IJEMD-SS, 5 (5) (2026) https://doi.org/10.54938/ijemd-ss.2026.05.5.888

International Journal of Emerging Multidisciplinaries: Social Science

Research Paper
Journal Homepage: www.ojs.ijemd.com
ISSN (Online): 2958-0277



Financial Inclusion and Energy Poverty: Empirical Evidence from a Household Survey in Pakistan

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Abstract

Energy poverty represents an important dimension of household welfare, particularly in developing economies where energy expenditures can constrain the resources available for other essential needs. This study examines the relationship between financial inclusion and after-fuel-cost energy poverty (AFCP) in Pakistan using nationally representative HIES 2018–19 household-

level data. The study measures energy poverty through the after-fuel-cost approach and develops a composite financial inclusion index using a two-stage Principal Component Analysis. Given the binary nature of AFCP and the potential endogeneity of financial inclusion, the empirical analysis employs OLS, Probit, 2SLS, and IV-Probit models. The results indicate considerable variation in AFCP across Pakistan, with the incidence differing between rural and urban households and across provinces. The empirical findings consistently show a negative association between financial inclusion and AFCP, while the relationship becomes considerably stronger after accounting for endogeneity through instrumental-variable estimation. The findings suggest that access to formal financial services can strengthen households' economic capacity to manage energy expenditures and reduce vulnerability to energy affordability constraints.

Keywords: Energy poverty, Financial inclusion, After-fuel-cost approach, Instrumental variable estimation, Pakistan

1. Background

The importance of energy particularly, electricity as a means of development, can be traced back to the second wave of industrial revolution. The provision of energy has contributing, since long, to speeding up of productivity and accruing welfare to the socioeconomic conditions of the people across the globe. It is considered that increase in productivity and efficiency, reduction in pollution, and health improvement are some of the fruits of provision of modern energy according to the United Nations (UN, 1954) and these attributes of energy provisions are linked with the concepts of energy poverty that further is reported to get consistence with the economic levels of people across the globe (Che et al., 2021).

The energy related issues including, energy poverty (EP), got importance in the development initiatives of designing effective energy policies in both the developed and developing countries

of the world (Primc et al., 2019). The study of Sagar (2005) has considered alleviation of energy poverty to uplift the poor from the miseries of poverty and underdevelopment. The global pictured on energy poverty is pioneered by the reports of the World Bank (1985) in discussion on the firewood scarcity and rural poverty are authenticated in the renewable energy poverty nexus in the literature (UNDP, 2007; Zhao et al., 2022). Similarly, the Asian Development Bank (2010) has also explored energy poverty in the context of access to modern energy services in developing Asia. Therefore, the UN (2014) has declared the years from 2014 – 24 as the decade of sustainable energy for all, to likely reduce the probability of energy poverty.

The concept of energy poverty is sparked from the development of fuel poverty in discussion from the 1970s oil crisis. Despite the then increasing interest in these issues, there exists no integrated framework or understanding on energy poverty, with one exception that only the UK has official energy poverty measurement started in the early 1980s. In this context, the literature shows first study of Bradshaw and Hutton (1983) that was further explored by Boardman (1991), who defined energy poverty as if a household (HH) spends more than 10% of its total income on energy services/acquisition. Although the ten percent measure was originally developed in the UK, and are fundamentally expenditure-based indicators designed to assess the affordability of household energy consumption. In this study, After Fuel Cost Energy Poverty (AFCP) in relation with Financial Inclusion (FI) is used in the context of Pakistan by utilizing nationally representative HIES 2018-19 house household expenditure data and incorporating household energy expenditure patterns.

This study makes few contributions in existing literature on energy poverty and financial inclusion nexus. First, the study uses energy-expenditure approach to measure EP in rural-urban regions other than MEPI based deprivation approach previously used by Nussbaumer et al. (2013), construct the index of EP using five dimension of EP from the combinations of the cooking,

heating, lighting, household appliances for entertainment or education and means of communications. For this purpose, Hills (2011) to explore the after fuel cost poverty (AFCP).

Secondly, this study construct to link EP and FI statistically by employing the socioeconomic and demographic factors specific to the households in Pakistan. This is the first study to use the mechanism to counter traditionally used, using consumption poverty and household net income identified by (Koomson and Danquah, 2021) in Ghana. Third, this research contributes in the existing literature by converging the focus into developing country like Pakistan, however, it is widely analyzed in developed countries using static cross-sectional data and panel data, but this research uses micro data of HIES for Pakistan at household level.

Forth, empirically, this study uses two stage Principal Component Analysis (2-stage PCA) to construct the index of the financial inclusion for households in Pakistan. The index enhances financial inclusion indices in two ways. (i), the parametric method to avoid the problem of weights assignment to each parameter of the data because the PCA allocate weights to each dimension according to its importance. (ii), this study uses HH level data to construct the FI index, this helps policymakers to get insights at micro level, and therefore, the micro-foundations to national policy processes are justified from the household representative database in Pakistan. Fifth and the most importantly, this study has used two instrumental variables (IVs) as proxy for FI and these are the distance in kilometers to nearest school and, the mobile phone ownership. The literature shows to use the distance in kilometers to school as proxy to nearest bank as proxy for FI but the HIES (2018-19) lacks data on banking sector at household levels in Pakistan. At the time of HIES 2018-19 survey, around 94.14% of HHs use mobile phone facility and have mobile phone ownerships and subscriptions. This depicts that mobile phone ownership is one of the important IV for the FI. The construct and use of IVs as proxy for financial inclusion give justifications and the data of

these two IVs are also counted as contributions of this study in the literature concerned to the nexus between energy poverty and financial inclusions at the HHs levels in Pakistan.

