entities, we draw the following three observations. First, the energy poverty rates both in rural and urban area is close to the national average of modern cooking energy deprivation in the respective areas. This indicates that for those who are deprived of modern energy as prime source for lighting are mostly deprived of modern energy as prime source of cooking, but not vice versa. From the data it is evident that of the population who are deprived of electricity, 97% and 87% are deprived of modern energy sources for cooking in rural and urban areas respectively. Contrarily, of those who are deprived of modern cooking energy, 33% and 11% are deprived of electricity. In this sense, as a greater fundamental need, the deprivation in cooking dictates energy poverty in India.

The second observation from the data is that the incidence of energy poverty is greater for larger sized entities compared to smaller ones. Ordering the 35 entities of India as per population where Delhi turns out to be the median entity, one can consider the entities having more than population of Delhi as 'large' and entities less than the population of Delhi as 'small'.[26] Among

[26] In this way, in the order of population, the 17 large entities are - Uttar Pradesh, Maharashtra, Bihar, West Bengal, Andhra Pradesh, Madhya Pradesh, Tamil Nadu, Rajasthan, Karnataka, Gujarat, Odisha, Kerala, Jharkhand, Assam, Punjab, Chhattisgarh, Haryana; and the 17 small entities are - Jammu and Kashmir, Uttarakhand, Himachal Pradesh, Tripura, Meghalaya, Manipur, Nagaland, Goa, Arunachal Pradesh, Puducherry, Mizoram, Chandigarh, Sikkim, Andaman and Nicobar Islands, Dadra and Nagar Haveli, Daman and Diu, and Lakshadweep (Census of India, 2011). The large entities together have share of 94.6% population, and the small entities together account for 4.0% of population, Delhi accounting for the balance (Census of India, 2011).

the 10 most energy-poor entities in terms of incidence of poverty in rural and urban areas, seven positions in rural and eight positions in urban area occupied by large entities. Whereas among the 10 least energy-poor entities in terms of incidence of poverty in rural and urban areas, only two positions in rural and three positions in urban area occupied by large entities. One of the reasons for this trend can be for the same increment in that the larger entities have a much greater population to provide modern energy services for cooking and lighting.

Last but not the least, the rural areas typically give a lower incidence of energy-nonpoor. Overall in the country, the share of energy-nonpoor in urban area is 44.3%, whereas the corresponding figure for rural areas is 3.0%. This is along the expected line as rural areas exhibit energy stacking, whereas urban areas show energy ladder characteristics. This is also evident from the people in energy-transitional: the urban area has a share of 10.7%, whereas rural area has a share of 10.7%.

4.4 Depth and severity of energy poverty in India

Table A4 and A5 give depth and severity of energy poverty respectively for rural and urban areas of different entities of India.[27] The depth and severity are based on the extent of dependency of household on inefficient fuels. Both the energy-poor and energy-transitional have inefficient fuels in their energy basket. The tables give HCR, which is share of population who are not energy-nonpoor (i.e., combining energy-poor and energy-transitional).[28] The depth and severity are calculated both in the conventional fashion (where the same is averaged for total population considering zero contribution from energy-nonpoor) and the new way (where the same is averaged only for those who are not energy-nonpoor). The values of conventional depth and severity, being substitute measure of HCR, are bounded by HCR values, whereas the values of new measures of depth and poverty, being complementary poverty, are not such constrained (Nathan, 2018).

[27] The entities are ordered as per the new measure of severity of poverty. This is so, because among all the three measures considered here (HCR, PGR, and SPGR) is most advanced in the sense that it is distribution sensitive and satisfy all most all identified axioms of poverty in the literature (Zheng, 1997)

[28] Note that the ranking of entities as per HCR is the inverse of the ranking as per the proportion of nonpoor (see Table A2 and A2).

