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Assessing an empirical relationship between energy poverty and domestic health issues: A multidimensional approach

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ABSTRACT

Nowadays, it is imperative to examine potential health issues of household energy poverty, as in return, it leads to its reduction. Although extensive research has been done in other regions of the world, South Asia is overlooked in this regard. For this purpose, the study analyzes the health impacts of energy poverty in South Asia. First, it calculates the intensity and amount of energy poverty using a multidimensional index approach. Then, this study uses a one-way multivariate analysis of variance (MANOVA) to empirically examine the relationship between energy poverty and health problems analyzing a dataset from six South Asian countries. The results confirmed a statistically significant relationship of energy poverty with the sources of drinkable water, access to clean water, risks of mosquito bites, obesity, sterilization, marital status, literacy, occupation, and residence. After having robust findings, the study proposes effective policy measures to be taken to prevent energy poverty and control potential health consequences in South Asia. This study is an attempt to provide an empirical baseline to conduct further studies addressing a similar issue in other regions of the world.

1. Introduction

Energy poverty has become one of the central global problems risking millions of lives per annum in the contemporary world. It is posing potential threats to human development and health globally [1]. Households still lack complete electrification and safe cooking fuels. More than 1 billion people do not have access to electricity, and 2.7 billion people are burning polluted energy sources to prepare a daily meal [2]. The consumption of traditional energy fuels causes indoor smoking and envisages potential health consequences. Almost 3.6 billion people are exposed to indoor air pollution that is 47% of the world's population: over 800 million people in India and 450 million in China only in 2017. Half of the world's population still relies on solid fuels to cook food at the household level [3]. This reliance on traditional energy resources such as coal, charcoal, biomass, firewood, crops, straw, and animal dung envisage rampant health problems whose victims are women in most of the cases: 3.8 million premature deaths were reported globally in 2018 and about 60% of them were women [4].

South Asia is a region of developing countries that are facing similar energy poverty-related problems. Dependency on traditional polluted cooking fuels, primarily firewood and animal dung, makes South Asia one of the most susceptible regions to energy poverty. Rural areas lack electrification, clean cooking stoves, household appliances to support cooling, heating, and communication, and other modern energy services of washing, refrigeration, etc that cause severe health problems domestically [5]. Thousands of people die prematurely on annual basis, as they are exposed to indoor air pollution in the region. Almost 481,700 deaths in India, 59,100 in Pakistan, 19,400 in Afghanistan, 70,300 in Bangladesh, 11,200 in Nepal, 5480 in Sri Lanka, and 135 in Bhutan were attributed to indoor air pollution in 2017 [3]. More than half of the region's population is exposed to outdoor air pollution due to solid fuel consumption at the household as well as the national level [3]. The region covers 2 million square miles area that accounts for 3.5% of the world and 11.7% of the Asian continent. It is home to 1.92 billion people and one of the fastest-growing economy rates regions wise (7.1% in 2020–21) that accounts for 3.5 US trillion dollars (2020). With the above-mentioned characteristics, South Asia

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seems a good case study to examine the health impacts of household multidimensional energy poverty.

A plethora of studies has focused on the accessibility, reliability, and affordability of energy services. However, few studies examined the health consequences of energy poverty using a multidimensional index and a little attention was paid to discovering its health consequences in South Asia as well. Thus, the ultimate purpose of this study is to analyze the health implications of energy poverty in South Asia employing a multidimensional approach. First, it calculates the intensity and amount of energy poverty using an adjusted multidimensional energy poverty index (MEPI). Then, this study examines the statistical relationship between multidimensional energy poverty and health problems using a one-way multivariate analysis of variance (MANOVA) or also known as multivariate regression analysis. After having robust findings, the study proposes some effective policy measures to be taken to prevent energy poverty and control potential health consequences in South Asia. This study is an attempt to provide an empirical baseline to conduct further studies addressing a similar issue in other regions of the world.

2. Literature review

Energy consumption, economic productivity, and human well-being are closely linked. Abundant efficient energy consumption reduces air pollution, enhances economic productivity, comforts life, prevents potential health risks, improves household budgets, and contributes to the betterment of overall human well-being consequently [6–9]. Electrification spurs industrial production of the country and supports education, entertainment, and health at the household level [10]. Whereas energy vulnerability causes indoor air pollution and endangers human lives. The usage of solid fuels emits carbon monoxides and particulate matters and pollutes the indoor air that further leads to poor mental health and physical illness [11–13]. Lim and Vos estimated 3.5 million premature deaths by household air pollution resulting primarily from cooking with solid fuels in 2010 [14]. There were 500,000 deaths from outdoor air pollution caused by solid fuels used for household cooking in developing Asia [15]. Further, household air pollution causes birth weight reduction, high blood pressure, and lung function reduction [16,17]. The lack of access to electricity increases the injuries from falling and makes it harder to complete homework and causes stress, anxiety, and depression. The substitute for lighting, like, candles, may cause eyesight problems, house fire, and causalities [18]. Insufficient refrigeration spoils food and leads to food poisoning. It also contributes to the anxiety and stress when households need to spend more to replace the rotten food, as it affects the household monthly income. Inaccessibility to the central heating system affects the comfortability and quality of life [19]. If the houses lack adequate warmth in extreme weather conditions, it may trigger devastating health implications and endangers human life [20].

