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Energy poverty and economic development: Household-level evidence from India

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ABSTRACT

In this paper, we investigate the relationship between energy poverty and economic development in India and its trend over a decade. For this purpose, we estimate a Multidimensional Energy Poverty Index (MEPI) and an index of development at the district level using household level data. Empirical results show that energy poverty is quite extensive in India with substantial variations across the states and districts. Over the years, energy poverty shows a declining trend at all-India level, but with the exception of few bigger and less developed states. Further, the study records a negative relationship between economic development and energy poverty, the strength of relationship has increased during the study period. Among the components of economic development, education has a greater impact on reducing energy poverty compared with income. The study observes that energy poverty and socio-economic backwardness in India are highly correlated; Dalits and Adivasis have higher energy poverty and a lower rate in the reduction of energy poverty in comparison with the national average. Energy poverty is lower in urban India in comparison with rural India.

1. Introduction

Access to clean and modern energy resources like electricity and LPG are indispensable to the material wellbeing of the humanity today. The adoption of ensuring access to affordable, reliable and sustainable modern energy for all as one of the sustainable development goals (SDGs) of United Nations (UN) is, in fact, a testimony to the global recognition of the importance of energy in the progress of the mankind. Moreover, the issue of energy poverty and its consequences are multidimensional in nature [6,20]. A society deprived of access to energy resources will be reeling under fundamental challenges like poverty, ill-health, illiteracy and gender discrimination [10,28]. For example, IEA [12] has observed while detailing the role of energy in the promotion of development that 'the provision of secure, affordable and modern energy for all citizens is central to poverty reduction and economic growth'

Access to the clean modern energy resources can transform the destiny of people for better in many ways. For example, use of LPG for cooking instead of firewood can save millions of women from health issues like respiratory diseases and access to electricity at home can facilitate education to many more millions of children [1,5,19,22–24]. Likewise, access to electricity without interruption is expected to increase the quality and efficiency of healthcare provided at hospitals [28]. Above all, in a society with gender discrimination in the management of household chores, women will have to collect firewood in the absence of clean cooking fuel and therefore, could be even denied basic rights such as education and security [9,34].

Eradication of energy poverty has positive environmental implications also. For example, climate change caused by anthropogenic intervention in the environment and resultant emission of greenhouse gases (GHGs) like CO_2 is one of the major challenges faced by the modern human civilisation [3,11,18,26,30]. The United Nations Commission for Sustainable Development has observed that lack of access to energy resources like electricity and LPG shall obstruct the growth and development and will have a huge impact on the environment [32]. For instance, use of bio-fuels like firewood, agricultural crop residue, dung cake, etc. for cooking and other household purposes will increase the GHG emission and global warming [14,33]. Hence, the availability of clean energy resources to the households can go a long way in the mitigation of climate change.

Moreover, climate change has resulted in an increase in the cold weather in the regions such as western countries of the world. For example, according to Environment Canada [7], Canada's coldest weather in the last 57 years was witnessed in 2017. Likewise, according to the press release of the World Meteorological Organization (WMO), 2017 is one of the three hottest years on record. Given

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such vagaries of climate, access to modern clean energy resources is essential to ensure safety and healthy sustenance of human beings with heated homes, portable water etc. [15,25,36].

Overall, access to affordable and clean energy resources is crucial in the eradication of poverty and promotion of overarching wellbeing of the people. Therefore, in this paper, we analyze the trends in energy poverty in India over the last one decade and the relationship between development and energy poverty as well. Empirical results of this paper have huge policy implications because, as Barnes et al. [2] and Kandkher et al. [13] reported, even though households are economically sound, it does not necessarily mean that they will be energy secure. It is often impossible to get home electrified or own LPG connection for an ordinary household in the absence of collective effort on the part of society through the intervention of the state to provide such facilities (See, [29] also).