2. Literature Review

The recent waves of higher prices and tariffs of electricity bills for the domestic households are reported as policy concerns for financial intermediaries as well explored by (Abdullah et al., 2025). The study of Ahmad and Jamil (2024) is of the view that power outrage is mostly dependent of energy prices hikes and the probability of non-payment and theft of energy due to volatility in tariff policies in Pakistan. In such circumstances, the questions on integrating the energy prices through the mechanism of financial inclusion are arising to question further the policy processes for not affecting the expenditure function of the households. It is necessary to explore relationships between EP and financial inclusion for devising energy efficient policies to eradicate the negative impacts of expenditure functions of the energy poor populations in developing countries like, Pakistan.

In line with the above arguments, the literature also shows that there are many factors to affect the phenomenon of EP including the financial inclusion and exclusion due to energy price hikes at household levels. The snapshot of the literature in this context shows that there is inverse correlation between EP and financial inclusion (FI) and this sort of association are shown by studies like (Danquah et al., 2017; Koomson & Danquah, 2021; Churchill & Marisetty, 2020; Dogan et al., 2021; Khan et al., 2023) for many countries of the world.

The implications of these studies show that increasing FI may help individual and household out of EP. In case of Pakistan, the literature only relates the hikes of energy prices and tariffs and their implications for the energy outrage and theft due to most of the occurrences of energy crises to further affecting the energy consumption at household levels. These phenomena of energy related

aspects for the household customers give implications for directionless impacts on the billing attachment with financial inclusion aspects in Pakistan.

The literature on relating the EP and FI for the energy consumers other than Pakistan are the studies of Koomson and Danquah (2021) who used multidimensional energy poverty index (MEPI), as pioneered by (Nussbaumer et al., 2013), for the sample size of 22,714 households of a developing country like, Ghana. The study investigates the relationship between energy poverty and financial inclusion and shows it significantly negative linkages. Moreover, the research on how FI influence EP using multi-faceted index of financial inclusion and using 2SLS technique for estimation by (Dogan et al., 2021) in the case of Turkey. The results show that FI is significant and negatively affecting the EP in Turkey using index of FI composed of the saving behavior, credit card ownership, insurance ownership and internet shopping habits of the households in 2018. However, this result is less likely to affect female household heads.

Similarly, Xia et al. (2022) have analyzed FI and EP correlation for China, in the form of fiscal decentralization. The study uses data from first quarter of 2005 to fourth quarter of 2019 using MPEI as index of energy poverty which comprises three dimensions of EP including accessibility, affordability and reliability showing energy demand and supply respectively. Results show that fiscal decentralization worsen EP in the country using dynamic ARDL lag regression as primary analysis method. Thus, advocating the case to further explore the nexus between EP and FI for energy poor households facing the energy crises of outrage, theft, hikes in prices and tariffs, and no regimes of energy pricing policies in countries like, Pakistan.

Theoretically, the literature shows two prominent theories that predict the association between FI and EP, commonly known as energy ladder theory founded by Leach (1992) via the channel of income and energy stacking theory by (Hosier & Dowd, 1987; Masera et al., 2000). The channels of FI are the transfer of money and financial services to experience volatility amid the energy crises

environment that has strong implications for changing the EP conditions of people (Koomson & Danquah, 2021; Nguyen et al., 2021). The concepts of, the after-fuel-cost-poverty (AFCP) is calculable from expenditure share and household budget constraints of the households' overall expenses related to EP due to burden of higher energy costs. The empirical analysis of AFCP in the pre-amble of EP provides substantial findings with financial inclusion as one of the key determinants and the empirical evidence has shown that greater FI leads significantly to reduce the probability of households falling below the AFCP thresholds (Koomson & Danquah, 2021; Widyastuti et a,l. 2023; Kar & Bali Swain, 2024).

Notwithstanding, in today's world EP is a strategic issue, faced by several developing and developed countries, despite its significance, it is hardly explored in the literature. The empirical research on relating the energy poverty and financial inclusion at household level is lacking for Pakistan. Especially, the creation of the index of the two-stages principal component analysis (PCA) derived from the expenditure functions of the households for their FI in better capturing the phenomenon of EP is necessary on energy policy fronts in Pakistan. Similarly, the calculable aspects of the affordability measures of AFCP is not empirically explored in association between EP and FI for countries like, Pakistan. This sort of analysis is necessary for the provision of energy efficient policies in better composing the national development processes of expenditure-based initiatives of enhancing the standards of lives of the households in Pakistan.

3. Methodology and Data

This study uses HIES 2018-19 survey which include data on consumption, income, and other social factors. In addition, this survey collects data on education, ICT, health, population welfare, housing, and food insecurity experience scale. Furthermore, HIES 2018-19 data is collected from 24,809 households in 1802 urban and rural Primary Sampling Units (PSUs) consisting 8873

(35.8%) the number of urban HHs and 15,936 (64.2%) rural HHs. Household Income and Expenditure Survey (HIES) dataset provide valuable insights into household socioeconomic dynamics for energy poverty research.

First, the nationally representative stratified random sampling framework across urban-rural divides and socioeconomic strata allows robust macro and micro energy consumption generalizations. Furthermore, to put the poor on agenda, micro level empirical analysis of the study is necessary, it helps policy makers at macro level. Second, for SDG-7 progress assessment, multidimensional energy poverty indices that integrate accessibility, affordability, and reliability metrics are possible with this granularity. Its compatibility with national accounts frameworks makes it useful for calibrating macroeconomic models of energy subsidy impacts and household fuel combustion carbon emission trajectories.