When solid fuels burn inefficiently in non-ventilated or poorly ventilated spaces, it envisages physical complications such as damaging lungs, physical inactivity, body aches, chronic illness, and disability in the long term [21,22]. The International Energy Agency (IEA) has recently substantially revealed that the developing countries are facing the problem of the affordability of modern energy fuels for cooking, heating, and lighting [23] that negatively impacts life expectancy, literacy level, caloric intake, and other standards of living [24–26]. A study conducted in India revealed that the consumption of solid fuels to cook meals increased respiratory infections among children [27]. Besides, household living conditions and energy vulnerability also impact mental health and mortality [28,29]. Cold houses or inadequate indoor warmth leads to adverse health outcomes for children and adults [30,31], as regulation of indoor temperature is imperative in extreme weather conditions. The inability to control and maintain affordable warmth in the house causes asthma, flu, bronchitis, cardiovascular, and lungs related diseases [32] and also other physiological issues like depression, mood swinging, inactivity, social isolation, and mortality [32,33].

However, the global efforts have progressively reduced reliance on solid fuels and strived to achieve complete electrification providing universal access to lighting. The national governments, governmental organizations, non-governmental organizations, international agencies, and businesses are relentlessly working to overcome energy poverty, enabling people to use clean or green energy sources like electricity, natural gas, liquefied petroleum gas (LPG), and kerosene instead of traditional ones. Recently, 68 developing countries promised to improve electrification and efficient and eco-friendly cooking fuels to reduce indoor air pollution. Out of 68 states, 17 countries pledged to shift their cooking fuels from contaminated to clean cooking stoves. The IEA estimated 1.9 US billion dollars invested since 2009 worldwide to provide clean energy facilities and initiated its 2030 plan to invest US 14 billion dollars more annually in developing countries to provide universal modern energy services [2,23]. As result, the reliance on solid fuels has decreased from 57% in 2005 to 47% in 2017 [3]. Such policies and cooperative efforts will play a significant role in shaping the energy future by achieving complete electrification, providing universal access to clean energy fuels, and other basic modern energy services that will subsequently lead to the reduction of energy poverty.

3. Research methods and data

3.1. The key metric to measure energy poverty

The study uses an adjusted multidimensional energy poverty index (MEPI) to simultaneously measuring the amount (numbers of energy-poor) and severity (how much are they poor) of energy poverty. This model employs composite-indices to calculate energy poverty along with its multiple dimensions. As energy poverty is a complex and multifaceted concept, a single index method is unable to adequately cover its intrigued multidimensionality and intensity. Thus, the MEPI a recently proposed approach can comprehensibly capture its multidimensionals and gauge energy poverty adequately [34]. These multiple dimensions, their roles, and vital importance are specified and well explained by the proponents of this index [35]. The MEPI limits the scope of energy poverty to necessary domestic energy services such as lighting, cooking, telecommunication, education/entertainment, indoor air pollution, and household appliances to support cooling, heating, or preserving the food [36].

Table 1 presents these dimensions, indicators, weights, and deprivation cutoffs of multidimensional energy poverty specified in the MEPI model by its advocates [37]. The different indicators are set to measure deprivation for each dimension. The indicator to measure deprivation for lighting is access to electricity. However, the types of cooking fuels define the deprivation threshold for cooking, and for other dimensions, ownership status is a key metric to identify the dimensional deprivation. For example, the ownership of a mobile phone as an asset of communication defines the household deprivation for telecommunication, possession of refrigerator as a household appliance for the preservation of food, and television as a source of education or entertainment set the dimensional threshold.

As aforementioned, the MEPI gauges the headcounts and intensity of energy poverty in dimensions d across the population n.

Table 1
Dimensions, indicators, and deprivation cutoffs of multidimensional energy poverty.

Dimension	Indicator (weight)	Deprivation threshold Deprived if …
Cooking	Modern cooking fuel (0.2)	Using cooking fuel besides electricity, natural gas, kerosene, or biogas.
Indoor smoke	Separate room for cooking (0.15)	It has not a separate room for cooking with a chimney or hood.
Lighting	Electricity access (0.2)	It has no electricity connection.
Household appliances	Possession of appliance (0.15)	It has no fridge.
Entertainment /education	Ownership of asset (0.15)	It has no television.
Telecommunication	Ownership of asset (0.15)	It has not a mobile telephone.

We take a matrix of achievement, $Y = y_{ij}$, for all dimensions and overall population ($n \times d$) of individuals i in variables j. Where $y_{ij} \geq 0$ presents the degree of achievements of the individuals ($i = 1,2, 3 \ldots n$) across the variables ($j = 1,2,3 \ldots d$). The weights w is allocated to each variables j unevenly as per defined and specified in the model [34]. The allocation of weights to each dimension embraces the unequal significance of indicators of household energy services and their potential role in policy formulation and implications [36]. The weight w vector of all variables j is equal to $\sum_{j=1}^{d} \text{wj} = 1$. If a household is deprived in a particular dimension, the respective weight (0 or 0.15/.20) will be added to its row vector. The row vectors present a household's accumulated achievements in all variables. However, column vectors present the distribution of achievements of variables for each household. For example, if a household is deprived of all dimensions, the household's aggregated achievement will be equal to 1 and 0 otherwise.