We report ranks of entities as per the conventional and new measures of depth and severity of energy poverty. We also report the rank difference when the method changed from conventional to new. The rank difference is positive (negative) for those whose ranks fell (increased) in poverty with the new measure suggesting a better situation when compared to that of indicated by the conventional measure. The rank difference for entities for rural areas is marginal compared to urban areas. This is expected as energy stacking in the rural areas makes the proportion of nonpoor extremely low in the population leading to less dilution in the values of depth and severity with inclusion of nonpoor. Overall, in India's rural areas, with only 3% energy-nonpoor, the values of depth and severity for those who are not energy-nonpoor (new measure) are not much different from the corresponding values for the entire population (conventional measure). It is worth noting that the dilution of values in the conventional measures compared to the new measure will be in proportion to share of nonpoor. Of the 35 entities, for 24 entities in rural areas the dilution of depth and severity with inclusion of nonpoor is less than 10%, of which for eight entities the dilution is less than 1%, whereas there are only two entities for which the dilution is more than 50%. The low dilution is reflected in the rank difference. Of the 35 entities, for 26 entities the rank difference for depth of energy poverty is two or less and for 29 entities the rank difference for severity of energy poverty is two or less. In short, in rural areas with a very low share of energy nonpoor the new complementary measure does not result in a large increase in values given by the conventional substitute measure in order to reflect the situation of exclusively those who are not energy nonpoor.

Unlike rural areas, urban areas with substantial nonpoor population brings forth the impact of new complementary measure as against the conventional substitute measure. Overall for the country, with 44% energy nonpoor in urban areas, there is same level of dilution in values of energy poverty depth and severity with inclusion of nonpoor. So, the values of depth and severity for exclusively those who are not energy-nonpoor (new measure) are substantially greater than the corresponding values for the entire population (conventional measure). Contrary to rural areas, of the 35 entities, only for two entities, the dilution of depth and severity with inclusion of nonpoor is less than 10%, whereas for as many as 17 entities the dilution is more than 50%. This is reflected in larger rank difference for urban areas. Unlike rural areas, of the 35 entities, for 27 entities the rank difference for depth of energy poverty is three or more and for 24 entities the rank difference for severity of energy poverty is three or more. We further elaborate the result on the rank difference for urban areas.

Table 1: Entities with whose poverty severity worsened as indicated by the new measure compared to the conventional measure

Entities (States or Union Territories)	Energy poverty head count ratio (HCR)	Energy poverty gap ratio (conv.) (PGR-C)	Energy squared poverty gap ratio (conv.) (SPGR-C)	Energy poverty gap ratio (new) (PGR-N)	Energy squared poverty gap ratio (new) (SPGR-N)	Rank PGR-C	Rank SPGR-C	Rank PGR-N	Rank SPGR-N	Rank diff. PGR	Rank diff. SPGR
Chandigarh	0.306	0.191	0.148	0.623	0.484	26	24	6	7	-20	-17
D & N Haveli	0.359	0.251	0.202	0.700	0.562	20	18	2	2	-18	-16
Rajasthan	0.467	0.287	0.228	0.614	0.488	15	15	7	5	-8	-10
Haryana	0.181	0.100	0.070	0.556	0.386	33	32	14	22	-19	-10

Table 2: Entities with whose poverty severity improved as indicated by the new measure compared to the conventional measure

Entities (States or Union Territories)	Energy poverty head count ratio (HCR)	Energy poverty gap ratio (conv.) (PGR-C)	Energy squared poverty gap ratio (conv.) (SPGR-C)	Energy poverty gap ratio (new) (PGR-N)	Energy squared poverty gap ratio (new) (SPGR-N)	Rank PGR-C	Rank SPGR-C	Rank PGR-N	Rank SPGR-N	Rank diff. PGR	Rank diff. SPGR
Manipur	0.789	0.338	0.258	0.429	0.327	12	12	27	25	15	13
Lakshadweep	0.995	0.590	0.446	0.593	0.448	1	1	9	13	8	12
West Bengal	0.810	0.404	0.322	0.499	0.397	9	9	23	20	14	11
Assam	0.744	0.262	0.198	0.352	0.266	19	19	30	30	11	11
Bihar	0.895	0.450	0.379	0.503	0.423	6	7	21	17	15	10

Table 1 and Table 2, respectively, gives the entities that had shifts in ranking of 10 or more indicating worsening and improvement in poverty when the severity of poverty measure changed from conventional to new. The entities in Table 1 have typically a greater share of nonpoor, when excluded in the new measures reflecting the true poverty situation of the those who are nonpoor, there is a substantial increase in the values of energy poverty depth and severity. The entities in Table 2, contrarily, have typically greater share of those who are nonpoor. That has led to less dilution of the gap and severity values with inclusion of nonpoor.

