

HOUSEHOLD ADOPTION OF SOLAR ENERGY IN PAKISTAN: INSIGHTS FROM NATIONALLY REPRESENTATIVE DATA FOR ACHIEVING SEVENTH SUSTAINABLE DEVELOPMENT GOAL

*Muhammad Irfan**, Michael P. Cameron, AND Waqar Akram

1. Introduction

Ensuring the availability of affordable, reliable, sustainable, and modern energy for all is the seventh United Nations Sustainable Development Goal (UN, 2025).

*Muhammad Irfan is a Lecturer in Applied Economics at Unitec, Auckland, New Zealand. He previously served as an Assistant Professor at Xiamen University Malaysia and as a Research Fellow at both the University of Otago and the University of Waikato. He holds a Ph.D. in Economics from the University of Waikato, with a specialization in energy, environmental, and health economics. His research has been published in leading journals, including *Energy Policy*, *PLOS Medicine*, and *Environmental Science and Pollution Research*. ORCID: <https://orcid.org/0000-0002-3876-4941>.

Michael Cameron is a Professor of Economics in the School of Accounting, Finance, and Economics (SAFE) at the University of Waikato, and a Research Associate at Te Ngira – Institute for Population Research. He holds leadership roles as Vice President of the Population Association of New Zealand (PANZ) and Vice President – New Zealand of the Australia New Zealand Regional Science Association International (ANZRSAI). His research has been published in esteemed journals such as *World Development*, *Population and Environment*, *Population Research and Policy Review*, *Journal of Population Research*, and *Energy Policy*. ORCID: <https://orcid.org/0000-0002-4296-3775>.

Waqar Akram holds a Ph.D. in Economics and is a seasoned academic and researcher with many years of experience in various academic and administrative roles. He is currently teaching at Waikato University, New Zealand. His research focuses on framework-based, policy-oriented studies, and he
(continued)

The Journal of Energy and Development, Vol. 50, Nos. 1-2

Copyright © 2025 by the International Research Center for Energy and Economic Development (ICEED). All rights reserved.

The world's fossil fuel reserves, such as oil, coal, and natural gas are finite and depleting rapidly (Wang and Azam, 2024). The consumption of fossil fuels leads to increased carbon dioxide and particulate matter emissions, which damage the environment and cause global warming. Despite efforts to reduce the use of solid and fossil fuels, almost 2.4 billion people globally use these energy sources for cooking and heating purposes, and almost 700 million people lack a reliable source of lighting. Moreover, the recent war in the Ukraine has driven up energy prices, causing energy insecurity around the world (Zakeri et al., 2022).

Reducing the impact of energy crises will ultimately depend on a shift from fossil fuels to renewable and sustainable energy sources such as solar energy, wind energy, hydroelectric energy, biogas, and tidal energy. Renewable energy sources are sustainable, and they do not emit carbon dioxide and other greenhouse gases. Furthermore, renewable energy sources are more broadly available, enabling countries to become more self-sufficient in producing energy, thereby increasing energy security. Solar energy could be the cleanest and widely available source of renewable energy (Akhtar et al., 2018), particularly in summer months and arid tropical and subtropical zones. Therefore, if a country's geographical location and climate provide abundant solar resources, harnessing solar energy could be an attractive option to mitigate future energy crises.

Pakistan is located on the sun belt and gets around five to seven kwh/m²/day in average insolation (sun exposure) in the sunniest areas. The sun shines almost 300 days per year on average, with an average of 8 hours a day. This means that around 3,000 to 3,300 sunshine hours are available per year, which could generate around MWh/m²/year of energy (Kamran, 2018). Pakistan has great potential to generate solar power, and only utilizing 0.07 percent of the available land area could fill its electricity demand gap (World Bank, 2025). While according to an estimate Pakistan has a capacity to generate 24,953 megawatts through renewable and sustainable energy sources which can easily fulfill the energy demand (Zameer and Wang, 2018). However, the question of whether households would adopt solar energy or transition from electricity or dirty fuels to solar energy in Pakistan remains unanswered.

In the past few years, international agencies including the World Bank and Asian Development Bank have funded solar energy power plants in Pakistan. To install the solar energy along with other renewable energy plants, the Pakistan Council of Renewable Energy Technology (PCRET) was established. It has roughly installed 300 solar photovoltaic plants for schools, parks, mosques, houses, and streetlights (Kamran, 2018). PCRET has also conducted training for

has published in prestigious journals, including the *South Asian Journal of Macroeconomics and Public Finance*, *Journal of Sustainable Finance & Investment*, *Renewable and Sustainable Energy Reviews*, *Sustainable Production and Consumption*, and *Journal of Cleaner Production*. ORCID: <https://orcid.org/0000-0002-3003-0062>.

households to operate solar plants, as well as motivated many households to adopt solar energy systems. However, the power generation has not achieved expectations, perhaps because of inadequate renewable energy policy, low technical know-how, and unawareness of the local community (Khan and Latif, 2010). After almost a decade's efforts, Pakistan is producing just over 1,500 megawatts, which equals to two percent of total electricity generation, and only 5.6% households have adopted solar energy as their main lighting source (PSLM-2018-19). In other words, despite many concrete policies, the production and adoption of solar energy is extremely low in Pakistan.