3.1. Measures of Energy Poverty

The objective of the United Nations SGDs – 7 is ending energy poverty by providing access to sustainable, affordable, reliable and modern energy for all. Moreover, SDG – 7 addresses EP in all forms including access to and affordability which requires the HH level analysis in Pakistan based on income and expenditure surveys. Therefore this study uses after fuel cost energy poverty (AFCP) approach of EP in the case of Pakistan at HH levels.

3.2. After Fuel Cost Poverty Energy Poverty

Hills (2011) explored after fuel cost poverty (AFCP) approach for UK which determines fuel poverty by determining if a representative HH residual income below a poverty threshold after domestic fuel costs. Moreover, in the present study, fuel consumption refers only to fuels used for household energy purposes including LPG, kerosene, coal firewood, electricity and dung cake for cooking, heating, and lighting fuels. However, transportation fuels such as diesel, petrol and CNG

are not included in the fuel expenditure measures. This definition of EP is consistent with the (HIES 2018-19) classification of HH energy consumption expenditure. This approach generally asks, after a HH pays for its energy costs, does it fall below the general poverty line? This method directly links EP to monetary poverty by focusing on the financial resources available for other essential needs after energy costs are met. After paying for energy services, a household is fuel poor if its remaining income is insufficient to maintain a minimum standard of living.

To measure after fuel cost energy poverty this study has used Iqbal (2020) poverty line per adult equivalent per month for Pakistan. This poverty line is constructed using HIES (2018-19) at national level per adult equitant per month. The study has converted it into OECD (2024) Equivalence Scale, which is used to account for differences in HH size and composition. Under this scale, a weight of 1.0 is assigned to the first adult household member, 0.5 to each additional household member age 14 and above, and 0.3 to each child below 14 years of age, and multiplied by 12 to get annual poverty line per adult equivalent. Now if an individual after paying for energy cost, the remaining income less than Z (threshold poverty line), is considered energy poor.

$$EP_{AFCP} = 1, if\ Y_i - E_i < Z$$

$$0, otherwise$$

3.3. Financial Inclusion

Literature show that poverty reduction goes beyond income poverty because it is multidimensional approach as explored by (Banerjee et al., 2015). However, this study examines how FI affects EP at HH levels in Pakistan. FI reduces EP by improving family income and education, it helps to improve energy efficiency. FI affects EP through the channel of HHs income, poverty and income inequality explained by (Koomson & Danquah, 2021). In the literature there exist multidimensional definitions of EP and different indicators of FI, consequently, there is lack of

unanimous consensus on a unique and single definition of FI. These differences also stems from data variability in different countries. For example, (Koomson and Danquah, 2021) explained four dimensions of FI mobile or ownership of money banking account, access to credit/loan, insurance and receipts from remittances through baking or mobile money in Ghana. These dimensions are in line with (Zhang and Posso, 2019; Koomson et al., 2020a; Koomson et al., 2020b). Moreover (Dogan et al., 2021) used four dimensions of FI- saving behavior of HHs, credit card, insurance ownership and online internet shopping in Turkey consistent with (Churchill & Marisetty, 2020).

All the studies in the literature have assigned 0.25 equal weights to each dimension. In China, (Yu and Tang, 2023) used four indicators of FI- account with age greater than 15, financial institutions account with age greater than 15, credit card ownership with age above 15 and finally debit card ownership above age 15. (Aarakit et al., 2022) indicators of FI are consistent with the World Bank (2014) conceptual definition and the Bank of Uganda, which include mobile money, use of formal banking accounts, remittances and credit to construct the index of FI. These indicators are in line with (Demirgüç-Kunt et al., 2018; Zhang & Posso, 2019); Churchill, 2020; Koomson et al., 2020a) & Koomson et al., 2020b).

However, the present study use parametric method to avoid the problem of weights assignment to the index of FI using two stage Principal Component Analysis (2 stage-PCA). However, non-parametric (weights assigned exogenously) such as (Alkire & Foster, 2011) sensitive to subjective weights. Furthermore, in the first stage PCA, the study identify indicators for each dimension available in the HIES (2018-19) dataset and run PCA on these indicators to make dimensions. This study has identified three dimensions such as access to financial services, availability, and Liquidity and assets dimensions. Each dimension has its suitable indicators such as access dimension have five indicators (remittances received from abroad, source of remittances received, such as bank, mobile banking, hundi and other sources). Availability dimension have two

indicators (receipts from life and general insurance). Liquidity and assets dimension have three indicators (total net saving of HH at present, net saving of HH during last one year and present value of stocks/shares/bonds and other securities held by HH). Moreover, in second stage PCA, the study compute overall FI index by combining above-mentioned three dimensions.

Moreover, in the literature, parametric and nonparametric methods are used to construct composite indices. Researchers use intuition to weight indicators in non-parametric methods these indicators are sensitive to subjective weight assignment because a small weight change can drastically change results explored by Lockwood (2004). Financial inclusion indices like (Sarma and Pais, 2011; Sarma, 2012; Bhattacharya et al., 2010) use this method to measure usage and access from supply-side country data sets. Parametric methods assume that a set of correlated indicators has a latent structure, so the weights of indicators in the overall index can be determined endogenously by covariation on each dimension of the structure.

The purpose of dividing the overall set of indicators into three sub-indices is twofold. On one hand, the three sub-indices have meaning, providing disaggregated information for policymaking. Since the sub-indices contain highly inter-correlated indicators, the study estimate these sub-indices first rather than the overall index by picking all the indicators at once for methodological reasons. The empirical evidence that PCA favors highly correlated indicators makes this strategy preferred according to (Mishra, 2007). Two-stage PCA reduces this issue explored by (Nagar and Basu, 2002). The three financial inclusion sub-indices access, availability, and assets and liquidity, are estimated first. The study use dimensions as explanatory variables to estimate dimension weights and the final FI index is estimated in the second stage.