Table 3 gives some of the contrasting the entities which had similar values of conventional energy severity. But with the new measure the ranks changed in opposite directions. Considering Uttar Pradesh and Madhya Pradesh, both the states have 10th and 11th rank in conventional energy severity. However, when nonpoor were excluded for the new measure the values are indicative of worse poverty situation of those who are energy nonpoor in Madhya Pradesh compared to those who are in Uttar Pradesh. So, though Uttar Pradesh has more share of people who are not energy nonpoor than Madhya Pradesh, the severity of poverty for those who are nonpoor is more in Madhya Pradesh than in Uttar Pradesh.

Table 3: Comparison of the entities who had similar energy poverty severity under the conventional measure, but the same changed under the new measure

Entities (States or Union Territories)	Energy poverty head count ratio (HCR)	Energy poverty gap ratio (conv.) (PGR-C)	Energy squared poverty gap ratio (conv.) (SPGR-C)	Energy poverty gap ratio (new) (PGR-N)	Energy squared poverty gap ratio (new) (SPGR-N)	Rank PGR-C	Rank SPGR-C	Rank PGR-N	Rank SPGR-N	Rank diff. PGR	Rank diff. SPGR
Madhya Pradesh	0.576	0.353	0.292	0.612	0.507	11	11	8	4	-3	-7
Uttar Pradesh	0.752	0.386	0.317	0.514	0.421	10	10	20	19	10	9
Uttaranchal	0.434	0.242	0.198	0.558	0.456	21	20	13	11	-8	-9
Assam	0.744	0.262	0.198	0.352	0.266	19	19	30	30	11	11
Gujarat	0.412	0.229	0.182	0.554	0.443	22	21	15	14	-7	-7
Jammu & Kashmir	0.560	0.267	0.181	0.478	0.323	18	22	25	26	7	4
Chandigarh	0.306	0.191	0.148	0.623	0.484	26	24	6	7	-20	-17
Mizoram	0.584	0.201	0.141	0.344	0.241	24	25	31	31	7	6

Likewise, Uttaranchal and Assam have similar level of energy poverty severity when the same is calculated for the entire population. However, under the new measure of energy poverty severity, Uttaranchal shows a substantial greater poverty severity than Assam. This also indicated that though Assam has a greater share of population than Uttaranchal who are not energy-nonpoor; the poverty level of those people in terms of depth and severity of energy poverty is substantially greater for Uttaranchal than Assam. A similar trend observed in the next two examples: Jammu & Kashmir has a greater share of population who are not energy-nonpoor than Gujarat, but the latter has greater level of energy poverty than former in terms of depth and severity of energy poverty for those who are energy-nonpoor. Similarly, Chandigarh has less share of population who are not energy-nonpoor compared to Mizoram, but these population has a greater energy poverty level in terms of depth and severity in Chandigarh compared to Mizoram.

The important point to note here that the new measures do not impose poverty depth and severity to be bound by the HCR and hence, whereas the conventional measures do so (Nathan, 2018). Hence, the values of depth and severity reflect the true situation of those who are not energy-nonpoor unlike to the conventional measure where the corresponding values get diluted with inclusion of energy-nonpoor into the calculations. The urban areas with substantial nonpoor and energy ladder characteristics find greater applicability of the proposed method. Also, urban areas are those where all forms of modern forms of energy (electricity and LPG network) are available. So, the reason for a household not able to avail modern forms of energy would reflect its poverty and unaffordability. Also, in general, urban areas in India characterized by more inequality than rural areas (Pal and Ghosh, 2007; Salve, 2015).

5. Concluding remarks

As history is often written by the victors, so the history of energy is dominated by energy victors (Birol, 2014). Traditionally, energy poverty remained a neglected area which has got attention only in the recent times with the UN agenda and subsequently energy finding place among the SDGs. Acknowledging that one of the lagging factors in prioritizing energy poverty lies in the lack of methodological consensus on deriving the same, this paper visits the three approaches in literature in assessing energy poverty, viz., economic, engineering, and access-based. The economic based measures are essentially an indirect way of assessing energy through income thereby making energy poverty a mere proxy for income poverty. The engineering method is a direct method, but this bottom-up way of calculating energy use in households makes the approach cumbersome, expensive, and dynamic. Both the economic and engineering approaches suffer from arbitrariness of cutoffs and incoherence of quantity of energy which is less meaningful than energy service because quantity would change with change in energy devices of different efficiencies.

