https://doi.org/10.52131/joe.2024.0603.0232

*i*RASD Journal of Economics

Volume 6, Number 3, 2024, Pages 677 – 693

Journal Home Page:
https://journals.internationalrasd.org/index.php/joe

Household Energy Poverty in the Context of Socioeconomic Status and Area of Residence: A Comparison of Central and Southern Punjab

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ARTICLE INFO

Article History:

Received:	May	03, 2024
Revised:	August	20, 2024
Accepted:	August	22, 2024
Available Online:	August	24, 2024

Keywords:
Energy Poverty
Household Energy Poverty
Pakistan Demographic and Health Survey Data
Socioeconomic Factors
Multidimensional Energy Poverty

JEL Classification Codes:
O13, P18, Q43,

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

Researchers have increasingly focused on the impact of energy poverty across various sectors of the economy. This paper aims to identify the determinants of household energy poverty in Central and Southern Punjab, Pakistan, utilizing the Pakistan Demographic and Health Survey Data from 2017-18. The analysis employs descriptive statistics and binary logistic regression to assess the influence of various socioeconomic and demographic factors on multidimensional energy poverty. The survey results indicate a disparity between the two regions, with just over 50 percent of respondents reporting energy poverty. The education level of the household head, wealth status, and place of residence are critical factors influencing multidimensional energy poverty. The findings highlight the substantial influence of socioeconomic factors on household energy poverty and underscore the necessity for effective policies to address these challenges.

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Citation: Malik, M. Z., Noureen, T., Mehmood, A., & Ghauri, T. A. (2024). Household Energy Poverty in the Context of Socioeconomic Status and Area of Residence: A Comparison of Central and Southern Punjab. *IRASD Journal of Economics*, *6*(3), 677–693. https://doi.org/10.52131/joe.2024.0603.0232

1. Introduction

Energy poverty in emerging regions significantly hinders socioeconomic growth by restricting households' access to affordable and sufficient energy services. Reliable energy access is crucial for enhancing living standards, promoting economic growth, and attaining sustainable development goals (SDGs). However, many households in developing countries struggle with energy poverty, exacerbating existing inequalities and hampering progress toward achieving SDG 7—affordable and clean energy for all. Energy poverty is not restricted to heat, light, and cooking; it suppresses health, education, and economic well-being (Khandker, Barnes, & Samad, 2010).

Pakistan, a developing country with large disparities in socioeconomic status, has several challenges in providing energy to different regions and the affected populations. Specifically, Central and Southern Punjab are regions characterized by rather sharp disparities in population density, income levels, and living standards. Such discrepancies help promote the different levels of energy poverty, which requires an analysis to improve and look for the proper intervention. Earlier literature has established various antecedents of energy poverty, such as income, education, gender of the head of the house, and region (Abbas, Li, Xu, Baz, & Rakhmetova, 2020; Awan & Bilgili, 2022). However, limited information has been found in peer-reviewed scientific literature regarding the interrelations between socioeconomic level and residential location concerning energy poverty in specific regions of Pakistan, particularly Central and Southern Punjab.

Previous studies indicate that energy poverty is more pronounced in rural areas than urban regions, attributed to insufficient infrastructure and limited access to modern energy sources. For example, one of the studies that sought to understand the impact of subsidy programs in rural China showed that households changing from coal to electricity and natural gas experienced relatively higher levels of energy poverty. However, they were subsidized (Xie, Hu, Zhang, & Zhang, 2022). Studies conducted in Bangladesh indicate that households with lower incomes and higher levels of education exhibit greater vulnerability to energy poverty. (Hasanujzaman & Omar, 2022). Khandker et al. (2010) observed significant disparities in energy poverty between rural and urban households in India, with urban households exhibiting lower rates of energy poverty than their rural counterparts.

The case of energy poverty in urban areas, though comparatively rare, also constitutes a significant problem. In Guangzhou, China, the study established that age has a U-shaped pattern in energy poverty; young and old subjects remain vulnerable to energy-poor situations (Jiang, Yu, Xue, Chen, & Mi, 2020). Urban energy poverty and dwelling conditions are generally associated with poor residential housing, and renters or people living in cold and damp houses are predominantly affected by energy poverty (Chen & Feng, 2022). Therefore, the results raised policymakers' awareness about the necessity of focusing on rural and urban energy poverty eradication using specific policies adapted to the client's needs.

Increasing energy prices, a lack of access to contemporary fuel types, and inadequate energy infrastructure are the three factors contributing to the prevalent energy poverty in Pakistan. Cutting energy subsidies and fiscal costs also contribute to consumer pressures, and affordability of energy services becomes a challenge, affecting families (Awan & Bilgili, 2022). Furthermore, another factor that has exacerbated the energy poverty situation in Pakistan is geographical inequality since some regions are more needy than others based on social and geographical factors and infrastructure. For example, even though Southern Punjab is somewhat less developed than Central Punjab, it has more substantial challenges regarding the availability of electricity and the cost of that energy.

Consequently, eradicating energy poverty is vital to its effects on the well-being of homes and the general development of countries. Energy poverty manifests not only as a level of comfort and quality of life but also as a form of health, education, and work deprivation. People without access to electricity and gas use conventional biomass for cooking. Many people develop diseases associated with the respiratory system. Hence, lack of light and heat can compromise the children's learning via restricted study time and overall discomfort (Oktaviani & Hartono, 2022).