As far as the Indian economy is concerned, 2004–2012 was a remarkable period as growth rate increased from 7.92% in 2004–05 to 9.8% in 2007–08, the highest growth rate the Indian economy ever witnessed. But, India was slow in translating its potential to tangible social benefits. For example, while Brazil was ranked at 18th position in the Global Hunger Index [8], India was ranked at the 100th position out of 121 countries. GHI [8] also observed that 21% of children in India are wasted and India's child wasting rate has not substantially improved over the past 25 years. India's performance in basic education measured by literacy rate has registered some progress from 64.8% in 2001 to 74.4% in 2011 and a decrease in infant mortality from 58 to 44 per 1000 live births was also registered during the same period [21]. Regarding energy access, India has provided electricity to half a billion people since 2000 and the goal of universal access to electricity is projected to be achieved by 2020s with a sizeable contribution from renewable sources. Still, 239 million people remain without electricity access in 2016, about a quarter of the worldwide total [12]. On the cooking side, even though the share of people depending on bio-fuels for cooking has fallen from 66% in 2011 to 59% in 2015, about 830 million people still lack access to LPG. Thus, India's development story is a mixed bag with great potential to deal with huge challenges it currently faces.

Therefore, insights of this study would be useful to devise appropriate policies and programs in the energy sector like "24 × 7 Power for All" by 2019 to provide electricity to about 245 million people by 2019 and hence deal with issue of energy poverty and socio-economic backwardness.

2. Theoretical base of the study

As outlined above, energy poverty is certainly a source of various challenges like illiteracy, ill-health, etc. in the contemporary world. This line of reasoning leads us to accept that energy poverty is a question of 'freedom and capability' following Amartya Sen's [27] approach to development. Sen viewed development as a situation in which one has the freedom to choose the life he/she value with various instruments of freedom such as economic freedom. Thus, instance of denial of such freedoms to choose is termed as deprivation which is the source of social injustice like poverty. Therefore, absence of access to affordable energy resources is undoubtedly a form of deprivation resulting in various forms of social injustices [6]. For example, according to IEA [12], 2.5 million premature deaths takes place each year attributable to the indoor air pollution and access to clean energy could have avoided this sort of chronic hazards. This implies that energy poverty is a question of 'capability deprivation' in the sense Amartya Sen defined it as expansion of opportunities and choices and hence, removal of energy poverty is essentially one of the major forms of removal of socio-economic deprivation that exists today. For example, with electricity and LPG at home, women will be protected from health problems, girls will be able to spend more time for studying, and children will have incentive to do their homework in the evening and so on.

Specific nature of energy poverty too acts as a major developmental challenge and hence its remedy also qualifies capability approach of Amartya Sen to development more relevant to explain its existence and its consequences. As observed by Sadath and Acharya [23], it is almost impossible for an individual or a household to, say, get electricity connection on their own without collective effort of the society to electrify their area or village. In other words, energy accessibility requires state intervention as it needs huge infrastructure development with massive financial outlays. It is here, Sen's [[27], page No: 282] observation that "people themselves must have responsibility for the development and change of the world in which they live" comes handy to analyze energy poverty. It is quite clear that Sen is unambiguously arguing for collective responsibility as a social commitment to deal with issues such as energy poverty. He further observes that "the substantive freedoms that we respectively enjoy to exercise our responsibilities are extremely contingent on personal, social and environmental circumstances". Here, the significance of difference in circumstances is also very endemic as far as energy poverty is concerned. For example, as Kandkher et al. [13] and Wang et al. [35] found, economic affordability of an individual or household does not guarantee accessibility to energy resources.

Similarly, the socio-economic implications of lack of access to energy resources varies from developed and developing countries and therefore, while this issue is referred as 'fuel poverty' in the context of developed countries, it is known as 'energy poverty' in the developing countries [16,17]. Thus, this paper is developed on the theoretical underpinning of Amartya Sens's capability approach to freedom and development to explain and examine prevalence and extent of energy poverty in India.