The model also uses dual cutoff parameters to simultaneously measure the intensity and headcounts ratio of energy poverty. The deprivation cutoff z_j denotes the deprivation in a variable j and $g_{ij} = w_j$ designates the matrix achievements of deprivations across the variables and individuals. If the deprivation matrix g of an individual i in a variable j exceeds the deprivation cutoff ($g_{ij} > z_j$), the individual i is deprived of the concerned variable. However, the poverty cutoff k is an eligibility criterion term to identify multidimensionally energy-poor households, and we have set the poverty cutoff to 33% (that is $k \geq 0.35$) in this study as defined and limited within the model [34].

Lastly, we construct two additional column vectors. The first one presents deprivations counts (C_i) to sum up a household's achievements in all variables j. If deprivation counts (C_i) exceed the specified poverty cutoff ($C_i \geq k$), the household will be considered as multidimensionally energy-poor and otherwise not poor. The second one is a censor column vector C_ik to truncate the cases of multidimensional energy poverty in the population. To censor the vector, C_ik is set to 0, if deprivation counts C_i does not exceed the poverty cutoff ($C_ik < k$), and it is set to 1 if Ci exceeds the poverty cutoff.

After explaining all relevant indices, now we can compute Eqn 1 to measure the headcount ratio and Eqn 2 to calculate intensity of energy poverty.

$$H = q/n \tag{1}$$

where H is the headcount ratio, q presents the number of multidimensionally energy-poor households and n denotes the total population.

$$A = \sum_{i=1}^{n} Ci(k) \Big/ q \tag{2}$$

where A presents the intensity and $C_i(k)$ presents deprivation counts of the multidimensionally energy-poor observations and finally, we calculate multidimensional energy poverty by Eqn 3 as a product of headcount ratio and intensity of energy poverty

$$M = H \times A \tag{3}$$

3.2. Multivariate analysis of variance (MANOVA)

Table 2 gives definitions of the dependent variables. The deprivation scores Ci of the MEPI is an independent variable that presents the level of household multidimensional energy poverty for each observation. As above-mentioned, the column vector of deprivation scores Ci denotes the accumulated achievements of a household across the variables/dimensions of energy poverty. The study uses a one-way multivariate analysis of variance [38] also known as multivariate regression to examine the statistical relationship of multidimensional energy poverty with the variables of health. The MANOVA is a multivariate analysis that is employed to determine an empirical relationship between one or more independent variables and more than one dependent variable. It allows testing the hypothesis based on the causal relationship between the group of dependent and independent variables [39]. The SPSS 26.0 was used to execute this multivariate analysis and check the assumptions followed up with post-hoc tests required for a one-way MANOVA.

3.3. Data source

A dataset of 674,834 households from 6 South Asian countries is utilized for an outcome of the interest; 24,395 households from Afghanistan, 14,540 households from Pakistan, 601,509 households from India, 17,300 households from Bangladesh, 11,040 households from Nepal, and 6050 households from the Maldives. Table 3 presents a statistical summary of variables and reference categories of the combined dataset with mean, standard deviation, minimum, and maximum value. The dataset comprises of complete demographic and health profile of the households and is available on the agency's official website [40]. It provides complete information on household possessions, characteristics, composition, and health profile of the households. Thus, this data provides an insightful empirical information base for policy implications for the stakeholders.

The data is collected through a household survey by an international agency, the United States agency for international development (USAID), with the collaboration of national population study institutes of respective states. The USAID conducts surveys in Pakistan annually with the collaboration of the National Institute for Population Studies, Islamabad. Similarly, the USAID cooperates with the International Institute for Population Sciences in India, the National Institute of Population Research and Training in Bangladesh, the Central Statistics Organization in Afghanistan, the

Table 2
Description of dependent health variables.

Variable	Description
Education	The education level of the respondent such as no education, primary, secondary, or higher.
Marital status	Current marital status of the respondent
Occupation	Types of occupation (grouped)
Residence	Types of residence (urban/rural)
Source of water	Source of drinking water: a categorical variable to captures the common sources of water supply
Clean water	Anything was done to water to make it safe to drink?
Mosquito-borne diseases	Has mosquito bed net for sleeping?
Age of sterilization	A categorical variable to define the age groups of sterilization
Obesity level	Rohrer's index/Corpulence index to capture fatness/obesity level of a respondent: calculated as CI = weight/height^3

Table 3
Statistical summary of observatory variables in the study area.