From an economic point of view, energy poverty slows down the rate of production and reduces the chances of income production. This is because the limited energy in the households means they cannot participate in several economic activities that require energy, such as operating small businesses or using modern farming methods like machinery. This, in turn, reinvents the poverty wheel and keeps the economic ladder at a firm hold (Nuryitmawan, 2021). Eradicating energy poverty is essential for any society that wishes to unlock inclusive economic growth for sustainable development.

The primary objective of this research is to determine the percentage of households in central and south Punjab experiencing energy disadvantages and the correlations between those disadvantages and socioeconomic class and geographic location. In each region of interest, the strategy is to determine the elements contributing to energy poverty and investigate how the currently available data demonstrates the impact of social inequality on accessible energy sources. In light of this, the fundamental significance of the study lies in the fact that it addresses the dearth of research in this particular field and provides the following policy suggestions to the relevant authorities in order to facilitate the development of intervention strategies for the homes that are the focus of the study in Central and Southern Punjab.

This study will employ a mixed-method approach integrating quantitative and qualitative methodologies to achieve the stated aims. The quantitative analysis will utilize essential household survey data to compute the energy poverty rate and its determinants. Initiatives will be undertaken to elucidate the adoption of energy solutions and energy poverty, considering factors such as household income, the educational attainment of the household head, the gender of the household head, and geographical area. Additionally, one-way qualitative interviews will facilitate a deeper understanding of households facing energy poverty and the contextual factors contributing to energy inequities.

The expected outcomes of this study are that it will add valuable knowledge to the existing literature on energy poverty and its antecedent factors and consequences in the elucidated regions of CSP. Firstly, the study will focus on cross-sectional differences and relationships in energy poverty outcomes to better understand how SES and area of residence affect them so that policies that target these aspects can be developed effectively. For example, increased energy facility investments in rural regions, energy cost subsidies for the poor, and increased adoption of clean energy technologies will significantly reduce energy poverty and positively impact the population's well-being.

In addition, this study will benefit the national and regional policymakers, who, in turn, will have a clear understanding of the factors affecting the households in Central and Southern Punjab and will be in a position to develop and enact programs that would be relevant to the ones facing such challenges. By attending to the effects of socioeconomic status and area of residence, the study will provide a better avenue for diagnosing energy poverty comprehensively. Thus, it will foster an excellent balance in development outcomes and help advance similar objectives of Pakistan to meet SDG 7 and several other related goals in development.

The current study fills a significant gap concerning the relationship between SES, place of living, and HEVP in CSP and Sindh, Pakistan. The study is expected to advance the knowledge database and facilitate the fight against energy poverty, thus enhancing the region's sustainable development.

2. Literature Review

Energy poverty in the household has become a significant concern across the developing regions, bearing the brunt in almost all life and human health sectors. Differences in energy distribution by region, state, socioeconomic status, and area of residence might explain the differences noted in Central and Southern Punjab in excess energy. Energy poverty, or energy insecurity, refers to the challenge people face in providing their households with sufficient and affordable energy. It has attracted much attention in the recent past because of its significant impacts on the processes of social and economic development.

Extensive literature has been published on identifying the incidence and causes of energy poverty, especially in developing countries due to their inability to afford modern energy.

Khandker et al. (2010) investigated energy poverty in India, focusing on the differences between rural and urban regions. Their research indicated that most energy-poor households in rural areas are not income-poor, leading to recommendations for policies promoting modern cooking methods and rural electrification.

Where urban and industrial development had accelerated more in Central Punjab, the proportion of people affected by energy poverty is lesser in that area. (Khalid, Samargandi, Shah, & Almandeel, 2019) their study states that households in Lahore and Faisalabad have better access and availability of steady electricity and gas supply because those centres are more developed in energy storage and the population is more affluent. This access is associated with better employment opportunities in energy-suckering industries and more municipal capital invested in energy facilities. On the other hand, Southern Punjab, defined by its rural geography and relatively low level of human capital, has severe energy deprivation. According to (Zahra Naqvi, Shahzad, Haider Naqvi, Ayub, & Tanveer, 2024), rural households in districts such as Bahawalpur and Multan suffer regular power cuts, and they do not have a constant supply of clean cooking fuels since Pakistan provinces, especially rural ones, do not receive the same care as urban ones.

Moreover, in the framework of the SES, energy poverty remains the primary concern regarding its level. Households within these regions that earn higher income show lower levels of energy poverty due to a capacity to afford other energy sources and backup systems during a power blackout. However, Jiang et al. (2020) found that electricity use is low among low-income households, particularly those in rural Southern Punjab, which employed inefficient biomass and other energy sources, deepening energy poverty.

The type of residence also differentiates energy poverty, although users living in urban areas are reported to have better energy access than those in rural areas. Introducing Energy Security in Urban Central Punjab: Jabeen and his team of researchers proposed that a modern integrated urban energy policy will enhance energy security in the region. However, in regions without significant urbanization in Southern Punjab, there are no such policies to reduce energy poverty (Shafiullah & Rahman, 2021).