4. Empirical Model

The study utilize Instrumental Variable Probit (IV-Probit) model as main framework on EP and FI, however, for robustness of IVs the study imply simultaneously simple OLS, Probit model and 2SLS in energy poverty and financial inclusion analysis due to binary nature of the outcome variables. To analyze the impact of FI on EP for empirical analysis due to limited dependent variable (energy poverty) is of binary nature. This take value 1 if a representative HH is energy poor, and 0 for non-energy poor HHs. The reason to use IV-Probit regression model is bivariate nature of energy and use of IVs to measure the risk of endogeneity.

$$EP_i = \beta_0 + \beta_1 FI_i + \beta_2 X_i + \varepsilon_i \quad (4.1)$$

In Eq. (4.1) EP_i is binary dependent variable which shows EP take the value 1, if a representative HH i is energy poor, or otherwise 0 for non-energy poor HHs. FI_i represents the status of the HH i, financial inclusion and X_i vector of other covariates to determine EP including household size, household head education, asset, age, marital status, region, gender and province. β_0 is constant and β_1 β_2 are coefficients of FI and other determinants of EP in the vector X_i to be estimated and ε_i is error term.

FI_i is said to be endogenous if it is correlated with error term ε_{it}. This mean, the error term is affecting the predictor FI_i and thereby affecting EP_i indirectly. Therefore, it is needed to correct for the problem of endogeneity between financial inclusion (FI_i) and (EP_i) energy poverty. Furthermore, (Koomson and Danquah, 2021) used distance in kilometers to nearest bank as instrumental variable (IV) to counter the risk of endogeneity for FI using Ghana household data. This variable is meaningful to correcting endogeneity in FI at HH levels. However, (Widyastuti et al., 2023) expand this IV to financial infrastructure to improve FI. Whereas, (Koomson and Danquah, 2021; Dogan et al., 2021) also address endogeneity, but they only use banks as the

reference point for the instrumental variable, which may limit its effectiveness if financial infrastructures are unevenly distributed between rural and urban areas. This study corrects for endogeneity using distance in kilometers to school as proxy for distance to nearest bank due to HIES (2018-19) lacks data on banking sector. Therefore, the study use distance in kilometers to school as IV to financial inclusion.

Additionally, mobile phone ownership can be another strong instrumental variable to FI. The reason, that mobile phones are used for almost all mobile money and other formal financial transactions. This encourages the proportion of financially included individuals, but it is omitted from the model. Moreover, this is evident, that at the time of HIES (2018-19) survey 94.14% of HHs uses mobile phone facility. Therefore it is important to address the problem of endogeneity using mobile phone ownership as IV for FI. Furthermore, there are three requirements for IV in this model to get the second objective.

- z is correlated with predictors (FI_i), E[$z'\ FI$] $\neq$ 0 i.e.
- z is uncorrelated with error term ε_i, E[$z'\varepsilon_i$] = 0
- z is not a direct cause of the dependent variable (EP), cov[$EP, z|FI$] = 0

4.1. Instrumental Variables Strategy

The study used two instruments to identify household FI, each grounded in a distinct channels of access. The HIES 2018-19 does not record HH distance to nearest bank branch, so the study relies on distance to nearest school as a proxy for geographic proximity to formal financial infrastructure. This substitution is defensible on institutional grounds specific to the case of Pakistan. Bank branches, schools, markets, and other administrative or public facilities are overwhelmingly co-located within established town and union council headquarters, reflecting the same underlying settlement hierarchy and public investment pattern. A HH`s distance to a school is therefore a

reasonable proxy for its broader distance from formal service infrastructure, including banking outlets, and has been used analogously in the development literature where direct measure of financial access are unavailable. Greater physical distance from such centers raises the transaction cost of opening and maintaining a formal account, which is expected to depress FI, a mechanism consistent with the access cost barriers documented in the cross-country FI of (Demirgüç-Kunt et al., 2018; Allen et al., 2016).

The second instrument is HH mobile phone ownership, reflecting a more direct and increasingly dominant channel of financial access in Pakistan. Mobile phones are principal gateway to branchless and mobile banking services such as Easy paisa and Jazz cash, which have substantially expanded the reach of formal financial transaction to HHs that remain distant from conventional banking branches. Mobile phone ownership is therefore expected to raise the probability and intensity of engagement with formal financial services independently of physical proximity to a branch, consistent with the digital FI literature (Sahay et al., 2015; Ozili, 2023; Park & Mercado, 2018). Together, the two instruments depicts complementary dimensions of access, physical and digital that jointly determine a HH`s practical ability to participate in the formal financial system.

Given the initial model

$$EP_i = \beta_0 + \beta_1 FI_i + \beta_2 X_i + \varepsilon_i$$

The problem of endogeneity occurs when one or more predictor variables are correlated with error term. E $[FI|\varepsilon_i]$ = cov$[FI'\varepsilon_i] \neq 0$, therefore simple OLS estimation coefficient are biased.

$$b = \beta + (FI_i' FI_i)^{-1} FI_i' \varepsilon_i, E[b] \neq \beta$$

Therefore, rewrite the model as follows in structural equation form.

$$EP_i = Dist_i' \beta_1 + X_i \beta_2 + \varepsilon_i$$

$$EP_i = mobile_i'\beta_1 + X_i\beta_2 + \varepsilon_i$$

Where EP_i is dependent variable, $Dist_i'$ and $mobile_i'$ are endogenous variables and (X_i) are vector of exogenous variables. The structural equation model involves combined set of FI_{it} = ($Dist_i'$, X_i) and FI_i = ($mobile_i'$, X_{it}) both endogenous and exogenous variables for both equations. The need to find set of instrument z = (x_1,x_2) for exogenous variables only, where x_1 is instrument for itself and x_2 is instrument for endogenous variable. The study estimate the model is two steps.