3. Data

The present study uses the India Human Development Survey (IHDS) data collected in 2004–05 and 2011–12. The survey was jointly conducted by the University of Maryland and the National Council of Applied Economic Research (NCAER), New Delhi. The first round of survey interviewed 41,554 households across 1503 villages and 971 urban centres in India. The second round of the survey collected data from 42,152 households and re-interviewed the most of the households covered in the first survey. IHDS is a multi-topic survey covering over 50 topics. In this study, we make use of the information collected under fuel & energy use, income, health, and education.

The study collects district level data on education and Gross District Domestic Product (GDDP) from the Open Government Data (OGD) platform of Government of India for 23 states. Data is in 1999–2000 prices from 1999–2000 to 2007–08. However, some states do not have the data for last couple of years. District wise GDDP data is not available for the year 2011–12. We also collect the Gross State Domestic Product (GSDP) data from 2004–05 to 2011–12 from the same source. We use the Gross State Domestic Product (GSDP) to calculate the GDDP data using the average share of different districts in the GSDP during 1999–2000 to 2007–08 or whatever available in case of few states.

4. Methodology

The primary objective of the paper is to measure energy poverty over the years and to quantify the strength of its relationship with education and income of the people. Following Sadath and Acharya [23], the present study uses the multi-dimensional approach to measure energy poverty.[1] Energy poverty index is constructed using three broad dimensions, namely lighting, cooking and additional measures with an equal weight of 33.33% each. Under the lighting category, if a household do not have access to electricity is coded as 1 or otherwise 0. In the same manner, under the cooking category there are two dimensions, namely access to LPG and type of stove. If a household do not have access to LPG is coded as 1 and otherwise 0, whereas if a household do not use a stove with chimney is coded as 1 or 0 if the household uses a traditional stove with chimney. The two sub-dimensions under cooking category are assigned equal weight with 16.66% each. Finally, under additional measures, use of five kinds of fuel, namely firewood, dung cake, crop residue, kerosene, and coal/charcoal are considered. It is necessary to consider these fuels because a household may have electricity and LPG connection, but may extensively use these fuels as they are cheap or freely available. If any household uses these fuels for lighting, cooking, and heating purposes are coded as 1 or 0 otherwise. Each of the five sub-dimensions is having an equal weight of 6.66%. Composite energy poverty index is calculated by multiplying the assigned weight of the dimension with the code and totalled across all dimensions. A higher value in the energy poverty index indicates prevalence of higher level of energy poverty.

To explore the relationship between energy poverty and economic development, the study proposes to construct an index of development using education and income as components at the district level. We confine to education and income for measuring development because energy poverty due to the use of firewood, coal, charcoal, and crop residue instead of clean energy resources could be due to non-availability of the latter and at the same time, it could also be due to non-affordability and illiteracy. Education index is constructed using two dimensions, viz. percentage of literacy and population with education of 12th standard and above; both are calculated from the IHDS survey data. Each dimension index is constructed based on the standard index construction formula as follows:

$$\frac{Actual\ Value - Minimum\ Value}{Maximum\ Value - Minimum\ Value}$$

where *Actual Value* is the observed value of a district in literacy or percent of population above 12th standard education. *Maximum Value* is the observed maximum value of literacy or percent of population above 12th standard education and *Minimum Value* is assumed as zero.[2] Above formula is applied to both literacy and above 12th standard education. Finally, the composite education index is constructed by taking the average of the two sub-indices.

Income index is constructed in the same manner as in the case of education index. We collect the GDDP and find the maximum and minimum values. Income index for a district is calculated using the index construction formula. We take the observed maximum and minimum values of the GDDP in the calculation. The study calculates the correlation between energy poverty and education, and income index.

5. Empirical results

Table 1 presents the state/union territory-wise average energy poverty index values for 2004–05, 2011–12 and the growth rate between the two periods. As shown in the table, lowest energy poverty index values are recorded in the union territories which are small as well as urban centres, for example, Chandigarh and Delhi.[3] On the contrary, states like Rajasthan, Uttar Pradesh, Bihar, West Bengal, Jharkhand, Orissa, Chhatishgarh, and Madhya Pradesh have average energy poverty index values of greater than 40 during both time periods. These states account for slightly over 50 percent of the total population of India. Assam is very close to the 40 mark during both time periods. Rest of the states and union territories have relatively smaller energy poverty index values, especially in 2011–12 with figure less than 30.