Dogan, Madaleno, and Taskin (2021) examined the effects of Financial Inclusion on Energy Poverty in Turkey. They determined that financial inclusion diminishes energy poverty by fifty percent, as demonstrated by a study of the observed impacts, particularly an enhancement in the quality of life for female-headed households. Indeed, this study implies that enhancing the use of financial services can be a good approach in the fight against energy poverty.

Nuryitmawan (2021) work was on the effect of credit on multidimensional poverty in rural Indonesia, especially in agriculture. Therefore, the study supports the idea of credit programs for poverty reduction, especially among poor farmer households, noting the importance of financial means in such occurrences and positing that the type of credit programs could be expanded to other areas.

Khundi-Mkomba, Saha, and Wali (2021) also tested an inter-indicator analytical approach for determining energy poverty in Rwanda. They adopted a multidimensional analysis and a modified expenditure-based method; they realized the worst-off households were from the rural regions. The research is a reminder of energy poverty and that the solutions must be tailored according to the regions in question.

Awan, Bilgili, and Rahut (2022) analyzed Pakistan's energy poverty trends and their causes in light of a cross-section of quantitative data collected from eight waves of the HIES from 1998 to 2019. The authors noted that energy deprivation has escalated in the last two decades despite some level of economic development. From their study employing the Probit model, the above authors noted that the likelihood of energy poverty is higher in countries with fewer endowments, low education, and headed by females. Such evidence highlights the difficulty of attaining Pakistan's development goal of contributing to SDG 7, which is to target affordable and clean energy provision by the year 2030, thereby indicating the necessity of developing specific programs in clean energy for underprivileged groups.

Abbas et al. (2022) analyzed the South Asian countries' household-level multidimensional energy poverty indices of 674,834 households. They used an MEPI index adjusted for the analysis and a Tobit model to discover that factors like the size of the house, the level of household wealth, education levels, and the job status of the head of the household all affect energy poverty. From their studies, they infer that a rise in socioeconomic status is essential for reducing energy poverty and, therefore, presents very useful information in formulating policies.

Oktaviani and Hartono (2022) selected Indonesia to examine how energy poverty affects education. They established the inverted U-shaped association between energy poverty and the mean number of years spent in school by employing a two-layer structural equation modelling (SLS) technique with the set of regional features serving as an instrumental variable. This study expands the understanding of the effects of energy poverty and further indicates that it goes beyond current energy use for a household and reaches educational outputs that will keep the cycle of poverty going on for the entire dependent family as long as they are registered at the school.

On energy poverty, a clean heating program in rural China was examined by Xie et al. (2022). From this, they established that while phasing out coal and opting for electricity and natural gas, the energy cost charge on households went up despite the subsidies. The effect was far-reaching, especially in the less developed regions and the low-income groups, a fact that should inform policymakers to ensure that they provide policies that address the disparity in development between the energy-rich and the energy-poor.

Hasanujzaman and Omar (2022) conducted a study in Bangladesh to examine the socioeconomic factors associated with the HEPP and HIHP. They used Multilevel logistic regression analysis for their investigation. Their study said that identifying income, education, and residence in urban areas decreases energy poverty. In addition, the gender of the person in charge of the family and the geographical location within the country, which is determined by the distance from the division's headquarters, contribute to an increase in energy poverty. The results of this study point to the necessity of developing specialized methods that consider the differences between households and areas.

Chen and Feng (2022) identified a correlation between housing conditions and energy poverty in China, demonstrating that those living in substandard housing are more susceptible to energy poverty. This paper implies that upgrading housing standards and enhancing energy installations can help alleviate energy poverty to a large extent; for this reason, housing policies are critical in eradicating energy badgers. Hosan, Rahman, Karmaker, Chapman, and Saha (2023) examined the impact of remittances on multidimensional energy poverty in Bangladesh. The findings indicate that remittance money significantly reduces energy poverty, suggesting financial transfers from migrants might alleviate energy deprivation in underdeveloped nations.

Jiang, Shi, Feng, and Yan (2024) examined the impact of energy poverty in the case of Guangzhou, China. According to their research, both young and older adults are more energy-poor, meaning there is a U-shaped curve relating to age. It thus points out the need to account for demographic characteristics in energy poverty studies, especially in age differences, which were evidently impactful within urban settings.

Ren, Kuang, and Klein (2024) examined the disparity in wealth between urban and rural areas and its impact on rural energy poverty in China. Rural energy poverty escalates with income inequality, and financial development exerts a substantial impact. Consequently, it is essential to establish synergy between policy programs to eliminate the income disparity and those intended to improve access to credit to address energy poverty.

The literature review demonstrates that this issue is multifaceted and contingent upon the nation's economic, demographic, geographical, and policy attributes. Research literature addressing these factors' interaction and cumulative impact on energy poverty is limited, particularly in the context of Central and Southern Punjab, which features diverse socioeconomic settings. Prior research often focuses on particular variables or geographic regions, limiting the generalizability and comprehensiveness of the findings.