Following an access-based approach, the study proposes a method based on households energy utilization in terms of two basic energy services: cooking and lighting. As per the method, an energy-poor is one who is deprived of modern fuels as a prime source for either cooking or lighting and energy-nonpoor is one who does not have any such deprivation and any dependency on any energy inefficient fuels for any purpose whatsoever. This novel method introduces a transitional group between energy-poor and energy-nonpoor who have some dependencies on inefficient fuels, though not as the prime source of cooking or lighting. Also, unlike the conventional approach, the proposed method calculates the depth and severity of poverty (that are based on extent of inefficient fuel used) by excluding the energy-nonpoor, thereby using these measures as complementary measures to HCR. This method is applied for rural and urban areas of different states and union territories of India by taking data from the 68th round of National Sample Survey.

The results show that overall in India, in the rural areas the share of energy-poor, energy-transitional, and energy-nonpoor are 86%, 11%, and 3%, respectively. The corresponding values for the urban areas are 30%, 26%, and 44%. The lower incidence of energy-nonpoor in rural areas accounts for energy stacking characteristics of villagers. Among the energy-poor, 28% and 3% share of total population in rural and urban areas, respectively, are extreme energy-poor, i.e., those who are deprived of modern fuels as a prime source for both cooking or lighting. It is observed that, among the different entities in India, in general the larger ones show a greater incidence of energy-poor. Also, the data shows that between the two services: cooking and lighting: the former dictates the energy poverty scene in both urban and rural areas in the sense that when one is deprived in modern lighting fuels is most likely deprived in modern cooking fuels, but not the vice-versa; indicating cooking to be a more fundamental need.

The study's proposed method of finding depth and severity could give the poverty level of the population excluding energy-nonpoor. This way, unlike the conventional measure of depth and poverty, which substitutes HCR, the proposed measures complement to HCR indicating how much poor the poor are. The difference between the conventional and new measure is less striking in rural areas because of lower incidence of nonpoor. However, in urban areas the difference is more pronounced because of larger incidence of nonpoor. The new measure of depth and severity could capture exclusively the depth and severity of energy poverty of those who are not energy-nonpoor. These complementary measures of HCR, unlike the conventional measures, are not bounded by HCR values.

The utility of the new measure was exemplified by certain states or union territories of India. For instance, the urban Gujarat has less share of population who are not energy-nonpoor, compared to Uttar Pradesh or Bihar. However, in terms of new measure of depth and severity, those who are not energy-nonpoor in Gujarat are in worse off situation than those in Uttar Pradesh or Bihar. This clearly shows that though urban Bihar or urban Uttar Pradesh have more share of population who are not energy- nonpoor than urban Gujarat, such population in urban Gujarat are poorer than those of in Bihar or Uttar Pradesh. In short, the new measures of depth and severity are useful in depicting the level of poverty of poor; hence must replace the conventional measure of depth and severity.

Appendix

Table A1 Fuels and their calorific values

Fuel	Calorific values and prices
Coke[a]	24.8 million Btu/ton ⟹ 28842.4 kJ/kg
Firewood and chips[b]	4500 kcal/kg ⟹ 18828 kJ/kg
Electricity (std. unit)	3600 kJ/kg
Dung cake[c,d]	2092 kcal/kg ⟹ 8752.9 kj/kg; (Price = Rs. 3/kg) ⟹ 2917.643 kJ/Rs.
Kerosene[b,e]	10638 kcal/kg ⟹ 44509.4 kJ/kg; (density = 8724.2 kcal/lit) ⟹ 36502.153 kJ/lit
Coal[b]	4000 kcal/kg ⟹ 16736 kJ/kg
LPG[b]	11300 kcal/kg ⟹ 47279.2 kJ/kg
Charcoal[f]	6900 kcal/kg ⟹ 28869.6 kJ/kg
Gobar gas[g,h]	4713 kcal/m^3 ⟹ 19719.2 kj/m^3; (Price =Rs. 6.87/m^3) ⟹ 2870.334 kJ/Rs.

Notes: The calorific values are given in units that complies with the data collected in the NSS survey. For instance, for dung cake, data is collected in terms of household expenditure in Rs.; hence the calorific value is expressed in terms of kJ/Rs. The references for the data is given below.

[a] Calorific value from Speight (2013)
[b] Calorific value from TERI (2007)
[c] Calorific value from KVIC (1983) as reported in Sampath Kumar *et al*. (1985)
[d] Price from GoI (2015); Lal *et al*. (2016)
[e] Density of kerosene, 0.8201 g/cm^3 as reported in Endmemo (2015)
[f] Calorific value from Ramachandra (2000)
[g] Calorific value from Ramachandra *et al*. (2000)
[h] Price of biogas was obtained from inflation-adjusted current price (Chaba, 2018; RBI, 2017).