While, like many developing countries, Pakistan has excess demand for electricity. Blackouts in rural areas of Pakistan average around 18 hours a day, and in urban areas blackouts range from 8 to 12 hours a day, because of an acute shortage of almost six gigawatts of electricity supply (Mirjat et al., 2017). This shortage may increase further in the future, because of population increases (Zameer and Wang, 2018), alongside outdated infrastructure, line losses, electricity theft, reliance on imported oil and fossil fuels, overconsumption, mismanagement, and the government's relative lack of attention towards renewable and sustainable energy sources. Pakistan currently produces most of its electricity by thermal means (25,098 MW), with 9,915 MW hydroelectric, 1,248 MW wind, 530 MW solar, 369 MW bagasse, and 2,612 MW nuclear making up the balance.¹ A heavy reliance on thermal energy sources not only increases the oil import burden but also adversely affects the environment. According to the Pakistan's Vision of 2025, the country would optimize the energy generation mix between hydro, oil, nuclear, solar, wind, and coal, with reference to their economic feasibility. Nevertheless, Pakistan aims to complete two major hydroelectric power projects (Dasu and Diamer Bhasha) in 2025, with a capacity to produce 8.82 gigawatts, which would make them a major electricity production source.² Regarding the production and diffusion of solar photovoltaic panels, no clear policy is available. Surely, energy production through oil and coal would exacerbate the ambient environment and economic condition, and therefore, Pakistan should stick with the cleaner and renewable energy production goals only (such as hydro, wind, biogas, and solar).

Given the potential for solar energy generation, many studies have attempted to uncover the barriers in the way of adopting solar photovoltaic energy. In this paper, we focus on the socio-economic determinants of household solar photovoltaic adoption in Pakistan, using nationally representative household survey data. The acute energy shortages that Pakistan suffers, and the need to move towards renewable and sustainable energy sources, motivates this study. It will help policy makers to better understand the household solar adoption behavior and to adapt

¹ <https://nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202021.pdf>.

² <https://www.pc.gov.pk/>.

policy to enhance the adoption rate. The remainder of the paper proceeds as follows. Section 2 discusses the relevant extant literature, Section 3 presents the data and methods, Section 4 offers the results, and Section 5 concludes the article with a discussion of policy implications.

2. Literature Review

An extensive literature is available on the adoption of solar photovoltaic energy worldwide. However, in Pakistan only a handful studies have uncovered the factors associated with the adoption of solar energy, all carried out at small scales.

Qureshi et al. (2017) explored the factors associated with household solar energy adoption in Lahore. Using data from only 36 households they found that the cost of solar photovoltaic system was the most significant barrier in the diffusion of solar energy. Moreover, a lack of financial support by the government, shortage of reliable vendors, and difficulty of using all appliances at the same time were the main hindrances for solar energy adoption. In contrast, the environmentally friendly features of solar energy were a significant contributor to adoption. In southern Punjab, Kamran et al. (2019) collected data from 300 respondents to investigate the main barriers to the adoption of solar energy. They found that installation cost is the most important variable which hinders adoption. They suggested that the government should provide incentives or subsidies for solar plant installation. All of these studies were relatively small-scale, were based on straightforward descriptive analyses, and did not investigate the range of energy options available to households in Pakistan. In contrast, Jan et al. (2020) used a binary logit model to explore the determinants of solar photovoltaic systems. Using primary data from 100 respondents from Peshawar, they found that the age of the household head, household income, education level, and awareness about solar photovoltaic systems were positively associated with the adoption of solar energy. However, binary logit models do not account for the full range of available alternative energy sources for households.

Several other small-scale studies in Pakistan have sought to identify factors influencing the adoption of solar energy. For example, the work of Asif et al. (2023) focuses on the intention to adopt renewable energy using data from five metropolitan cities in Pakistan, representing a wide range of populations. Using value orientation as a guiding framework, they estimated the impact of utilitarian benefits, collectivism, reasons behind adoption, attitudes, and value orientation, and analyzed them using structural equation modeling. They found that attitudes towards renewable energy significantly explain the intention to use renewable energy. Other factors like value orientation impact reasons for adoption and attitudes; likewise, utilitarian benefits impact attitudes, and collectivism and reasons for adoption impact attitudes. Similarly, Hasheem et al. (2022) found that purchase

intention for solar is significantly explained by attitudes, which are significantly impacted by optimism, innovativeness, perceived benefits, ecological lifestyle, and product knowledge, using data from regional capital cities in Pakistan. Liang et al. (2021) investigated the impact of social support and source credibility on purchase intention, with the mediation of social influence and willingness to buy solar panels and moderation of environmental concerns and perceived monetary benefits. Their results are based on primary data from three capital cities in Pakistan, and they found that willingness to buy is significantly impacted by normative social influence and informational social influence.