This research examines the prevalence of energy poverty in Central and Southern Punjab, focusing on the respondents' socioeconomic status and geographical location. This work addresses the identified gap in the existing literature and provides essential insights for policymakers and stakeholders. This analysis will facilitate the development of effective strategies to eliminate energy poverty and promote sustainable development in the region.

3. Data and Methodology

3.1. Data Source

The data used for analysis in this research study is collected from the Pakistan Demographic and Health Survey (PDHS) 2017-18. The PDHS 2017-18 is the most recent available, nationally representative, and comprehensive survey based on the household sampling frame. It gives quite specific data at the household level on different demographics and some health and socioeconomic characteristics.

3.2. The Study Area

The present study attempts to identify the factors affecting the management of two different zones in Punjab, Pakistan. The above household data of the Sahiwal division is for Central Punjab, and the household data of the Bahawalpur division is for Southern Punjab.

3.3. Model Specification

The relationship between a household's multidimensional energy poverty and various socioeconomic and demographic factors is modelled as follows:

$$MEP\ Status\ of\ Household = f\ (Age\ of\ Household\ Head, Gender\ of\ Household\ Head, Educational\ Attainment\ of\ Household\ Head, Ownership\ of\ Land\ Usable\ for\ Agriculture, Household's\ Wealth\ Status, Type\ of\ Place\ of\ Residence) \quad (1)$$

Briefly, we can write the functional form as:

$$ME\_POV = f\ (AGE\_HH, GEN\_HH, EDU\_HH, OWN\_AL, HH\_WS, AREA) \quad (2)$$

3.4. Description of the Variables

The variables used in the model are described in the table below:

Table 1
Description of the Variables

Variables	Abbreviation	Description of the Variable
MEP Status of Household	ME_POV	The household's position in terms of multidimensional energy poverty (MEP): ME poor = 1, ME non-poor = 0
Age of Household Head	AGE_HH	The age of the household head is categorized as follows: Below 30 years = 1, 30 to 60 years = 2, over 60 years = 3
Gender of Household Head	GEN_HH	Gender of the household head: male = 1, female = 2
Educational Attainment of Household Head	EDU_HH	No education = 0, incomplete primary = 1, complete primary = 2, incomplete secondary =3, complete secondary = 4, higher = 5
Ownership of Land Usable for Agriculture	OWN_AL	Owning land usable for agriculture: No = 0, yes = 1
Household's Wealth Status	HH_WS	Poorest = 1, poorer = 2, middle = 3, richer = 4, richest = 5
Type of Place of Residence	AREA	Urban area = 1, rural area = 2

The Multidimensional Energy Poverty Status of Household (ME_POV) denotes the dependent variable under investigation, reflecting a household's condition regarding Multidimensional Energy Poverty (MEP). This variable is a binary indicator that differentiates households with M.E. low status, with a value of 1, from those without, assigned a value of 0. Consequently, the classification is highly advantageous in determining the extent of energy hardship in the studied areas.

Age of Household Head (AGE_HH): Among the demographic variables is the age of the household head. This is divided into three subgroups: individuals under thirty, those aged thirty to sixty, and those over sixty. This variable highlights the impact of the head of household's age on the household's energy poverty status relative to age.

The gender of the household head (GEN_HH) is represented as a dummy variable, with male heads coded as '1' and female heads coded as '2'. This variable facilitates the examination of gender inequality in household energy poverty, enhancing comprehension of the positions of male- or female-headed households regarding energy poverty.

Educational Attainment of the Household Head (EDU_HH): The educational attainment of the household head is categorized into six groups: no education, incomplete primary education, completed primary education, incomplete secondary education, completed secondary education, and tertiary education or above. Integrating this variable enhances the examination of education's role in alleviating energy poverty, as elevated educational attainment correlates with improved access to energy resources.

Ownership of Land Usable for Agriculture (OWN_AL): This is a dummy variable that captures the aspect of land that would be useful in a household owning agricultural land. This has a value of 1 if the respondent has agricultural land; otherwise, it has a value of 0. Having agricultural land is a valuable property, which means it can be another funding source and improved living standards to help fight energy poverty.

Household's Wealth Status (HH_WS): The household / Person is categorized into five wealth status brackets: the poorest, poorer, middle, more prosperous, and the richest. This variable goes a long way in that it assists in the disaggregation of the economic component of energy poverty, given that higher-wealth households are expected to attain better access to energy services than poorer households.

Type of Place of Residence (AREA): The type of residence is binary, either an urban area or a rural area. This variable is crucial for pointing out the areas of concentration of energy poverty since the problem tends to be heavier in rural areas, and the households in those regions have limited access to affordable energy compared to their urban counterparts.

Table 1
MEP Index: Dimensions, Indicators, Deprivation Cut-offs, and Relative Weights (as Defined by Nussbaumer, Bazilian, and Modi (2012))

No.	Dimensions	Indicators	Deprivation Threshold (Energy impoverished if ...)	Relative Weights
1	Cooking	Modern cooking fuel	Utilizing any fuel except electricity, liquid petroleum gas, kerosene, natural gas, or biogas	0.2
		Indoor pollution	Indoors, using any fuel other than electricity, LPG, kerosene, natural gas, or biogas when cooking on a stove or open fire (without a hood or chimney)	0.2
2	Lighting	Electricity access	Lacks access to electricity	0.2
3	Services rendered through domestic appliances	Ownership of household appliances	Does not possess a refrigerator	0.133
4	Entertainment /education	Entertainment/education appliance ownership	Has NO radio OR television	0.133
5	Communi-cation	Telecommunication means	Has NO landline OR mobile phone	0.133
Total Weight				1

3.5. Estimation Techniques

Household multidimensional energy poverty and the numerous independent variables are examined using two basic estimate techniques: The data obtained from the respondents will be evaluated utilizing descriptive statistics and binary logistic regression.