Table A2: Incidence of energy poverty in rural areas of different states of India

States	Deprived of modern cooking fuel (%)	Deprived of modern lighting fuel (%)	Energy poor (P) (%)	Extreme energy-poor (E) (%)	Energy transitional (T) (%)	Energy nonpoor (N) (%)	Rank P	Rank E	Rank T	Rank N
Chhattisgarh	98.1	14.0	98.1	14.0	1.6	0.4	1	12	35	34
Jharkhand	97.5	37.5	97.5	37.4	2.0	0.5	2	4	34	31
Orissa	96.4	31.7	96.4	31.7	2.9	0.7	3	6	32	28
Bihar	94.7	73.9	96.1	72.5	3.7	0.2	4	1	31	35
Uttar Pradesh	94.3	58.2	95.1	57.5	4.4	0.5	5	2	30	32
Tripura	95.0	15.9	95.0	15.9	4.5	0.5	6	10	29	30
Lakshadweep	94.0	0.0	94.0	0.0	5.4	0.6	7	32	26	29
Madhya Pradesh	93.8	15.8	93.9	15.7	5.1	1.0	8	11	28	27
West Bengal	93.7	28.7	93.9	28.6	5.7	0.5	9	7	25	33
Meghalaya	92.7	18.4	92.7	18.4	5.3	1.9	10	9	27	22
D & N Haveli	91.9	3.6	91.9	3.6	6.3	1.8	11	20	23	24
Rajasthan	91.2	21.2	91.4	21.0	6.1	2.5	12	8	24	20
Karnataka	85.3	2.8	85.3	2.8	12.7	2.0	13	24	19	21
Gujarat	84.0	4.3	84.1	4.2	9.0	6.8	14	19	21	15
Assam	82.4	42.0	82.8	41.5	15.3	1.9	15	3	15	23
Haryana	78.3	5.0	78.7	4.6	10.1	11.3	16	18	20	11

States	Deprived of modern cooking fuel (%)	Deprived of modern lighting fuel (%)	Energy poor (P) (%)	Extreme energy-poor (E) (%)	Energy transitional (T) (%)	Energy nonpoor (N) (%)	Rank P	Rank E	Rank T	Rank N
Himachal Pradesh	76.7	1.8	77.4	1.1	15.4	7.2	17	29	14	14
Uttaranchal	75.1	6.0	75.2	5.9	13.0	11.8	18	17	18	10
Maharashtra	74.3	8.8	74.6	8.5	21.1	4.3	19	16	12	19
Jammu & Kashmir	73.7	3.2	74.0	2.9	17.3	8.7	20	22	13	13
Arunachal Pradesh	70.5	33.0	71.4	32.0	22.4	6.2	21	5	11	17
Punjab	70.8	2.0	71.0	1.8	15.3	13.7	22	27	16	7
Kerala	69.3	3.9	69.9	3.4	28.9	1.2	23	21	8	26
Andhra Pradesh	67.5	2.1	67.5	2.1	25.7	6.8	24	26	9	16
A & N Islands	64.8	10.5	64.8	10.5	8.9	26.3	25	15	22	5
Mizoram	63.7	14.0	64.4	13.4	23.0	12.6	26	14	10	8
Manipur	63.3	13.6	63.5	13.4	32.2	4.3	27	13	6	18
Tamil Nadu	61.2	2.8	61.3	2.8	30.0	8.8	28	23	7	12
Nagaland	46.8	2.4	48.7	0.5	49.6	1.8	29	30	1	25
Sikkim	44.8	0.1	44.9	0.0	38.5	16.6	30	31	4	6
Daman & Diu	40.5	0.0	40.5	0.0	47.3	12.2	31	33	2	9
Pondicherry	25.1	2.1	27.2	0.0	36.6	36.2	32	34	5	3
Goa	25.2	2.2	25.2	2.2	47.2	27.6	33	25	3	4
Chandigarh	13.4	0.0	13.4	0.0	15.1	71.5	34	35	17	2
Delhi	9.6	1.2	9.6	1.2	2.6	87.8	35	28	33	1
India	**85.8**	**28.8**	**86.2**	**28.4**	**10.7**	**3.0**				

Table A3: Incidence of energy poverty in urban areas of different states of India