Table 1
State/Union Territory wise average energy poverty.

State/Union Territory	2004–05	2011–12	Growth rate
Jammu & Kashmir	23.80	17.91	−24.77%
Himachal Pradesh	22.02	25.65	16.46%
Punjab	23.93	22.97	−4.01%
Chandigarh	11.41	2.86	−74.90%
Uttaranchal	34.90	31.91	−8.57%
Haryana	38.33	32.98	−13.96%
Delhi	20.44	2.98	−85.40%
Rajasthan	43.93	43.24	−1.58%
Uttar Pradesh	51.54	54.24	5.23%
Bihar	54.53	57.56	5.55%
Assam	38.87	38.99	0.30%
West Bengal	47.19	44.12	−6.50%
Jharkhand	46.26	43.40	−6.18%
Orissa	55.50	50.87	−8.35%
Chhatishgarh	49.32	46.82	−5.07%
Madhya Pradesh	46.79	50.63	8.21%
Gujarat	34.86	29.73	−14.72%
Daman and Diu	36.08	21.41	−40.66%
Dadra and Nagar Haveli	29.78	24.58	−17.47%
Maharashtra	36.48	32.55	−10.76%
Andhra Pradesh	39.21	25.59	−34.74%
Karnataka	41.40	30.91	−25.35%
Kerala	32.54	21.44	−34.12%
Tamil Nadu	35.53	20.07	−43.51%
Pondicherry	28.63	8.19	−71.39%

We present the growth rate in the energy poverty index values in two time periods in the last column of the Table 1. As expected, most of the states have recorded negative growth rates indicating a decline in the energy poverty. However, Himachal Pradesh, Uttar Pradesh, Bihar, Madhya Pradesh and Assam have recorded positive growth rates implying energy poverty situation has worsened in these states. It should be noted that Uttar Pradesh, Bihar, and Madhya Pradesh are larger states and account for nearly over 30% of population of India. Fastest decline in energy poverty recorded by Chandigarh and Delhi is on the expected line as they are the capital city of two states and union respectively. Among the states, Jammu & Kashmir, Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu have recorded a decline of 25% or more. Overall, results show that despite some progress in the eradication of energy poverty between 2004–05 and 2011–12, the situation of energy poverty is quite severe and there is wide geographical variation. This finding is mostly consistent with the finding of Tang and Liao [31] from China who found that about 17% decline in the use of solid fuel during 2000–2010 with geographical variations.

We present the district/union territory wise energy poverty results for the year 2004–05 and 2011–12 in Table 2. Results are presented in total 10 bins, each representing 10%. For example, first bin represents the energy poverty score of 0 to 10% and in the same manner, 10th bin represents the energy poverty score of 90 to 100%. Number of districts/union territory falling in each bin, percent of districts and cumulative percent is presented for both years. For the year 2004–05, there are no districts having energy poverty score of 80% and above as well as figures less than

[1] For a detailed account of alternative methodologies to measure energy poverty, their uses and limitations see Sadath and Acharya [23].

[2] Similar assumption is made in the construction of education dimension index of Human Development Index (HDI).

[3] Delhi is the capital city of India and Chandigarh is the capital city of two states viz. Haryana and Punjab.

Table 2
District/Union Territory wise distribution of energy poverty.

Bins	2004–05			2011–12		
	No. of districts/ Union Territory	Percent	Cumulative percent	No. of districts/ Union Territory	Percent	Cumulative percent
1	0	0%	100%	40	10.8%	100%
2	19	5%	100%	48	12.9%	89%
3	64	18%	95%	66	17.7%	76%
4	99	27%	77%	65	17.5%	59%
5	80	22%	50%	50	13.4%	41%
6	53	15%	28%	51	13.7%	28%
7	40	11%	13%	40	10.8%	14%
8	8	2%	2%	9	2.4%	3%
9	0	0%	0%	3	0.8%	1%
10	0	0%	0%	0	0.0%	0%

Table 3
Religion wise average energy poverty.