3.6. Descriptive Statistics

Percentages are used to present the data and describe the general pattern of the various categories of the variables concerning the number of households.

3.7. Binary Logistic Regression

The probability of a household encountering energy poverty can be assessed by computing the odds ratios of the independent variables through a binary logistic regression analysis. This technique assists in assessing the magnitude and direction of the association between each predictor variable and the dependent variable, precisely the MEP status of the household. The Binary Logistic Regression model produces coefficients (Beta), standard errors (S. E.), p-values, and odds ratios for all independent variables. The model's utility is evaluated using -2 Log Likelihood, Cox & Snell R Square, and Nagelkerke R Square metrics. These statistics are employed to verify the model's suitability in representing the energy poverty status of families and the significance of the predictors in assessing this status.

This research aims to employ the methodologies above to examine the determinants contributing to energy poverty in households in Central and Southern Punjab and identify the most significant socioeconomic and demographic factors influencing energy poverty status in these regions.

4. Results And Discussion

Table 3
Spearman's Correlation Matrix for Central Punjab

Spearman's Correlation Matrix	MEP Status of Household	Age of Household Head	Sex of head of household	Educational attainment	Owns land usable for agriculture	Wealth index combined	Type of place of residence
MEP Status of Household	1.000	-.002	.005	-.165**	.091**	-.663**	.577**
Age of Household Head	-.002	1.000	.022	.041	.120**	.125**	.004
Sex of head of household	.005	.022	1.000	-.019	-.006	-.043	.009
Educational attainment	-.165**	.041	-.019	1.000	.083**	.303**	-.131**
Owns land usable for agriculture	.091**	.120**	-.006	.083**	1.000	.106**	.300**
Wealth index combined	-.663**	.125**	-.043	.303**	.106**	1.000	-.521**
Type of place of residence	.577**	.004	.009	-.131**	.300**	-.521**	1.000

**: The correlation demonstrates statistical significance at the 0.01 level (two-tailed).
*: The correlation demonstrates statistical significance at the 0.05 level (two-tailed).

4.1. Correlation Matrix for Central Punjab

The Spearman's correlation matrix for Central Punjab illustrates the relationships and trends between household MEP status and various socioeconomic indicators. The coefficient for the age of the household head is notably low and negative (-0.002), indicating no relationship with MEP status. The gender of the household head exhibits a weak positive correlation with MEP status, r=0.005. Therefore, it can be concluded that there is no relationship between gender and MEP status. A significant negative correlation (-0.165**) exists between the educational attainment of the household head and MEP, indicating that greater educational attainment is linked to a lower MEP status (reduced energy poverty). A significant positive correlation (0.091**) exists between households' agricultural land ownership status and MEP, suggesting that households with agricultural land ownership are marginally more likely to encounter energy poverty.

Table 4
Spearman's Correlation Matrix for Southern Punjab

Spearman's Correlation Matrix	MEP Status of Household	Age of Household Head	Sex of head of household	Educational attainment	Owns land usable for agriculture	Wealth index combined	Type of place of residence
MEP Status of Household	1.000	-.062**	.091**	-.310**	.036	-.693**	.621**
Age of Household Head	-.062**	1.000	-.157**	.028	.144**	.070**	-.062**
Sex of head of household	.091**	-.157**	1.000	-.043*	-.114**	-.067**	-.007
Educational attainment	-.310**	.028	-.043*	1.000	.029	.405**	-.293**
Owns land usable for agriculture	.036	.144**	-.114**	.029	1.000	-.060**	.381**
Wealth index combined	-.693**	.070**	-.067**	.405**	-.060**	1.000	-.639**
Type of place of residence	.621**	-.062**	-.007	-.293**	.381**	-.639**	1.000

**: The correlation demonstrates statistical significance at the 0.01 level (two-tailed).
*: The correlation demonstrates statistical significance at the 0.05 level (two-tailed).

A significant negative correlation of -0.663** exists between household wealth status and MEP, indicating that wealthier households are less likely to experience energy poverty. A significant positive correlation (0.577**) exists between the type of place of residence and MEP, suggesting that households in rural areas are more prone to experiencing energy poverty.

4.2. Correlation Matrix for Southern Punjab

The Spearman correlation matrix for Southern Punjab illustrates the relationships between households' Multidimensional Energy Poverty (MEP) status and various socioeconomic factors.