Reduced form equation $$FI_i = Dist_i\gamma_1 + X_i\gamma_2 + \mu_i$$

Similarly to get reduced form equation for mobile phone ownership as follows.

$$FI_i = mobile_i\gamma_1 + X_i\gamma_2 + \mu_i$$

4.2. Instrument Relevance

Both instruments are expected to satisfy the relevance condition, through clear structural channels. Distance to school operates through proximity to formal service infrastructure; shorter distances lower the transaction cost of accessing banking services, which raises FI. Mobile phone ownership operates through the digital financial channels; ownership enables branchless and mobile banking, which raises FI. The empirical strength of these channels is assessed through the first-stage regression of the FI index on both instruments and the full set of controls, with instruments strength evaluated using the first-stage F-statistic and formally tested against the weak instrument benchmarks established by Staiger and Stock (1997). A first-stage F-statistic substantially above the conventional thresholds would indicate that two instruments jointly explain a meaningful share of the variation in FI, supporting their use in IV-Probit model.

$$EP_i = \beta_0 + \beta_1\widehat{FI_\iota} + \beta_2X_i + \varepsilon_i$$

4.3. Identification Diagnostics

Several diagnostic tests are used to evaluate the identification strategy. The Wald test of exogeneity, reported as part of the IV-Probit model, tests null hypothesis that II is in fact exogenous, rejection of null hypothesis supports the use of IV-Probit model over conventional OLS, Probit and 2SLS. The first-stage F-statistics and the Kleibergan-Paap rk Wald F statistics assess the strength of IVs, indicating whether occupational composition is sufficiently correlated with II to avoid the weak0instrument bias documented by Staiger and Stock (1997) and addressed more generally in Kleibergen and Paap (2006). Moreover, Craag-Donald Wald F statistics is test of relevancy of IVs, ideally with value greater than 10, shows IVs relevancy. Because the model relies on occupational composition which consist of formal and informal sector employment shares, therefore, over-identification test such as Hansen (1982) J-statistics test is reported. That is rejection of null hypothesis confirms overall IVs are uncorrelated with error term and jointly exogenous.

Table 1: Descriptive Statistics

	Total n = 24,809	Rural n = 15,936	Urban n = 8,873
Variables	Mean % (S.D)	Mean % (S.D)	Mean % (S.D)
Energy Poverty %			
AFCP	5.1 (0.22)	7.3 (0.26)	1.1 (0.11)
Asset index	9.7 (1.7)	-51.5 (1.1)	9.25 (2.1)
Household size	6.45 (3.2)	6.55 (3.2)	6.3 (3.18)
Head schooling in year	8.8 (3.7)	8.15 (3.5)	9.6 (3.85)
Household head age	45.9 (13.6)	45.6 (13.9)	46.3 (13)
Marital status of head	2.05 (0.33)	2.05 (0.32)	2 (.35)

Number of rooms	2.4 (1.4)	2.29 (1.38)	2.5 (1.37)
Water round trip (km)	48.8 (0.93)	49.1 (0.93)	48.3 (0.92)
time spent water (mnt)	16 (0.97)	16.6 (0.99)	15.2 (0.93)
Wall paka	76.2 (0.42)	67.1 (0.46)	92.7 (0.26)
house ownership	84.2 (0.36)	91.3 (0.28)	71.5 (0.45)
Toilet improved	63 (0.48)	54.4 (0.49)	78.5 (0.41)
Piped water	69.7 (0.45)	76.5 (0.42)	57.4 (0.49)

According to AFCP measure, at national level 5.1% HHs are recognized as energy poor, while 7.3% in rural and 1.1% in urban area. This depicts that the ratio of energy poor household is significantly higher in rural areas as compared to urban counterpart indicating rural households are greatly affected by EP. The ownership of assets index reflect spatial disparity in the region as shown in the table, at the national level assets ownership is 9.7% however rural households are 51.5% adversely affected lacking basic household appliance such as air condition, fan, refrigerator, washing machine, TV, cooler and freezer. The assets holding is significantly higher 9.25% in urban areas highlighting deep structural wealth inequalities favors urban areas. Average household size is modest both in the regions and the national level reflects 6.45 persons, while household rural area is slightly larger (6.55 persons) as compare to urban household size 6.3 persons.

From the table educational attainments of the household head significantly differs such as at the national level household heads have on average 8.8 year of schooling but rural heads have average 8.15 year compared to 9.6 year in urban areas. This reflects urban household have advantage in human capital. Similarly, the average age of household heads at national level is 45.9 years while slightly differs between rural and urban areas as 45.6 years and 46.3 years respectively.

Housing characteristics show spatial inequalities, at the national level, on average households have 2.4 rooms however, rural households have 2.29 rooms as compared to 2.5 in urban household, indicating slightly better housing space in urban areas. Access to water remain a challenge, at the national level, households travel on average 48.8 km for a round trip to collect water. However, rural households travel more than urban households as 49.1 km and 48.3 km respectively. Similarly at the national level it takes 16 minutes to collect water and 16.6 minutes and 15.2 minutes in rural and urban setting respectively. In term of housing quality, 76.2% of the national households live in paka or walls made of bricks houses, while 67.1% and 92.7% live in paka houses in rural and urban counterpart respectively, reflecting urban advantages in housing infrastructure.