Variable	Observation	Mean	Standard deviation	Min/Max	Skewness
Education level		1.44	1.021	0/3	−0.274
No education	187,858				
Primary	85,513				
Secondary	320,539				
Higher	80,385				
Marital status		1.61	0.571	0/5	−1.238
Unmarried	44,074				
Married	127,236				
Living with a partner	498,081				
Widowed	3398				
Divorced	1450				
Occupation		2.44	2.024	0/7	1.487
Unemployed	98,035				
Professional/managerial	18,413				
Clerical	413,738				
Sales	12,748				
Agricultural	50,543				
Services	19,172				
Skilled & unskilled	40,084				
Residence		1.70	0.459	1/2	−0.866
Urban	203,737				
Rural	471,158				
Source of drinking water		21.43	13.11	1/16	2.287
Piped into dwelling	108,327				
Piped to yard/plot	84,332				
Public tap/standpipe	87,002				
Tube well or borehole	6874				
Protected well	258,366				
Unprotected well	26,014				
Protected spring	36,457				
Unprotected spring	8124				
River/dam/lake/ponds/stream/canal/irrigation channel	13,933				
Rainwater	6229				
Tanker truck	8861				
Cart with small tank	2375				
Bottled water	11,690				
Community RO Plant	3198				
Other	1999				
Anything was done to water to make it safe to drink?	674,834	0.39	0.54	0/1	3.018
Has mosquito bed net for sleeping?	651,484	0.37	0.48	0/1	0.519
Age of sterilization		2.14	1.04	1/6	0.777
<25	79,069				
25–29	94,034				
30–34	54,221				
35–39	21,285				
40–44	5880				
45–49	703				
Obesity level	635,855	1585.74	1059.47	1132/6530	10.845

Ministry of Health in Nepal, and the Ministry of Health in the Maldives to collect primary household data. The survey was conducted at the household level, taking demographic and health features of the households, and collected by the field workers funded by the concerned national institutes of population studies and the agency.

4. Results and discussion

4.1. Energy poverty results

Fig. 1 describes the occurrences of the multidimensional energy poverty index in South Asia. The results disclose that Bangladesh is

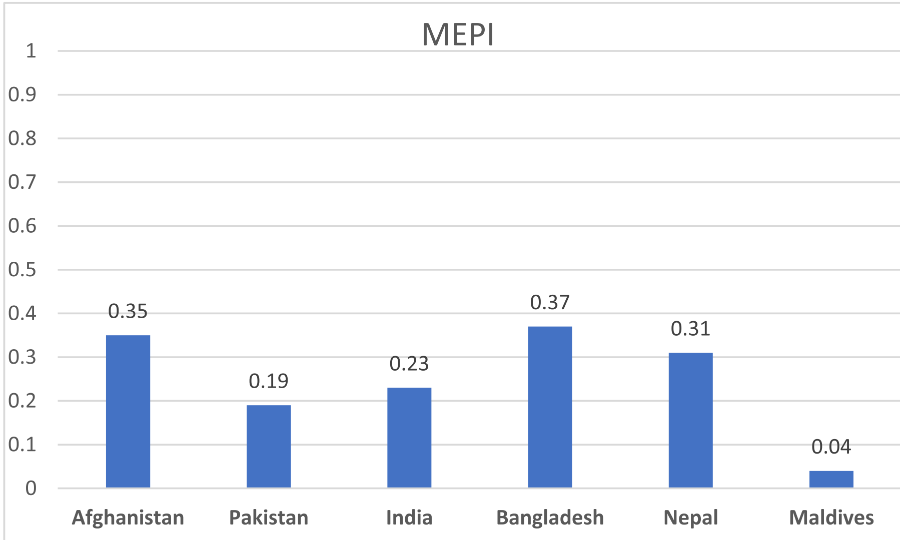

Fig. 1. Results of multidimensional energy poverty index across the South Asian countries.

the most energy-poor country in South Asia, according to the multidimensional energy poverty index with 0.37 counts. The geographical terrain of the country makes it harder to provide complete electrification and the incapacity of the power generating system to quench the excessive energy demands of the dense population leaves the rural households susceptible to energy poverty. However, the rapid economic growth will enable the country to manage the deprived areas and provide electricity.

Similarly, Afghanistan is the second most multidimensionally energy-poor country in the region with 0.35 respective scores. The reasons behind this considerable vulnerability are the weak economy, political instability, and geographical steppe that prevent the networks of infrastructure and transmission lines from the national grid. Geographically, Afghanistan is an underdeveloped landlocked country that heavily depends on its neighboring countries for supply and trade routes. Another primary reason behind its vulnerability is political instability for the last five decades. The country has been a battleground for unending wars and military operations. The political fragility prevents its growth and development so far, thus, leads to the vulnerability of electricity and modern energy services. Ironically, the Maldives, an archipelago country, is the least deprived state in South Asia, less than 1% of the households do not have electricity. The results also reveal that the Maldives and Pakistan are the least poor states in the region with 0.04 and 0.19 indices sequentially.

Fig. 2 demonstrates that Bangladesh is one of the most precarious countries in South Asia regarding access to modern cooking fuels. Over 80% of households do not have access to modern cooking fuels such as electricity, natural gas, biogas, kerosene, and LPG, etc. They still rely on contaminated traditional energy fuels, for example, firewood, coal, charcoal, crops, agricultural straws, and animal dung to prepare a meal. Likely, nearly 70% of the population of Afghanistan and Nepal depend on inefficient fuels for cooking. Over 50% of the households in India and Pakistan also uses traditional energy fuels to cook food. The lack of access to modern energy fuels in rural areas of the region exacerbates the situation leaving no other choice except to rely on woods or animal waste for cooking purposes. Fig. 3 describes the rates of households that are exposed to household air pollution. The results reveal that 28.5% of households in India and Nepal, 26.8% in Pakistan, and 22.6% in the Maldives are exposed to indoor air pollution.