	2004	2011	Growth rate
Hindu	40.93	36.85	−9.95%
Muslim	42.04	38.24	−9.05%
Christian	34.50	20.82	−39.65%
Sikh	23.78	23.38	−1.65%
Buddhist	38.40	37.30	−2.87%
Jain	21.39	9.56	−55.32%
Tribal	66.04	51.74	−21.66%
Others	34.44	35.09	1.87%
None	26.67	12.42	−53.41%

Table 4
Caste/Community wise average energy poverty.

Caste/Community	2004–05	2011–12	Growth rate
Brahmin	28.76	23.59	−17.97%
Forward caste	31.66	24.61	−22.25%
Other Backward Castes (OBC)	42.15	37.77	−10.39%
Dalit	45.91	42.83	−6.71%
Adivasi	54.33	48.56	−10.63%
Muslim	42.04	38.24	−9.00%
Christian, Sikh, Jain	25.90	15.37	−40.66%

10%. At the same time, nearly 49 percent of districts fall in the category with energy poverty score of 30 to 50%. The cumulative percent column shows that nearly 77% of district/union territories have energy poverty score of more than 30% indicating acute energy poverty. There is an improvement in the energy poverty condition in 2011–12 compared with the 2004–05. There are nearly 10% of the districts with energy poverty score of less than 10%. At the same time, there are 59% of districts with energy poverty score of more than 30%.

Religion wise energy poverty scores for the year 2004–05, 2011–12, and the change during this period is presented in the Table 3. Highest average energy poverty score is recorded in the case of Tribals followed by the Muslims and Hindus. Lowest energy poverty score is recorded in the case of Jain community. Almost all religious groups have recorded reduction in the energy poverty, marginal increase in energy poverty is observed among those who belonged to other religions. Maximum reduction in the energy poverty is recorded in the case of Jains, households who did not disclose the religion and Christians. To probe further into the difference in energy poverty across communities, we divide the sample based on the caste/community and the results are presented in the Table 4. Lowest energy poverty as well as highest decline is recorded in the case of Christian, Sikh, and Jain communities. Further, Brahmin and forward castes have lower energy poverty scores compared with Other Backward Castes (OBC), Dalits, Adivasis and Muslims. Highest energy poverty score is recorded in the case of the Adivasis. At the same time, faster improvement is recorded in the case of Brahmin and forward castes in comparison with the other communities. Similar results are reported by Barnes et al. [2] from Bangladesh and Legendre and Ricci (2015) from France where energy poverty is rampant among income poor and vulnerable sections of the society.

Table 5
Village town difference in average energy poverty.

	2004–05	2011–12	Growth rate
Village	47.52	23.74	−50.05%
Town	27.19	9.86	−63.75%

Energy poverty situation could be different in urban and rural areas. To probe that we classified the energy poverty scores of urban and rural areas separately; the results are reported in Table 5. As expected, energy poverty is widespread in rural areas compared to urban areas. Both urban and rural areas have recorded decline in the energy poverty, but urban area recorded faster decline in the energy poverty in comparison with the rural area.

Above analysis, thus, shows difference in the energy poverty across regions and communities and further research may be undertaken to unravel factors responsible for this difference. However, based on the existing evidences, we believe that observed differences in energy poverty essentially characterizes the real nature of India as a country with vast socio-economic, cultural and regional differences. Naturally, one can expect disparity in the energy poverty across regions and communities in such a country.