A weak, significant negative correlation (-0.062**) exists between the age of the household head and MEP, indicating that younger household heads are marginally more prone to energy poverty. A weak significant positive correlation (0.091**) exists between the gender of the household head and MEP, suggesting that households led by males are marginally more prone to energy poverty. A significant negative correlation (-0.310**) exists between the educational attainment of the household head and MEP, indicating that greater educational attainment correlates with a lower MEP status (reduced energy poverty). The relationship between agricultural land ownership status and MEP is weakly positive (0.036), suggesting an absence of a significant correlation between land ownership and MEP status. A significant negative correlation (-0.693**) exists between household wealth status and MEP, indicating that wealthier households are less likely to experience energy poverty. A statistically significant positive correlation (0.621**) exists between habitation type and MEP, indicating that households in rural areas are more likely to experience energy poverty.

4.3. Descriptive Statistics

Table 5
Household Energy Poverty, Socioeconomic Status, and Area of Residence in Central Punjab

Variable	Category	Percent
Multiple Dimensions of a Household's Energy Poverty	Multidimensional Energy Non-Poor	45.6
	Multidimensional Energy Poor	54.4
Age of Household Head	below 30 years	9.6
	30 to 60 years	73.5
	above 60	16.9
Sex of Head of Household	Male	92.8
	Female	7.2
Educational Attainment of Head of Household	No education	51.9
	Incomplete primary	14.1
	Complete primary	9.3
	Incomplete Secondary	13.3
	Complete secondary	5.0
	Higher	6.4
Ownership of Land Usable for Agriculture	No	73.0
	Yes	27.0
Household's Wealth Status	Poorest	17.0
	Poorer	25.0
	Middle	20.3
	Richer	26.5
	Richest	11.2
Type of Place of Residence	Urban	26.5
	Rural	73.5

4.4. Household Energy Poverty, Socioeconomic Status, and Area of Residence in Central Punjab: Descriptive Statistics

Central Punjab's energy poverty, socioeconomic status, and residential area breakdown are in the descriptive statistics table. Regarding the multidimensional energy poverty status of households, 45.6% are not experiencing energy poverty, while 54.4% of households are experiencing energy poverty, indicating that in Central Punjab, slightly more than half of the households are energy poor. Concerning the age of household heads, 9.6% of household heads are below 30 years old, 73.5% of household heads are between 30 and 60 years old, and 16.9% of household heads are above 60 years old. In central Punjab, 92.8% of households are headed by males and 7.2% by females. Nearly 52% of household heads have no education, 14.1% have incomplete primary education, 9.3% have complete primary education, 13.3% have incomplete secondary education, 5.0% have completed secondary education, and 6.4% have higher education. Most households do not own land for agriculture. Only 27.0% of households own land usable for agriculture. Regarding household wealth status, 17.0%, 25.0%, 20.3%, 26.5%, and 11.2% of households fall into, respectively, the poorest, the poorer, the middle, the richer, and the wealthiest category. Most (73.5%) households reside in rural areas, and only 26.5% live in urban areas.

Table 6
Household Energy Poverty, Socioeconomic Status, and Area of Residence in Southern Punjab

Variable	Category	Percent
Multidimensional Energy Poverty Status of Household	Multidimensional Energy Non-Poor	46.0
	Multidimensional Energy Poor	54.0
Age of Household Head	below 30 years	7.6
	30 to 60 years	73.3
	above 60	19.1
Sex of Head of Household	Male	91.1
	Female	8.9
Educational Attainment of Head of Household	No education	57.1
	Incomplete primary	13.6
	Complete primary	7.6
	Incomplete Secondary	10.1
	Complete secondary	5.8
	Higher	5.7
Ownership of Land Usable for Agriculture	No	56.5
	Yes	43.5
Household's Wealth Status	Poorest	19.0
	Poorer	29.2
	Middle	23.6
	Richer	14.9
	Richest	13.2
Type of Place of Residence	Urban	30.0
	Rural	70.0

4.5. Household Energy Poverty, Socioeconomic Status, and Area of Residence in Southern Punjab: Descriptive Statistics

The descriptive statistics table comprehensively summarises household energy poverty, socioeconomic conditions, and geographical location in Southern Punjab. The descriptive statistics show that, like Central Punjab, slightly more than half (54%) of the households in Southern Punjab are energy-poor. Most household heads are in the 30 to 60 age group (73.3%), with a slightly higher proportion of older household heads (compared to Central Punjab). Also, 7.6% of household heads are below 30 years old, and 19.1% are above 60 years old. Most households are male-headed (91.1%), with a slightly higher proportion of female-headed households than in Central Punjab. Respectively, 57.1%, 13.6%, 7.6%, 10.1%, 5.8%, and 5.7% of household heads have no education, incomplete primary, complete primary, incomplete secondary, complete secondary, and higher education in southern Punjab. A more significant proportion of households (43.5%) own agricultural land than Central Punjab. Concerning wealth status, 19%, 29.2%, 23.6%, 14.9%, and 13.2% of households in southern Punjab belonged to the poorest, the poorer, the middle-income, the richer, and the wealthiest categories, respectively. With a slightly higher proportion of urban households than Central Punjab, most households reside in rural areas.