The burning of solid fuels envisages drastic health impacts if the cooking rooms are poorly ventilated. Even the combustion of traditional energy fuels in open areas contaminates the air. The findings disclose, shown in Fig. 4, that firewood is the most common cooking fuel in South Asia. Almost 6% of households in Nepal, 53% in Bangladesh, 48% in India, and 45% in Pakistan use firewood as primary cooking fuel. Straws and crops are the other conventional cooking fuels in Bangladesh, as 22.3% of the households rely on it. However, animal dung or waste is the second most common cooking fuel in Nepal, Bangladesh, India, Pakistan, and Afghanistan regarding solid fuels. Further, nearly 17% of the Afghanistan population burns straws that is the third most common cooking fuel. Interestingly, the Maldives is the only country with a minimum level of solid fuel consumption that is only 1% of the total population.

Furthermore, Fig. 5 summarizes the dimensional energy poverty results in South Asia, analyzing the combined dataset. The results reveal that South Asian nations are mostly deprived regarding the possession of household appliances. Nearly 87% of the households in South Asia do not have complete household appliances to live a comfortable life. Besides, 72% of the population cannot afford clean, modern, and environment-friendly cooking fuels. More than 52% of the population do not own assets of education such as television or computer. Moreover, still, 28% of the household in South Asia do not have electricity connection. Lastly, 19% are facing vulnerability in indoor air pollution, whereas 13% are deprived of telecommunication facilities.

Fig. 6 defines the relationship between headcount ratio versus intensity of multidimensional energy poverty in South Asia with a scatterplot. The plot clearly shows that the intensity of multidimensional energy poverty is higher than the headcount ratio. For example, the intensity of Pakistan's multidimensional energy poverty (0.60) is higher than its headcount ratio (0.31). The same is the case with other observations, like, the intensity of India is 0.63 is more than the headcount ratio 0.36.

4.2. Health impacts of multidimensional energy poverty

Table 4 explains the actual results of multivariate tests for one-way MANOVA. If we look at the second effect for label *'MEPI'*, the results revealed significant values of Wilks' Lambda test (Wilk's

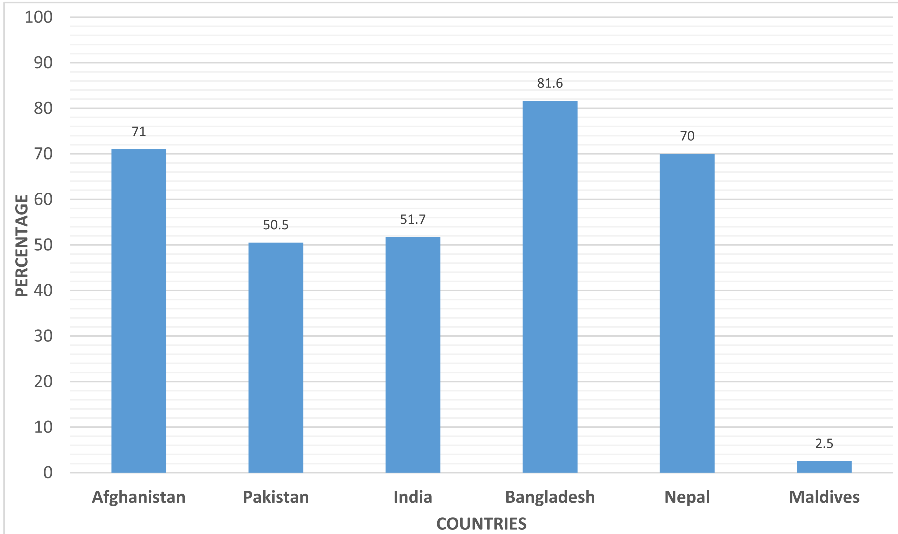

Fig. 2. Deprivation rates for each country regarding inaccessibility of modern cookstoves.

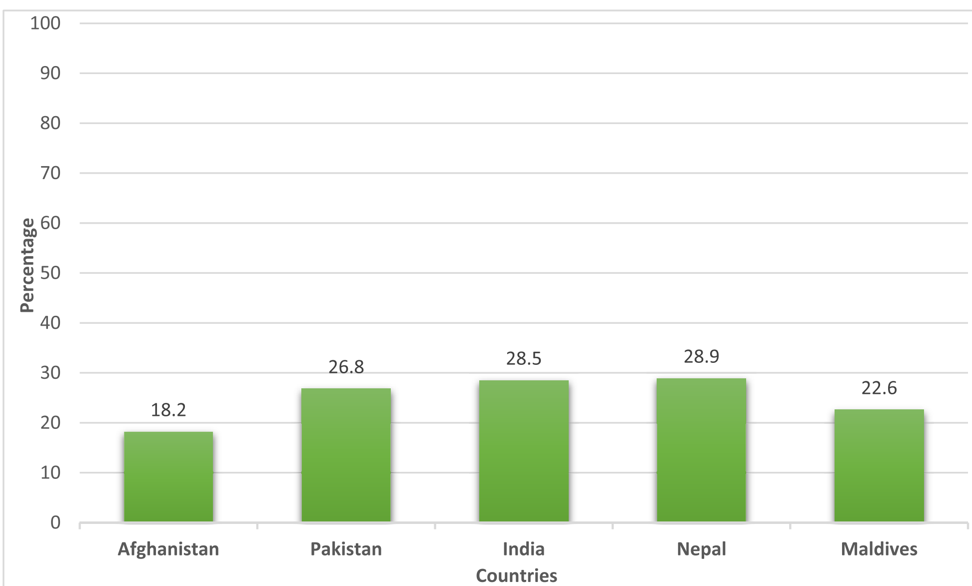

Fig. 3. Situational deprivation rates of indoor air pollution for each state.