Major objective of the paper is to understand the relationship between economic development and energy poverty. Fig. 1 presents the comparison of the education index values and energy poverty of the selected Indian states and union territories. Education index value of more than 0.4 is recorded in the case of union territories like Chandigarh, Delhi, Puducherry and Kerala, the only state. High education index value of union territories is understandable considering that they are cities and geographically small in size, whereas Kerala has been at the forefront of the human development among Indian states due to the importance given to education and health by the successive governments over the years. States like Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Assam, Maharashtra and Tamil Nadu have recorded an education index figure of more than 0.3 in 2011. Rest of the states have a score ranging from 0.2 to 0.3. Comparison of education index figures with MEPI shows that the states with better education record have lesser MEPI values. It indicates that people with more education are less likely to be energy poor.

Fig. 2 presents the comparison of GSDP percapita and energy poverty of the selected Indian states and union territories. The union territories have substantially higher percapita income level

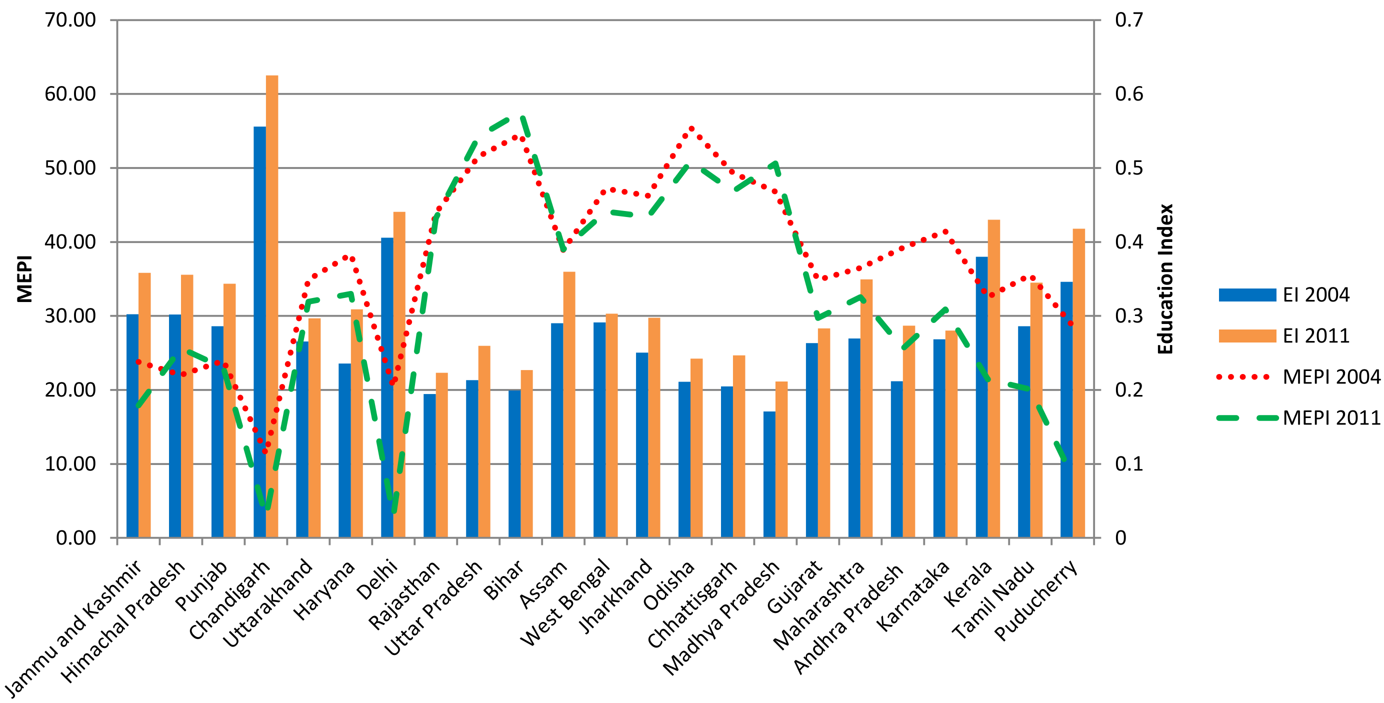

Fig. 1. Comparison of education index and energy poverty of selected Indian States and Union Territories.