In term of house ownership, 84.2% of households have own houses at the national level. However, the prevalence in rural areas, 91.3% as compared to 71.5% in urban areas, suggesting that rural households are more likely to own house even though the quality of houses in rural areas is lower than urban counterpart. Access to improved sanitation remains limited as only 63% at national level have improved toilet facilities, the rural share is significantly lower at 54.4% compared to urban households 78.5%. This indicates substantial differences in access to sanitation facilities. Lastly, at the national level, 69.7% of household have access to improved piped water, surprisingly access to clean water is higher in rural areas as 76.5% than 57.4% in urban areas. Overall the descriptive reflects substantial rural urban difference in terms energy poverty, income inequality and more substantially in assets ownership.

Table 2: After Fuel Cost Energy Poverty and Financial Inclusion Results

	Model 1	Model 2	Model 3	Model 4
	OLS	**Probit**	**2SLS**	**IV Probit**
Financial inclusion	-0.004 (0.015)	-0.133 (0.169)	-7.913*** (1.594)	-10.466*** (0.101)

Asset index	-0.011*** (0.001)	-0.338*** (0.021)	0.044*** (0.012)	0.010 (0.016)
Household size	0.002*** (0.000)	0.025*** (0.005)	0.007*** (0.002)	0.011*** (0.003)
Household head gender [a,1]	-0.021*** (0.005)	-0.349*** (0.073)	0.667*** (0.139)	0.838*** (0.037)
Household head age	0.001*** (0.000)	0.009*** (0.001)	0.008*** (0.001)	0.011*** (0.001)
MS_ Married [a, 2]	-0.048*** (0.009)	-0.446*** (0.085)	-0.359*** (0.073)	-0.493*** (0.047)
MS_ Widow [a, 2]	-0.035*** (0.011)	-0.267** (0.108)	-0.631*** (0.128)	-0.834*** (0.055)
MS_Divorced [a, 2]	0.007 (0.023)	0.015 (0.200)	-0.498*** (0.128)	-0.657*** (0.111)
MS_Separated[a, 2]	0.075 (0.064)	0.367 (0.447)	-0.228 (0.310)	-0.329 (0.299)
MS_ Nikkah [a, 2]	0.093 (0.089)	0.787 (0.687)	0.617 (0.496)	0.846** (0.424)
Number of rooms	-0.006*** (0.001)	-0.060*** (0.014)	0.065*** (0.015)	0.083*** (0.007)
Water round trip (km)	0.005*** (0.002)	0.051*** (0.015)	0.003 (0.005)	0.005 (0.008)
Wall paka [a, 3]	-0.043*** (0.004)	-0.285*** (0.032)	0.041* (0.021)	0.056** (0.022)

house [a, 4] ownership	-0.001 (0.004)	0.001 (0.043)	0.048*** (0.016)	0.066*** (0.019)
Toilet improved [a, 5]	-0.026*** (0.003)	-0.208*** (0.031)	0.075*** (0.023)	0.096*** (0.018)
Piped water [a, 6]	0.018*** (0.003)	0.151*** (0.035)	0.071*** (0.015)	0.099*** (0.016)
_cons	0.091*** (0.011)	-1.630*** (0.114)	2.188*** (0.423)	2.459*** (0.109)
	$R^2 = 0.037$	PseudoR^2 0.114	Cent $R^2 = -11.17$	
Wald test of exogeneity				$Chi^2 = 101.90$
Prob > chi^2				0.0000
Kleibergen-Paap Wald rk F statistic			16.43	
Cragg-Donald Wald F statistic			11.08	
Hansen J statistic			P-val = 0.7723	
N	24,809	24,809	24,809	24,809

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

[a] Dummy variable

[1] Base category: male household head

[2] Base category: unmarried household head

[3] Base category: no bricks

[4] Base category: house not owned

[5] Base category: unimproved toilet

[6] Base category: non-piped water

The table 2 reports estimates from four alternative models such as simple OLS, Probit, 2SLS and IV-Probit estimation methods used to examine the relationship between EP and FI from after fuel cost poverty measure, with binary dependent variable. Given the dichotomous nature of the outcome variable and the explicit treatment of endogeneity through instrumental variables, the IV-Probit results provide the main basis for inference, while the remaining models are used to assess robustness analysis and highlight potential biases at any stage. Results shows that the coefficient of FI is consistently negatively associated with after fuel cost poverty across all models, while the magnitude and statistical significance differs significantly by the method used. It is evident in the OLS and Probit models, the coefficient is negative but statistically insignificant, suggesting weak association when the problem of endogeneity is ignored. However, once endogeneity is corrected in the 2SLS and IV-Probit models, the effect becomes larger, with negative sign and highly statistically significant. The results reflects that in IV-Probit model, higher FI substantially reduces the probability of being energy poor after accounting for fuel costs. This sharp increase in magnitude relative to conventional models indicates that the OLS and the Probit models severely underscore the protective role of FI, this is likely to be occur due to omitted variables bias which are corrected by using IV-Probit model and the results are highly significant.

The Average Marginal Effects (AMEs) reveal that FI has a negative and statistically significant effect on EP under the AFCP approach. The Probit model estimates that an AME of -0.012 ($p < 0.01$), indicates that one-unit increase in FI reduces the probability of household being energy poor by 1.2%, holding other factors constant. After accounting for endogeneity, the IV-Probit model yields a substantially larger AME of -0.180 ($p < 0.01$), suggests that FI decreases the likelihood of EP by 18%. That is, the larger IV-Probit estimate indicates that the conventional Probit model underestimates the protective effect of FI, demonstrating that greater access to financial services significantly reduces household EP under AFCP in Pakistan.