$\Lambda = 0.76$, $F(135, 5{,}184{,}231) = 1338.98$, $\eta^2 = 0.029$) at $p < 0.01$. The significant F also indicated that there were significant differences between the groups of variables on a linear combination. Thus, it indicated that the test was significant, and no assumption was violated. If the assumptions of homogeneity of variance-covariance and multicollinearity were violated, we could use Pillai's Trace test (Pillai's $\Lambda = 0.24$, $F(135, 5{,}996{,}916) = 1204.62$, $\eta^2 = 0.026$, $p < 0.01$) that is a robust statistic and not linked to any assumption of normality of data: this metric is significant too. Finally, the multivariate $\eta^2 = 0.03$ implies that there is approximately 3% of the multivariate variance association of the dependent variables with the group factor.

Because the MANOVA's post hoc test was significant and no assumption was violated, now we can move on to the estimates of effect size between the MEPI and explanatory health variables, shown in Table 5. The outcomes reveal a statistically significant cause and effect relationship of multidimensional energy poverty with educational level, marital status, types of occupation, sources of drinkable water, purifying drinking water, affordability/accessibility of mosquito bed net for the households to prevent mosquito-bites diseases, sterilization, and obesity level of the women at significant level $p < 0.01$. These empirical results provide concrete evidence that the level of multidimensional energy poverty does affect the well-being of households in South Asia at large. The women of the households are more susceptible to health-related issues that have a higher level of energy poverty.

Besides, to capture a more comprehensive and detailed overview of the causal relationship, we provide multivariate regression results in Table 6, using an *i*th command in STATA ^{MP}16, about each category of the health variables. Most of the categories of the variable have a significant statistical relationship with multidimensional energy poverty in South Asia except for the obesity level. The results reveal that there is a rampant rate of energy poverty among divorced women whereas married women have lesser chances of

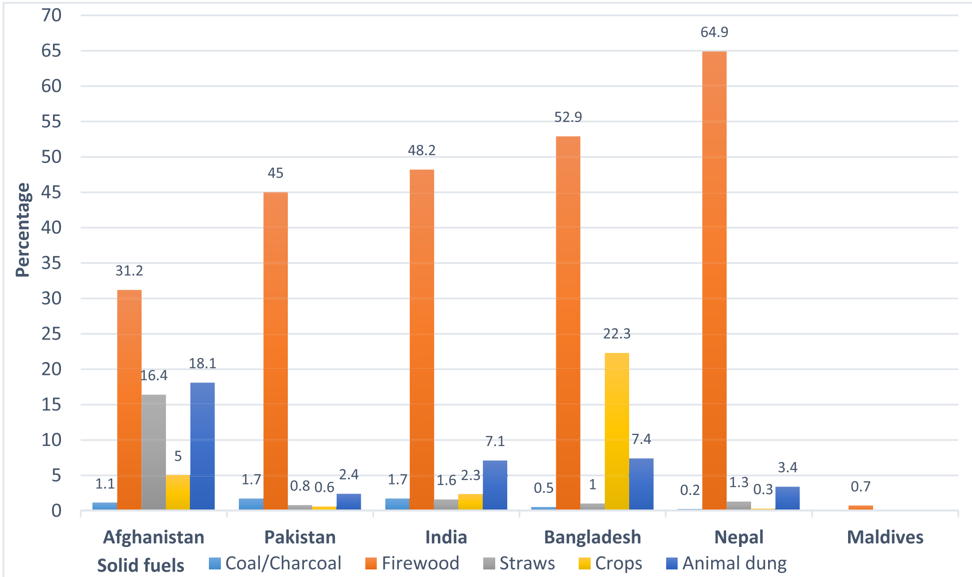

Fig. 4. Commonly used solid cooking fuels in South Asia.