Waris et al. (2023) investigated households' intentions to use small-scale solar energy as a function of information publicity, attitudes, green norms, perceived behavioral control, subjective norms, and income. The authors used data from seven diverse cities in Pakistan during the pandemic and analyzed it using partial least square modeling. The findings highlighted that behavioral factors and publicity information strongly impacted residents' intentions to use solar energy. Similarly, Shakeel et al. (2018) found a positive and significant impact of behavioral factors, whereas the impact of cost remained negative, using data from two metropolitan cities in Pakistan. However, they found an insignificant impact of environmental concerns and awareness.

The study of Ahmar et al. (2022) investigated the determinants of solar photovoltaic cells in four rural cities in Northwest Pakistan. The results of the logit and multivariate probit models revealed that the use of solar energy is limited in rural areas despite its enormous potential. The key determinants for the use of solar cells were age, education, school-going children, income, access to credit, female head of household, and the price of solar cells. In specific, the landholding, access to roads, age, education, school-going children, income, and access to credit were associated with the adoption of solar cells for home use, while household size, distance-to-market, access-to-grid-electricity, female head of household, and the price of solar cells were important for the adoption of solar shed-lighting and solar panel-kit systems. Finally, Shahid et al. (2022) found an inconclusive pattern of education in the adoption of renewable energy in Pakistan, using survey data mostly from university respondents, as the coefficient for education remained insignificant in their logit regression. In their analysis, awareness was the primary factor behind the poor adoption rate of renewable energy in Pakistan.

Many studies in other developing countries have investigated the household adoption of solar energy. For instance, in India, financial and economic cost were the main barrier to the diffusion of the solar energy in India (Reddy and Painuly, 2004). Moreover, high household income and education and young age is associated with the adoption of solar energy system in Uttar Pradesh India (Urpelainen and Yoon, 2015), in Kenya (Tong et al., 2015), and in Ethiopia (Guta, 2018). In Iran, Bashiri Alizadeh (2018) found that higher education and household size were positively associated with the adoption of solar energy; however, older people and

surprisingly households with higher income were less likely to adopt solar energy. In Uganda, Tanzania, and Ethiopia, Rahut et al. (2018) found higher income, education, family size, male headed, and younger household heads are more likely to adopt solar energy. In contrast, in Ethiopia, Guta (2018) found that male headed, and younger household heads are *less* likely to adopt solar energy. Similarly, the studies conducted in the developed countries have almost similar outcomes. For instance, In Ireland, well aware people are more likely to adopt the microgeneration technologies (e.g., solar heater, photovoltaic panels). However, income level was not significantly associated with the adoption of solar energy system (Claudy et al., 2010). In contrast, in the U.S. state of Wisconsin, Schelly, (2014) found that for the adoption of solar energy, the economic situation of a household is more important than calculated return on investment or payback period. The author suggested highlighting environmental benefits of solar energy may encourage more households to adopt it. Similarly, Komatsu et al. (2011) investigated the impact of solar energy adoption in Bangladesh, identifying various benefits for adopters, including reduced energy costs, improved quality of life, increased leisure time for activities such as watching television, and greater use of mobile devices. Likewise, Aklin et al. (2018) examined solar energy adoption in India and found that key determinants included the entrepreneurial attitude of the household head, savings, and overall household expenditures.

Apart from solar energy as the main lighting source, many authors including Heltberg (2005), Irfan, et al. (2021), and Lee (2013) have investigated the key determinants of household energy consumption for cooking and heating purposes. Moreover, some other researchers such as Ge et al. (2017), Irfan et al. (2021), Kumar et al. (2020), and Zhu et al. (2011) have explored the factors associated with the adoption of renewable energy sources (a mix of biogas, wind energy, hydropower, and solar energy). Moreover, some review research articles—Alipour et al. (2020), Best et al. (2023), and Best et al. (2024)—examined a vast number of studies and concluded that income and education are positively associated with the adoption of solar photovoltaics.

In summary, almost all studies have concluded that higher income, education, awareness, and lower cost of renewable, sustainable, and cleaner energy technologies are positively associated with the adoption of these sources. Age, gender of household head, and family size have mixed (positive and negative) impacts on the adoption of renewable energies. They have also highlighted the important role of psychological and social factors on the adoption of renewable energies, including solar cells. However, the specific thresholds of income and education required to reduce the use of dirty fuels or promote the adoption of cleaner fuels remain relatively unexplored. Furthermore, a notable gap in the extant literature is the limited comparison between grid-sourced electricity and solar energy adoption. This study addresses this gap and provides a more comprehensive analysis.