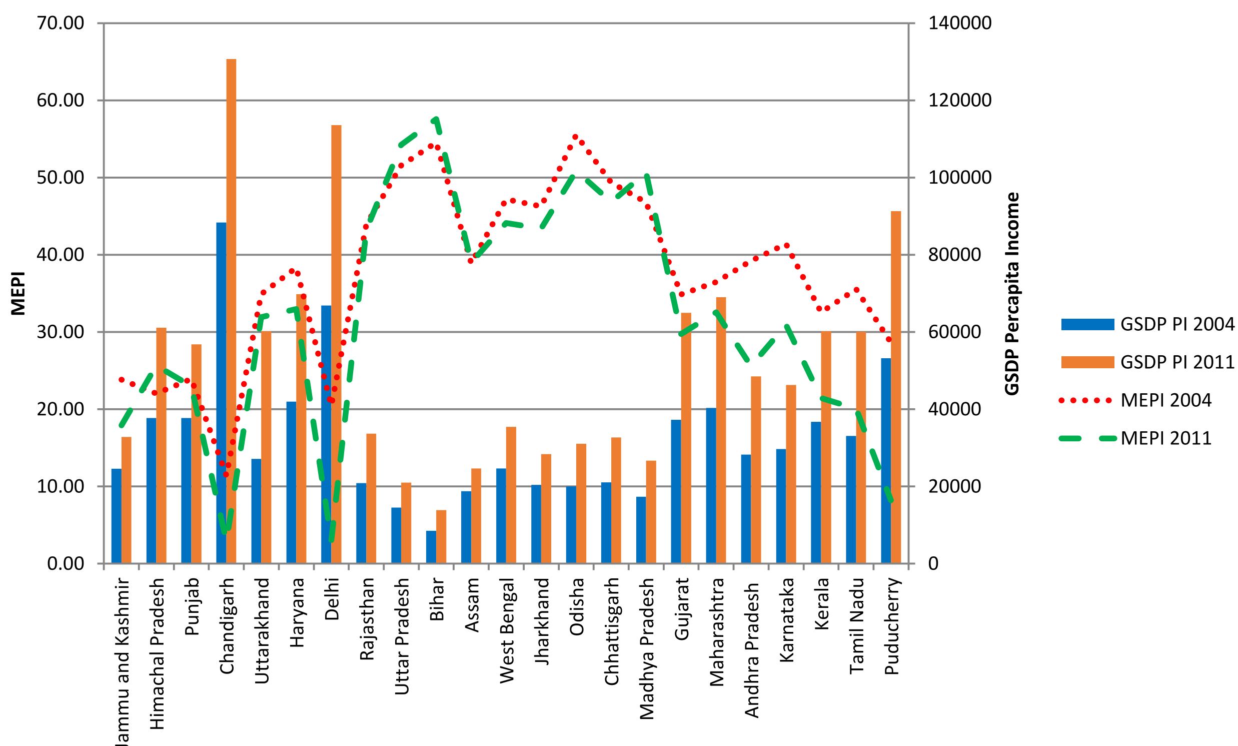

Fig. 2. Comparison of gross state domestic product percapita and energy poverty of selected Indian States and Union Territories.

owing to the reasons as already explained in the case of education. Lowest percapita income of less than Rs. 20,000 is found in the case of Bihar and followed by Utter Pradesh. States with a percapita income of less than Rs. 40,000 have MEPI scores of over 40% indicating that people are energy poor. Overall, states with better education and higher income have lesser MEPI values. Finally, to test the strength of relationship, we measure the correlation between energy poverty and constructed indices. The result of the same is reported in Table 6. Energy poverty is negatively related to both education and income indices. Education index has higher impact on reducing energy poverty than income. Further, closer examination shows that among the components of education, educated above 12th standard has higher impact than literacy. Finally, income index also has negative relation with energy poverty; its impact is lesser than education. The strength of relation has increased from 2004–05 to 2011–12. This could be an indication of the importance of energy access with increase in the standard of living of the people measured by education and income.

Table 6
Correlation of energy poverty with education and income.