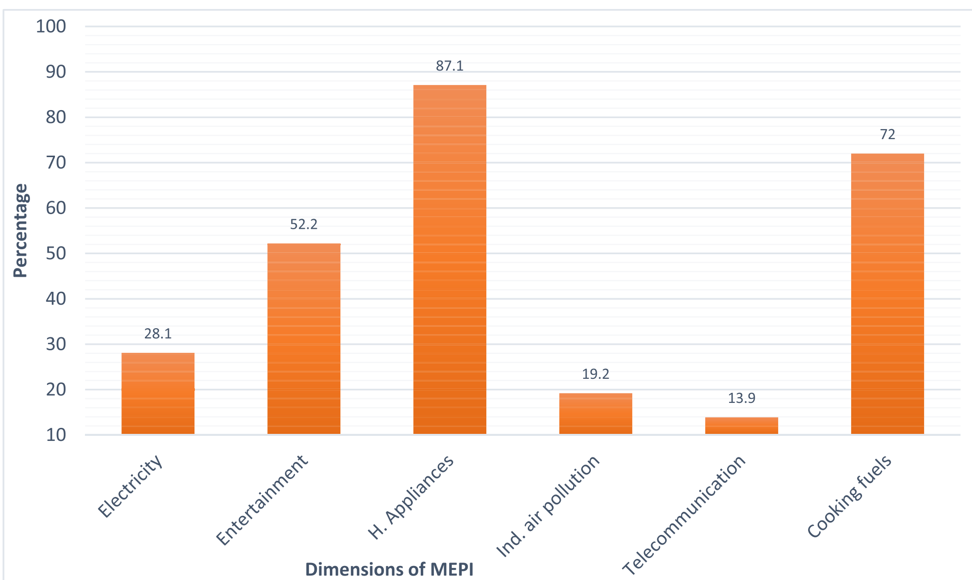

Fig. 5. Results of deprivation rates dimension wise in South Asia with the aggregate dataset.

susceptibility to energy poverty and there is an insignificant relationship with widowed and households living with partners. Further, households having occupations related to sales, agriculture, services, and skilled and unskilled professions are positively linked with energy poverty. In contrast, clerical job holders have a reverse effect relationship and energy poverty does not have an empirical significant relationship with professional/managerial posts holders. The types of residence of the respondent and education have a positive link to energy poverty indicating prevalent energy poverty in rural households than urban.

From a health point of view, it is imperative to recall that lack of access or affordability to basic modern energy services refers to energy poverty including assets of controlling air temperatures like an air conditioner or fans, etc. If a household lacks these services and also does not have mosquito/insects bed nets for protection, the households will be exposed to insect-bites diseases or infections while sleeping. In this case, the negative significant outcomes demonstrate that households with higher rates of multidimensional energy poverty have a greater probability of mosquito-borne diseases because of not having mosquito bed nets for sleeping. The findings also disclose that energy poverty does affect the sources of drinkable water at the household level: positive correlation of energy poverty with all the reference categories of sources of drinking water support the discussion. Likely, the houses that are more precarious to multifarious energy poverty do not have access to clean water. The findings disclose that manifold energy-poor households hardly have anything to pure water and make it drinkable. The inability to afford clean water envisage disastrous health implications for the households. It is worth noting that drinking contaminated water leads to various deadly diseases such as cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio.

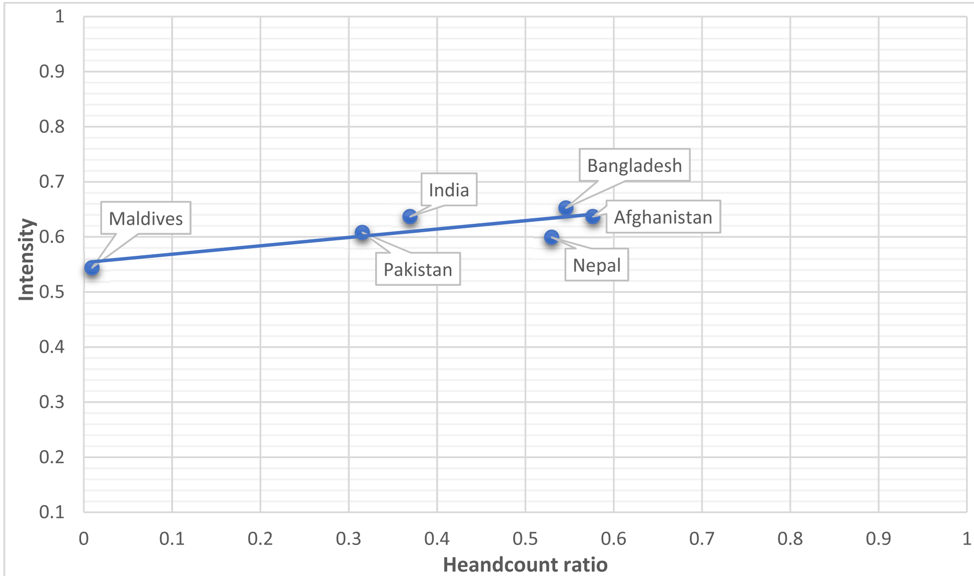

Fig. 6. Scatterplot of headcount ratio vs intensity of multidimensional energy poverty.

Table 4
Post hoc test of multivariate analysis.

Multivariate Tests[a]							
Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	0.504	75291.236[b]	9.000	666316.000	0.000	0.504
	Wilks' Lambda	0.496	75291.236[b]	9.000	666316.000	0.000	0.504
	Hotelling's Trace	1.017	75291.236[b]	9.000	666316.000	0.000	0.504
	Roy's Largest Root	1.017	75291.236[b]	9.000	666316.000	0.000	0.504
MEPI	Pillai's Trace	0.238	1204.623	135.000	5996916.000	0.000	0.026
	Wilks' Lambda	0.766	1338.976	135.000	5184231.315	0.000	0.029
	Hotelling's Trace	0.301	1485.579	135.000	5996828.000	0.000	0.032
	Roy's Largest Root	0.285	12668.846[c]	15.000	666324.000	0.000	0.222

[a] Design: Intercept + MEPI.
[b] Exact statistic.
[c] The statistic is an upper bound on F that yields a lower bound on the significance level.