4.6. Binary Logistic Regression Estimates

Table 7
Household Energy Poverty, Socioeconomic Status, and Area of Residence in Central Punjab: Binary Logistic Regression Estimates

Variable	Beta	S.E.	*p*-Value	Odds Ratios
Household Head's Age (above 60 years®)			.001	
Household Head's Age below 30 years	-1.340	.356	.000	.262
Household Head's Age 30 to 60 years	-.256	.214	.231	.774
Male Gender of Household Head (Female®)	.481	.310	.121	1.618
Household Head's Educational Status (Higher®)			.630	
No education	.225	.373	.546	1.253
Incomplete primary	.346	.418	.408	1.413
Complete primary	.618	.447	.167	1.855
Incomplete Secondary	.510	.412	.216	1.665
Complete secondary	.401	.509	.431	1.493
Not Owning Land Usable for Agriculture (Own land®)	-.570	.198	.004	.566
Household's Wealth Status (Richest®)			.000	
Poorest	5.715	.516	.000	303.386
Poorer	4.661	.443	.000	105.697
Middle	2.991	.412	.000	19.914
Richer	1.926	.416	.000	6.863
Urban (Rural®)	-2.144	.261	.000	.117
Constant	-2.576	.575	.000	.076
® represents the reference category				
Model Summary				
-2 Log likelihood	968.154			
Cox & Snell R Square	.478			
Nagelkerke R Square	.639			

4.7. Socioeconomic & Demographic Factors and MEP in Central Punjab: Binary Logistic Regression Estimates

The binary logistic regression estimates provide insights into the relationship between household multidimensional energy poverty and various socioeconomic and demographic factors in Central Punjab.

Household heads under 30 are less likely to experience energy poverty than those over 60. The probability of experiencing energy poverty diminishes by around 74% (1 - 0.262) for homes led by individuals under 30. Household heads aged 30 to 60 are less susceptible to energy poverty than those over 60. This association is statistically insignificant. Male-headed households exhibit a greater likelihood of experiencing energy poverty than female-headed households; nevertheless, this finding lacks statistical significance. Household heads with lower educational attainment have a greater likelihood of experiencing energy poverty compared to their counterparts with higher education. Nevertheless, none of these associations exhibit statistical significance. Households lacking agricultural land ownership are far less prone to energy poverty than those with land ownership (Dogan et al., 2021; Hasanujzaman & Omar, 2022; Jiang et al., 2024; Mohammad, 2015).

Households that do not own land have a probability of experiencing energy poverty that is approximately 43 percent lower than households that own land (1 - 0.566). While households in the most disadvantaged category are significantly more likely to be energy-poor, households in the wealthiest category are significantly less likely to be energy-poor. When it comes to homes struggling to make ends meet, the likelihood of experiencing energy poverty is exceptionally high. Those households who fall into the category of having a lower income are significantly more likely to be energy-poor when compared to those households that have the highest income. A greater probability of experiencing energy poverty is also associated with economically disadvantaged homes.

Compared to the households with the highest levels of wealth, those that fall into the median category are far more likely to have low energy consumption levels. The likelihood of households with a middle-income level falling into the category of energy poverty is relatively high. Compared to the wealthiest homes, households that fall into the wealthier category have a significantly higher probability of being energy-poor. However, this is to a lesser extent than the households that fall into the middle-income and lower-income categories. Compared to households in rural locations, those in metropolitan areas have a far lower likelihood of being deficient in energy. There is a reduction of around 88 percent (1 - 0.117) in the likelihood of low home energy consumption for urban households (Khandker et al., 2010; Ren et al., 2024).

The constant term signifies the reference categories' baseline log chances of energy poverty. The Log Likelihood number reflects the model's fit, with lower values indicating superior fit. The Cox & Snell pseudo-R square score of 0.478 signifies that the model elucidates about 47.8% of the variation in the dependent variable. The Nagelkerke pseudo-R-squared score of 0.639 indicates that the model accounts for about 63.9% of the variation in the dependent variable.

The binary logistic regression findings indicate that many socioeconomic factors significantly affect family energy poverty in Central Punjab. Young household heads and urban residents are less prone to energy poverty. The wealth status of a household is a robust predictor of multidimensional energy poverty, with economically disadvantaged households exhibiting markedly higher probabilities of experiencing energy poverty than affluent ones. The ownership status of agricultural land among households influences energy poverty, as landowners are less prone to experience it. Educational achievement and the gender of the household head have demonstrated some impact; nonetheless, the results lack statistical significance.

4.8. Socioeconomic & Demographic Factors and MEP in Southern Punjab: Binary Logistic Regression Estimates

The binary logistic regression estimates reveal the connections between household energy poverty (dependent variable) and a range of socioeconomic and demographic factors (independent variables) in Southern Punjab.

Compared to households led by individuals over the age of 60, those with heads under 30 exhibit a higher likelihood of experiencing energy poverty; however, this association does not achieve statistical significance. Household heads aged 30 to 60 experience a significantly lower likelihood of living in poverty due to energy access issues compared to those over 60. The likelihood of experiencing energy poverty decreases by approximately 42% (1 - 0.580) for households led by individuals aged 30 to 60. Households led by males exhibit a markedly lower likelihood of experiencing energy poverty than females. The likelihood of experiencing energy poverty decreases by approximately 64% (1 - 0.360) for households led by males. (Adusah-Poku, Adams, & Adjei-Mantey, 2023; Feenstra & Clancy, 2020; Ngarava, Zhou, Ningi, Chari, & Mdiya, 2022; Tandrayen-Ragoobur, 2024).