States	Deprived of modern cooking fuel (%)	Deprived of modern lighting fuel (%)	Energy poor (P) (%)	Extreme energy-poor (E) (%)	Energy transitional (T) (%)	Energy nonpoor (N) (%)	Rank P	Rank E	Rank T	Rank N
Lakshadweep	57.6	0.0	57.6	0.0	41.8	0.5	1	32	7	35
Chhattisgarh	56.4	7.0	57.2	6.2	12.9	29.9	2	4	27	24
Orissa	53.2	6.4	53.2	6.3	23.7	23.1	3	3	21	27
Jharkhand	47.3	5.2	48.3	4.2	32.1	19.6	4	6	13	29
Bihar	43.0	19.4	46.2	16.1	43.2	10.5	5	1	6	33
Kerala	43.7	2.3	44.1	1.9	41.1	14.7	6	15	8	31
West Bengal	42.7	4.3	43.1	3.9	37.9	19.0	7	8	9	30
Tripura	41.5	5.1	42.6	4.0	46.1	11.3	8	7	5	32
Uttar Pradesh	36.6	11.6	37.8	10.4	37.3	24.8	9	2	10	26
Madhya Pradesh	36.4	1.8	36.6	1.6	21.1	42.4	10	18	22	21
D & N Haveli	31.1	0.0	31.1	0.0	4.7	64.1	11	33	34	8
Gujarat	31.0	2.1	31.1	2.0	10.1	58.8	12	11	30	11
Manipur	30.9	1.9	31.1	1.7	47.8	21.1	13	16	4	28
Rajasthan	30.4	1.9	30.4	1.9	16.3	53.3	14	13	25	14
Daman & Diu	28.3	1.9	28.3	1.9	19.8	51.9	15	14	24	16
Karnataka	27.0	1.0	27.0	1.0	31.2	41.8	16	22	14	22
Meghalaya	24.4	2.5	26.0	0.9	24.0	50.0	17	25	20	17
Chandigarh	25.5	1.7	25.5	1.7	5.2	69.4	18	17	33	4
Assam	24.0	6.7	24.6	6.0	49.8	25.6	19	5	3	25
Himachal Pradesh	20.1	6.4	23.4	3.2	11.6	65.0	20	9	29	7
Tamil Nadu	22.7	1.2	22.9	1.0	28.3	48.8	21	23	15	18
Maharashtra	22.5	1.0	22.6	0.9	24.3	53.1	22	26	19	15

States	Deprived of modern cooking fuel (%)	Deprived of modern lighting fuel (%)	Energy poor (P) (%)	Extreme energy-poor (E) (%)	Energy transitional (T) (%)	Energy nonpoor (N) (%)	Rank P	Rank E	Rank T	Rank N
Uttaranchal	22.4	3.2	22.5	3.1	21.0	56.6	23	10	23	12
A & N Islands	22.1	0.0	22.1	0.0	11.9	66.0	24	34	28	6
Jammu & Kashmir	19.0	1.8	19.7	1.1	36.3	44.0	25	21	12	20
Punjab	17.7	1.1	17.7	1.1	13.0	69.3	26	20	26	5
Andhra Pradesh	17.3	1.3	17.6	0.9	26.4	55.9	27	24	17	13
Arunachal Pradesh	13.6	3.3	15.6	1.3	36.5	47.9	28	19	11	19
Pondicherry	13.9	0.4	14.3	0.0	25.1	60.5	29	35	18	10
Delhi	11.3	1.5	12.3	0.5	2.9	84.9	30	28	35	1
Nagaland	11.3	0.4	11.3	0.4	79.5	9.2	31	30	1	34
Haryana	10.6	1.2	11.3	0.6	6.8	81.9	32	27	31	3
Goa	11.2	2.0	11.2	2.0	27.5	61.3	33	12	16	9
Sikkim	9.7	0.5	9.7	0.5	6.2	84.1	34	29	32	2
Mizoram	5.6	1.1	6.4	0.2	52.0	41.6	35	31	2	23
India	**29.1**	**3.7**	**29.5**	**3.2**	**26.1**	**44.3**				

Table A4: Depth and severity of energy poverty in rural areas of different states of India