Year	Literacy	Educated (12th and above)	Education index	Income index
2004–05	−0.397	−0.411	−0.428	−0.181
2011–12	−0.503	−0.534	−0.519	−0.243

For example, a person who used to read with lighting facility will find it difficult to read without lighting compared to a person who is not so. However, further analysis is required to reveal the real factors responsible for the observed increase in correlation in 2011–12.

Thus, empirical results can be summarised as follows: Energy poverty is still widespread in India even though it has declined between 2004 and 2011 both in urban and rural areas. While decline in energy poverty was perceptible in most of the small and medium states, it has increased during 2004–05 and 2011–12 in major and poor states like Uttar Pradesh, Bihar, etc. who account for more than 30% of India's population. Results also indicate that energy poverty has declined faster in urban areas than in rural areas.

As far as the relationship between energy poverty and socio-economic development is concerned, results are straightforward indicating a negative association between them and this relationship appears to have strengthened over time. For example, southern states like Karnataka, Andhra Pradesh, and Kerala with relatively better economic conditions appear to have recorded a decline of 25% or more. The negative association between energy poverty and economic progress is also found among communities and castes. For instance, while energy poverty has declined drastically during the study period among communities like Jain and castes like Brahmins, there is marginal decline among backward communities like Muslims and Tribals.

These findings are basically strengthening the line of reasoning furnished in the Section 2 that eradication of energy poverty is an enabling measure to expand opportunity sets of the people in the form of better education, health and standard of living. Likewise, farmers will be inclined to use energy efficient techniques so that productivity will be rising [12].

6. Conclusion

Role of access to modern energy resources in the promotion of welfare of the society is well recognized all over the world. Access to energy can influence the welfare of the people not only in the present but also in the future. Children from electrified households would be more comfortable to study at night than children from un-electrified households. This implies that eradication of energy poverty is one of the most important forms of investment in the development of a society. Likewise, women in general and girls in particular will be more secure in vicinity with electrification. Eradication of energy poverty has huge health implications as well. Having access to LPG in the kitchen is one of the most helpful things as far as the women are concerned. It helps them not only to cook healthy and nutritious food to the family members rather comfortably, but also rescue them from serious health problems likely to be caused by burning traditional bio-fuels. Moreover, a shift from bio-fuels to clean energy will ensure that women and girls who are traditionally engaged in the collection of bio-fuels will find more time for other productive tasks and education. And in the northern part of the globe, energy or fuel security is a prerequisite to sustain life during winter season. Finally, in this era of industry driven economies, promotion of manufacturing sector of all sizes and generation of employment opportunities requires provision of reliable energy resources. Thus, energy security has crucial significance in the promotion of overall socio-economic progress of modern societies.

Therefore, in this paper we have examined the extent of energy poverty in India and the relationship between energy poverty and economic development between 2004–05 and 2011–12. While the extent of energy poverty is examined by calculating a multi-dimensional energy poverty index with district-level data, the relationship between energy poverty and economic development is examined by constructing an index of development using education and income as components. Overall, results suggest that even though India has made progress in alleviating energy poverty during the study period, a sizeable share of population especially in poor states still lack access to modern energy services.

Empirical findings of this paper have crucial policy implications. Results seems to suggest that concerted efforts and policies such as Electricity Act 2003 and followed by National Electricity policy 2005 with the aim of expanding access to electricity especially in rural areas have paid dividends in the form of considerable decline in the energy poverty in India. Similarly, provision of subsidised LPG to poor households has also helped to ameliorate the extent of the problem. However, evidences indicating that energy poverty is still widespread especially in poor and highly populated states should be an eye opener to the policy makers. To expand energy access further, therefore, policy makers have to adopt complementary approaches with technological and organisational innovations like promotion of private investment and tapping of renewable energy potential [4].

Conflict of interest statement

The authors of the paper do not have any conflict of interest in carrying out this research. The findings and conclusions of the paper is completely driven by the empirical results of the study and not influenced by any agency.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.enbuild.2018.11.047.

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