Table 8
Household Energy Poverty, Socioeconomic Status, and Area of Residence in Southern Punjab: Binary Logistic Regression Estimates

Variable	**Beta**	**S.E.**	***p*-Value**	**Odds Ratios**
Household Head's Age (above 60 years®)			.001	
Household Head's Age below 30 years	.488	.403	.227	1.628
Household Head's Age 30 to 60 years	-.544	.178	.002	.580
Male Gender of Household Head (Female®)	-1.021	.289	.000	.360
Household Head's Educational Status (Higher®)			.447	
No education	.634	.387	.102	1.886
Incomplete primary	.783	.413	.058	2.188
Complete primary	.406	.439	.356	1.500
Incomplete Secondary	.503	.424	.236	1.654
Complete secondary	.610	.470	.195	1.840
Not Owning Land Usable for Agriculture (Own land®)	1.251	.167	.000	3.493
Household's Wealth Status (Richest®)			.000	
Poorest	5.236	.492	.000	187.997
Poorer	3.028	.364	.000	20.652
Middle	1.621	.363	.000	5.058
Richer	.888	.387	.022	2.431
Urban (Rural®)	-3.376	.237	.000	.034
Constant	-1.112	.563	.048	.329
® represents the reference category				
Model Summary				
-2 Log likelihood	1435.061			
Cox & Snell R Square	.511			
Nagelkerke R Square	.683			

Individuals leading households with lower educational attainment face an increased likelihood of experiencing energy poverty when contrasted with their higher education counterparts. None of these relationships reach statistical significance, although incomplete primary education is close to significance (p=0.058). Households lacking access to agricultural land exhibit a markedly higher likelihood of experiencing energy poverty than those who possess such land. The likelihood of experiencing energy poverty rises by approximately 249% (3.493 - 1) for households lacking land ownership (Adusah-Poku et al., 2023).

Energy poverty is prevalent among the most disadvantaged households compared to the affluent. Low-income families face a notably high risk of encountering energy poverty. Energy poverty is prevalent in low-income households compared to their high-income counterparts. Energy poverty is prevalent in households with limited financial resources. Energy poverty is more prevalent among middle-class households than among the wealthiest. Households within the intermediate income range tend to face a higher likelihood of encountering energy poverty. While energy poverty is more frequently observed in wealthier households, it is less common among those with low- and middle-income levels. Urban households exhibit a significantly lower likelihood of experiencing energy poverty compared to their rural counterparts. Residing in an urban environment significantly reduces a household's likelihood of experiencing energy poverty by approximately 96.6% (1 - 0.034) (Khandker et al., 2010; Ren et al., 2024).

The constant term indicates the baseline log odds of experiencing energy poverty for the reference categories. The Cox & Snell pseudo-R square value of 0.511 suggests that the model accounts for around 51.1% of the variation in the dependent variable. The Nagelkerke pseudo-R square value of 0.683 indicates that the model accounts for around 68.3% of the variation in the dependent variable.

5. Conclusion and Policy Recommendations

Thus, this research aims to identify the factors influencing household energy poverty in Central and Southern Punjab. The study establishes that the educational level of the household head, the household's wealth status, and the type of place of residence are determinants of energy poverty. The results also show that access to higher education and better wealth status significantly reduce the probability of energy poverty. On the other hand, users who live in rural households are more likely to be in the energy poverty bracket. These findings stress that inequality in education and economic status should be targeted to reduce energy poverty. Also, more focused measures are required to advance energy accessibility in rural regions and decrease the differences between them and urban areas.

To these concerns, it is suggested that more emphasis should be placed on education, especially for the head of households, by providing more funds for educational programs, especially in rural areas. Education is also central to addressing energy poverty as it helps acquire employment and income. Thus, the necessity of adopting measures to improve the economic position of households, including microcredit, vocational education, and support for small businesses, especially for the lowest population stratum, should be noted. In addition, the policies to be created and advertised for improving energy accessibility in rural areas, including the extension of the electricity network, the usage of renewable sources of energy, and the subsidies for modern forms of cooking fuels, should also be developed. To decrease the energy poverty of female-headed households, it is necessary to consider the problems they face carefully and offer extraordinary support, such as monetary and social services. Supporting the ownership of land and efficient use of agricultural land through policy and incentives can reduce energy poverty by providing more resources and income. Last, developing an overall energy policy that would cover all the aspects of energy poverty as it has been discussed in this work, regarding the socioeconomic and demographic characteristics of the households in Central and Southern Punjab that were pointed out in this study, is the key to the further development of the equitable access to energy resources and the increase in the living standards of the inhabitants of the region.

Authors' Contribution

Muhammad Zahid Malik: Conceived the study, designed the methodology, and supervised the research process.
Tyiba Noureen: Conducted data collection and analysis.
Abid Mehmood: Assisted in literature review and statistical analysis.

Tauqir Ahmad Ghauri: Contributed to the interpretation of results and manuscript writing.

Conflict of Interests/Disclosures

The authors declared no potential conflict of interest w.r.t the research, authorship and/or publication of this article.

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