States	Energy poverty head count ratio (HCR)	Energy poverty gap ratio (conv.) (PGR-C)	Energy squared poverty gap ratio (conv.) (SPGR-C)	Energy poverty gap ratio (new) (PGR-N)	Energy squared poverty gap ratio (new) (SPGR-N)	Rank PGR-C	Rank SPGR-C	Rank PGR-N	Rank SPGR-N	Rank diff. PGR	Rank diff. SPGR
Tripura	0.995	0.937	0.908	0.942	0.912	2	1	2	1	0	0
Jharkhand	0.995	0.941	0.904	0.946	0.908	1	2	1	2	0	0
Bihar	0.998	0.925	0.889	0.926	0.890	4	3	4	3	0	0
Chhattisgarh	0.996	0.930	0.878	0.933	0.881	3	4	3	4	0	0
Uttar Pradesh	0.995	0.919	0.873	0.924	0.877	5	5	5	5	0	0
Meghalaya	0.981	0.892	0.840	0.910	0.857	8	7	6	6	-2	-1
Orissa	0.993	0.904	0.846	0.910	0.852	6	6	7	7	1	1
Rajasthan	0.975	0.882	0.820	0.905	0.841	9	10	8	8	-1	-2
Madhya Pradesh	0.990	0.893	0.831	0.902	0.840	7	8	9	9	2	1
Assam	0.981	0.866	0.822	0.882	0.837	12	9	11	10	-1	1
Karnataka	0.980	0.872	0.804	0.890	0.820	11	12	10	11	-1	-1
West Bengal	0.995	0.874	0.811	0.879	0.815	10	11	12	12	2	1
Gujarat	0.932	0.811	0.734	0.871	0.788	15	15	13	13	-2	-2
Mizoram	0.874	0.748	0.688	0.856	0.787	18	18	14	14	-4	-4
D & N Haveli	0.982	0.834	0.770	0.849	0.784	13	13	15	15	2	2
Uttaranchal	0.882	0.748	0.691	0.848	0.783	19	17	16	16	-3	-1
Arunachal Pradesh	0.938	0.780	0.734	0.832	0.783	16	14	18	17	2	3
Nagaland	0.982	0.832	0.724	0.847	0.737	14	16	17	18	3	2
A & N Islands	0.737	0.599	0.532	0.812	0.722	29	27	19	19	-10	-8
Jammu & Kashmir	0.913	0.737	0.641	0.808	0.702	22	20	20	20	-2	0
Himachal Pradesh	0.928	0.739	0.622	0.797	0.670	21	22	21	21	0	-1
Maharashtra	0.957	0.739	0.633	0.772	0.662	20	21	23	22	3	1
Kerala	0.988	0.768	0.642	0.778	0.650	17	19	22	23	5	4
Andhra Pradesh	0.932	0.709	0.597	0.761	0.641	23	23	25	24	2	1
Haryana	0.887	0.680	0.557	0.766	0.628	25	25	24	25	-1	0
Tamil Nadu	0.912	0.663	0.548	0.726	0.601	26	26	26	26	0	0
Manipur	0.957	0.648	0.567	0.677	0.593	27	24	30	27	3	3

States	Energy poverty head count ratio (HCR)	Energy poverty gap ratio (conv.) (PGR-C)	Energy squared poverty gap ratio (conv.) (SPGR-C)	Energy poverty gap ratio (new) (PGR-N)	Energy squared poverty gap ratio (new) (SPGR-N)	Rank PGR-C	Rank SPGR-C	Rank PGR-N	Rank SPGR-N	Rank diff. PGR	Rank diff. SPGR
Punjab	0.863	0.616	0.486	0.714	0.563	28	29	27	28	-1	-1
Sikkim	0.834	0.571	0.458	0.685	0.549	30	30	29	29	-1	-1
Lakshadweep	0.994	0.694	0.523	0.698	0.526	24	28	28	30	4	2
Delhi	0.122	0.061	0.036	0.505	0.296	35	35	31	31	-4	-4
Goa	0.724	0.290	0.196	0.400	0.270	32	32	34	32	2	0
Daman & Diu	0.878	0.364	0.219	0.414	0.249	31	31	33	33	2	2
Pondicherry	0.638	0.265	0.154	0.416	0.241	33	33	32	34	-1	1
Chandigarh	0.285	0.092	0.050	0.324	0.176	34	34	35	35	1	1
India	**0.970**	**0.841**	**0.771**	**0.868**	**0.795**						

Table A5: Depth and severity of energy poverty in rural areas of different states of India