Table 5
Results of test estimates for the Between-Subjects effects.

Ind. Variable	Dep. Variable	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MEPI	Education level	534.52	15	35.63	34.25	0.000	0.001
	Marital status	231.61	15	15.44	203.26	0.000	0.005
	Occupation	11655.0	15	777.00	158.17	0.000	0.004
	Residence	24289.87	15	1619.32	9289.77	0.000	0.173
	Source of drinking water	1396277.97	15	93085.19	550.17	0.000	0.012
	Clean water	14176.92	15	945.13	3473.70	0.000	0.073
	Mosquito-bite diseases	1765.46	15	117.69	515.84	0.000	0.011
	Age at sterilization	407.25	15	27.15	37.62	0.000	0.001
	Obesity	19801134.85	15	1320075.65	8.13	0.000	0.000

5. Conclusion and policy implications

The study aimed to examine the statistical causal relationship between energy poverty and health-related variables in South Asia. Conclusively, most of the health problems have an empirical cause and effect relationship with multidimensional energy poverty such as education level, marital status, residence, types of occupation, sources of drinking water of a household, purification of water to make it drinkable, mosquito bed facility in the house, age at sterilization, and obesity level. The results have empirically demonstrated that households with a rampant rate of multidimensional energy poverty are prone to more household health problems, especially women, than households with lower levels of energy poverty in South Asia. As, South Asian countries have developing economies, infrastructural problems, hard geographical terrain, poor technological advancement, agrarian society, and rampant population growth, so, the drivers of multidimensional energy poverty causing domestic health issues are somehow similar. The empirical results suggest the significant impacts of multidimensional energy poverty on health status due to indoor air

Table 6
Multivariate regression results for each reference category of the categorical variables.

MEPI	Coefficients	St. Err.	T-statistics
Education level			
Primary	0.0029	0.0009	3.21***
Secondary	0.0047	0.0006	7.06***
Higher	0.0073	0.0009	7.48***
Marital status			
Married	−0.0352	0.0012	−28.08***
Living with partner	0.0005	0.0078	0.07
Widowed	0.0062	0.0121	0.51
Divorced	0.0208	0.0107	1.93**
Occupation			
Professional/managerial	−0.0009	0.0018	−0.53
Clerical	−0.0099	0.0008	−11.88***
Sales	0.0162	0.0021	7.67***
Agricultural	0.0168	0.0012	13.50***
Services	0.0082	0.0017	4.59***
Skilled & unskilled	0.0111	0.0011	9.34***
Residence	0.1495	0.0006	234.77***
Source of drinking water			
Piped to yard/plot	0.0736	0.0010	70.86***
Public tap/standpipe	0.1359	0.0010	130.45***
Tube well or borehole	0.2084	0.0008	234.41***
Protected well	0.0878	0.0015	56.04***
Unprotected well	0.2539	0.0013	181.61***
Protected spring	0.1518	0.0026	58.40***
Unprotected spring	0.2406	0.0022	105.89***
River/dam/lake/ponds/stream/canal/irrigation channel	0.2440	0.0020	119.13***
Rainwater	0.2369	0.0029	79.14***
Tanker truck	0.0946	0.0024	38.04***
Cart with small tank	0.1319	0.0046	28.23***
Bottled water	−0.0371	0.0022	−16.85***
Community RO Plant	0.0117	0.0040	2.92**
Other	0.1709	0.0058	29.29***
Anything was done to water to make it safe to drink?	−0.0750	0.0005	−139.61***
Has mosquito bed net for sleeping?	−0.0143	0.0005	−24.14***
Age of sterilization			
25−29	−0.0048	0.0008	−5.97***
30−34	−0.0018	0.0010	−1.83*
35−39	−0.0021	0.0015	−1.35
40−44	−0.0064	0.0029	−2.18**
45−49	−0.0219	0.0084	−2.59**
Obesity	2.38e-07	2.66e-07	0.89
Observations	674,833	Parms	41
RMSE	0.2247	R. Sq	0.29
F ratio/value	6806.47	P-value	0.000

***Significant at the level 0.01, **Significant at the level 0.05, *Significant at the level 0.1.

pollution, compounded by households' living conditions, such as small space with in-house kitchen and the lack of modern latrines.

Therefore, the government should prioritize rural electricity distribution networks, and provide investment opportunities and incentives to potential private investors for rural electrification by developing appropriate policies. While ensuring access to electricity, it should be also accompanied by inclusive development policies to promote rural economy and narrow development gaps. Renewable energy technology should be promoted and encouraged through incentives and subsidies to reduce dependence on solid fuels, subsequently, overcome household air pollution and health issues. Lastly, the study renders empirical results of the current situation of energy poverty in South Asia, drivers, and factors of multidimensional energy poverty in the area and ultimately recommends practical measures to control its health implications at the household level.

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Author contributions

Khizar Abbas: Investigation, Data curation, Writing − original draft; Xiaoqing Xie: Data curation, Writing − original draft, Supervision, Writing − review & editing, Project administration, Funding acquisition; Deyi Xu and Khalid Manzoor Butt: Supervision, Writing − review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work eported in this paper.

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