The index of asset consist of household appliance for ordinary routine, shows a negative and statistically significant effect in the OLS and the Probit models. This imply that the greater asset ownership is associated with lower EP. However, in the 2SLS and IV-Probit models, the coefficient of asset ownership becomes positive and statistically insignificant. This change suggests that the apparent protective effect of asset in non-IV model may be due to endogeneity. Once the problem of endogeneity is corrected asset ownership does not employ an independent effect on EP. The household size is positive and statistically significant across all alternative specifications, including IV-Probit model. This reflects, that the larger households size, the more likelihood of falling into EP. This suggests that greater energy needs and expenditure pressure that prolong energy poverty even if adjusted for fuel costs.

Gender of the household is dummy variable having base category male headed household. The coefficient has negative and statistically significant in the OLS and Probit models, this imply that lower EP among female headed households in the conventional models. However, the sign reverse and becomes positive and highly statistically significant in the 2SLS and IV-Probit specification. Moreover, in the preferred IV-Probit model, male headed households experience significantly higher probability of after fuel cost energy poverty, this indicates that the initial negative association between EP and female household head was misleading and driven by endogeneity.

The sign of coefficient of household head age is positive and statistically significant in all models, including preferred IV-Probit model. This indicates that, older households are more prone to EP. This may reflect fixed income from pension or any other benefits from the government in term of subsidies, or increase energy prices shocks among older households. Marital status of the household head is a dummy variable with base category unmarried household heads. This indicates spatial heterogeneity but largely consistent pattern once the problem of endogeneiy is corrected. Results show that, the coefficient of being married is negative and statistically significant across

all four specifications, including IV-Probit model. This indicates married household heads less likely to be energy poor, this may due to economies of scale and marriage add additional potential earner to the household, therefore, it reduces EP. Moreover, widowed and divorce are also associated with lower energy poverty significantly including IV-Probit model, however, separation remains statistically insignificant. The nikah category shows a positive and significant effect only in the IV-Probit model, indicating a higher likelihood of EP once the problem of endogeneity is corrected.

The housing characteristics and infrastructure variables show strong and robust effects. The coefficient of number of rooms is negative and statistically significant in the OLS and Probit models, but becomes positive and highly significant in 2SLS and IV-Probit models. Furthermore, in the preferred IV-Probit model, household with more rooms faces a higher probability of EP after account for fuel expenditures. This suggests that larger dwelling size increases energy requirements and fuel expenditures. The coefficient of water round trip is positive and statistically significant in OLS and Probit models but becomes statistically insignificant in the IV-Probit model. This indicates that this apparent effect in conventional models does not hold once enedogeneity is addressed.

Wall paka or made of bricks is a dummy variable with base category wall made of mud. This shows that the coefficient of living in a permanent house is negative and statistically significant in OLS and Probit models, but turns positive and statistically significant in the IV-Probit model. This suggests that after addressing endogeneity households living in permanent structure are more likely to experience after fuel costs energy poverty, potentially due to higher reliance on commercial fuels and greater energy consumption. Similarly, house ownership is also a dummy variable having base category house not owned. The coefficient of house owned shows a similar pattern, it is insignificant in the OLS and the Probit models but positive and highly statistically

significant in the IV-Probit model, indicating higher EP risk among those who own a house due to additional fuel expenditure they are more prone to EP. The coefficient of dummy variable improved toilet facilities is negative and statistically significant in non-IV models but becomes positive and significant in the 2SLS and IV-Probit models. This implies that, households with improved sanitation infrastructure may simultaneously face higher fuel expenditures, increasing the likelihood of after fuel costs energy. Access to piped water is dummy variable, it is positive and statistically significant across all models, including IV-Probit, indicating a consistently higher probability of EP among households connected to piped water system, likely reflecting higher services and energy costs.

Furthermore, as the focused model is IV-Probit due to Instrumental Variable approach the strength and relevancy of instruments is confirmed by few tests. In the IV-Probit model, the Wald test of exogeneity determines whether potentially endogenous regressors can be treated as exogenous in a nonlinear framework with a binary dependent variable. The test result show that, with a chi-square value of 101.90 and P-value of 0.0000, this strongly reject the null hypothesis of exogeneity. This suggests that FI is endogenous and standard Probit model is inconsistent. Therefore mobile ownership and distance to institution as proxy of distance to nearest bank used as Instrumental Variables (IVs) are justified to correct for endogeneity, it is necessary to obtain consistent estimates of energy poverty determinants. The Kleibergen–Paap Wald rk F statistic for the 2SLS model assesses instrumental variable relevance and strength in heteroskedasticity. The value of 16.43 exceeds conventional critical thresholds (F>10) used to diagnose weak instruments, indicating that the instruments are strong and unlikely to bias 2SLS estimates.

Similarly The Cragg–Donald Wald F statistic, with a value of 11.08 provide further evidence on instrument strength under the assumption of homoskedastic errors. This statistics exceeds rule-of-thumb cutoffs (F>10) supporting the conclusion that 2SLS estimation instruments are relevant and

have sufficient explanatory power for the financial inclusion. The Hansen J statistic evaluates the validity of over identification in the 2SLS framework by determining if the instruments are jointly exogenous and uncorrelated with the error term. The reported P-value of 0.7723 do not rejects the null hypothesis of instrument validity, suggesting all the instruments are correctly identified and uncorrelated with error term. Overall, the comparison of models represents, that ignoring endogeneity leads to substantial spurious and inconsistent results. However, the IV-Probit model provide the most credible evidence and indicate that FI plays vital role in reducing EP after accounting for fuel expenditures.