States	Energy poverty head count ratio (HCR)	Energy poverty gap ratio (conv.) (PGR-C)	Energy squared poverty gap ratio (conv.) (SPGR-C)	Energy poverty gap ratio (new) (PGR-N)	Energy squared poverty gap ratio (new) (SPGR-N)	Rank PGR-C	Rank SPGR-C	Rank PGR-N	Rank SPGR-N	Rank diff. PGR	Rank diff. SPGR
Chhattisgarh	0.701	0.500	0.437	0.713	0.622	4	2	1	1	-3	-1
D & N Haveli	0.359	0.251	0.202	0.700	0.562	20	18	2	2	-18	-16
Orissa	0.769	0.484	0.418	0.630	0.544	5	4	5	3	0	-1
Madhya Pradesh	0.576	0.353	0.292	0.612	0.507	11	11	8	4	-3	-7
Rajasthan	0.467	0.287	0.228	0.614	0.488	15	15	7	5	-8	-10
Kerala	0.853	0.538	0.414	0.631	0.486	3	5	4	6	1	1
Chandigarh	0.306	0.191	0.148	0.623	0.484	26	24	6	7	-20	-17
Arunachal Pradesh	0.521	0.308	0.251	0.592	0.482	14	13	10	8	-4	-5
Nagaland	0.908	0.590	0.436	0.650	0.481	2	3	3	9	1	6
Jharkhand	0.804	0.441	0.375	0.549	0.466	7	8	17	10	10	2
Uttaranchal	0.434	0.242	0.198	0.558	0.456	21	20	13	11	-8	-9
Daman & Diu	0.481	0.278	0.217	0.579	0.452	17	16	11	12	-6	-4
Lakshadweep	0.995	0.590	0.446	0.593	0.448	1	1	9	13	8	12
Gujarat	0.412	0.229	0.182	0.554	0.443	22	21	15	14	-7	-7
Tripura	0.887	0.437	0.384	0.492	0.433	8	6	24	15	16	9
Meghalaya	0.500	0.280	0.216	0.560	0.433	16	17	12	16	-4	-1
Bihar	0.895	0.450	0.379	0.503	0.423	6	7	21	17	15	10
Karnataka	0.582	0.319	0.245	0.549	0.422	13	14	16	18	3	4
Uttar Pradesh	0.752	0.386	0.317	0.514	0.421	10	10	20	19	10	9
West Bengal	0.810	0.404	0.322	0.499	0.397	9	9	23	20	14	11
Punjab	0.307	0.167	0.122	0.546	0.396	30	30	18	21	-12	-9
Haryana	0.181	0.100	0.070	0.556	0.386	33	32	14	22	-19	-10
A & N Islands	0.340	0.179	0.128	0.526	0.375	27	27	19	23	-8	-4
Himachal Pradesh	0.350	0.175	0.127	0.500	0.362	29	28	22	24	-7	-4
Manipur	0.789	0.338	0.258	0.429	0.327	12	12	27	25	15	13
Jammu & Kashmir	0.560	0.267	0.181	0.478	0.323	18	22	25	26	7	4
Tamil Nadu	0.512	0.221	0.151	0.432	0.294	23	23	26	27	3	4
Maharashtra	0.469	0.194	0.136	0.413	0.290	25	26	28	28	3	2
Andhra Pradesh	0.441	0.178	0.126	0.404	0.286	28	29	29	29	1	0
Assam	0.744	0.262	0.198	0.352	0.266	19	19	30	30	11	11
Mizoram	0.584	0.201	0.141	0.344	0.241	24	25	31	31	7	6

States	Energy poverty head count ratio (HCR)	Energy poverty gap ratio (conv.) (PGR-C)	Energy squared poverty gap ratio (conv.) (SPGR-C)	Energy poverty gap ratio (new) (PGR-N)	Energy squared poverty gap ratio (new) (SPGR-N)	Rank PGR-C	Rank SPGR-C	Rank PGR-N	Rank SPGR-N	Rank diff. PGR	Rank diff. SPGR
Pondicherry	0.395	0.120	0.071	0.305	0.181	31	31	32	32	1	1
Goa	0.387	0.111	0.067	0.288	0.173	32	33	33	33	1	0
Delhi	0.151	0.038	0.025	0.249	0.163	34	34	34	34	0	0
Sikkim	0.159	0.027	0.019	0.173	0.118	35	35	35	35	0	0
India	**0.557**	**0.282**	**0.220**	**0.506**	**0.395**						

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