5. Discussion

In the context of EP and FI relationship, the study used affordability measure of AFCP. This measure shifts the attention from expenditure shares and relative cut-offs to association between household budget constraint and burden of energy costs. Furthermore AFCP statistics shows that EP have smaller effects on households at the national level, however, disparities in the acquisition of energy services still exhibits. In the regions, rural households show higher AFCP (7.3%) rate than national level statistics. This reflects that the persistent budget constraints and dependence on traditional fuels. However, the incidence of energy poor in urban region is 1.1% after incorporating for domestic energy costs, the result for urban area suggests that, better access to modern energy services, higher HHs income, and improved infrastructure, and greater availability of energy efficient technologies such as solar energy to reduce the likelihood AFCP among rural households.

Empirical analysis of AFCP energy poverty provides substantial findings with FI as key determinant under AFCP measure of EP. Findings show that in the OLS and Probit specifications, FI is negatively associated with EP, but the effects becomes substantially significant and stronger in the 2SLS and IV-Probit models. Under AFCP the IV-Probit estimates indicate that greater FI

significantly reduces the probability of households falling below the AFCP poverty line, this is also confirmed by using (AMEs) for FI in Probit and IV-Probit specifications. This suggests that access to formal financial services increases household ability to smooth consumption, manage energy expenditure and cope with fuel prices shocks. The stability of the results across models reflects the importance of FI as mechanism for improving energy affordability rather than merely energy access. Moreover, (Widyastuti et al., 2023) found the same conclusion on FI and EP for Indonesia, (Kabutey-Ongor et al., 2025) for Ghana, (Ghaffar and Gardezi, 2024) use panel data analysis from 1990-2022 for Pakistan, (Kar and Bali Swain, 2024) for 27 Sub Saharan African countries, (Yin et al., 2023) for China. This is evident from the literature that most studies have found as FI increases the likelihood of EP decreases.

Asset ownership also plays robust role and consistent across affordability measure. The asset index is negative and highly significantly associated with AFCP energy poverty measures across all models. This indicates that wealth accumulation remain consistent in previous analysis as well as in the current analysis, providing households with resilience against energy prices volatility and enable investment in more clean and efficient energy technologies, thereby lowering the risk of falling into affordability based energy poverty. The findings are consistent with (Prakash & Munyanyi, 2021) in the USA, (Khandker et al., 2012) in India and (Koomson & Danquah, 2021) in Ghana. Household size shows a positive and statistically significant association with AFCP outcomes, implying that larger households face systematically higher risk of EP when affordability is taken into account. Moreover, the findings are in line with previous literature such as (Awan & Bilgili, 2022; Qurat-ul-Ann & Mirza, 2021a, Ullah et al. (2026) for Pakistan, in contrast with (Dogan et al., 2021) for Turkey, (Mohr, 2018) for USA and (Churchill & Smyth, 2020) for South Africa.

Demographic characteristics show weaker and less consistent effect once endogeneity is corrected. Gender and age of households head appear significant in simpler models but often lose significance in IV-based specifications, suggesting that their apparent influence operates through correlated factors such as income, assets and housing conditions rather than exerting independent effects. It is consistent with (Dogan et al., 2021) for Turkey and (Awan and Bilgili, 2022) for Pakistan. Household head age is positive and insignificant in all specifications. Moreover, marital status of household head shows sensitive to model specification in several cases, the effects that appear significant in OLS or Probit models, diminishes or disappear in IV-Probit estimations, indicating that simpler models may conflate causal relationship with unobserved heterogeneity. This reinforces the methodological importance of addressing endogeneity. Particularly, when studying household welfare outcomes that are jointly determined with income labor supply and consumption behavior. Moreover, (Crentsil et al., 2019) found the negative impact of being married with energy poverty for Ghana.

Housing quality and infrastructure variables consistently emerges as key correlates of EP measure and for all four alternatives models. This confirms that living in paka house and having better housing conditions are associated with lower energy poverty risk, indicates higher energy efficiency and improved thermal comforts at paka houses. The finding is in line with (Qurat-ul-Ann and Mirza, 2021a) for Pakistan. However, the number of room variable is negative and significant in AFCP in conventional models, nevertheless positive and insignificant both in 2SLS and IV-Probit models, this finding is in contrast with (Awan and Bilgili, 2022) for Pakistan. More number of rooms are more likely to be associated with EP, this indicates, larger dwellings and greater infrastructure related costs are often linked with higher EP particularly, once endogeneity is corrected. These findings highlights that EP is closely associated with housing conditions and the built environment, not simply with fuel access.

The diagnostic tests applied to reinforces the integrity of these findings by confirming the presence of endogineity and the adequacy of the instrumental variables. Furthermore, the strength of key coefficient in IV-Probit models, particularly for FI, reflects that ignoring endogeneity leads to systematically understate the important association between EP and FI. These findings show that EP policies must go beyond subsidizing energy prices and include financial inclusion sector development and household interventions to address energy affordability constraints.

6. Conclusion

This study set out to provide comprehensive and integrated analysis of EP in Pakistan by analyzing expenditure based measure to EP. This study has made an attempt to explicitly associate household energy with the index of financial inclusion capturing socioeconomic effects. Furthermore explaining objectives in a broader term. EP affordability is assessed using after fuel cost energy poverty (AFCP) measure. AFCP affects fewer households at national level and urban area as compared to rural counterpart. EP reduces FI across AFCP findings, with stronger effects after endogeneity correction. FI and energy affordability are linked in the findings, proving that households use financial services to manage energy costs and cope with marketable price shocks. Future research can further extend the emissions based analysis by including evidences on energy appliance efficiency, energy technologies and the quality of fuels consumed by households will reinforce household level carbon emissions. For this purpose associating survey data with geospatial and administrative data on tariff rationalization and subsidy schemes as well as the infrastructure of energy, will further enhance the policy related findings.

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