3. *Data and Methods*

We used the 11th wave of the Pakistan Social and Living Standards Measurement Survey 2018-19 (PSLM) for this study. In 2015, questions related to the SDGs were included in the questionnaire upon United Nation's request (e.g., what is the main fuel for heating and lighting). Therefore, PSLM 2018-19 is the first survey which has covered solar energy related questions, hence making our study the first to investigate the adoption of solar energy at national level.

The Federal Bureau of Statistics (FBS) developed the data collection frame for the PSLM 2018-19. Each city was divided into enumeration blocks consisting of 200-250 households. Each enumeration block was then classified into three strata based on household incomes, i.e., low, medium, and high. A two-stage stratified sample design was adopted to collect the data. Each primary sampling unit (PSU) from a stratum was selected through a probability proportional to size (PPS) method, and within each rural PSU, 12 households were selected, and within each urban PSU, 16 households were selected. Initially, 25,940 households from 1,820 PSUs were selected. However, due to ongoing conflict in some areas, 18 PSUs were dropped, and 24,809 households were interviewed from 1,802 PSUs. Given the stratified random nature of sampling, the data can be considered to be reasonably representative of households in both rural and urban areas in Pakistan (excluding the conflict-affected areas). Most of the houses (91.5%) were owner-occupied, while a smaller proportion (8.5%) were rented at the time of the survey. Generally, households in Pakistan use electricity, natural gas, firewood, candles, and kerosene oil for lighting purposes. Some households ($n = 847$) did not respond to the main lighting source question. Therefore, we dropped them from the analysis, leaving an analytical sample of 23,962 households.

3.1 Variables: Our dependent variable, "main lighting source," has three categories: (1) Electricity from the grid; (2) Solar plant; and (3) Dirty fuels (kerosene oil, firewood, agricultural waste, and candles). Solar energy was only included in the options for main lighting and heating source in the questionnaire, and not for other potential uses of energy such as cooking. In response to the heating question, only 0.18% of households responded that they used solar energy. Thus, we focus on solar energy as the main lighting source, which 5.7% of households use. Overall, most households (92%) use electricity from the grid as their main lighting source and only 2.2% of the households use dirty fuel as their main lighting source. Households often use more than one energy source to meet their energy requirements (Irfan et al., 2021). However, we consider only the main sources used for lighting, which can be either electricity from the grid, solar or dirty fuels. An extensive literature on the importance of income, education, age, gender, family size, and households' locating area is available (see above). Hence, we include all of those variables in our main model, along with the size of household and agricultural occupation. The descriptive statistics for all variables are given in Table 1.

Table 1
DESCRIPTIVE STATISTICS^a

Variable	Obs	Mean	Std. Dev.	Min	Max
Household monthly Income (PKR thousands)	23,962	28.982	33.107	0	1500
Household head's education (schooling years)	23,962	4.957	5.159	0	20
Household head's age	23,906	45.983	13.585	16	99
Household head's gender (Male)	23,962	0.965	0.183	0	1
Family size	23,962	6.469	3.243	1	56
Number of rooms in dwelling	23,962	2.389	1.391	1	15
Region (Urban)	23,962	0.367	0.482	0	1
Agricultural occupation (Yes)	23,962	0.201	0.401	0	1

^aDirty Fuel = Firewood, agricultural waste, candles, or kerosene oil.

Accepting the high importance of income and education (as discussed in the literature), we first applied Tukey's test to examine whether the mean of income and education differs by main lighting source or not. The test is a multiple comparison test which compares more than two means (Ramachandran, 1956). In our case, we compare the mean income, education between the adopters of dirty fuels, solar energy, and grid-sourced electricity. The results are presented in Table 2. Household income differs significantly between households using different lighting sources. Households that use grid-sourced electricity for lighting have the highest average income, followed by those using solar energy, and those using dirty fuels have the lowest income. All differences between these household types are statistically significant. Similarly, households using grid-sourced electricity for lighting have the highest education (of the household head), followed by those using solar energy, and those using dirty fuels, and again these differences in means are statistically significant. This provides further support for investigating the relationship between income, education, and main lighting sources in depth. We then moved to apply multinomial logit model and run simulations of solar energy use under different scenarios of income and education levels.

3.2 Methods: We applied the Multinomial Logit Model (MLM) to estimate the log odds of adopting solar energy. The model shows the behavior of consumers with a common consumption objective when they are faced with the choice between many mutually exclusive options. In our case, this is the choice between consuming different main fuels for lighting purposes (grid-sourced electricity, solar energy, or dirty fuels). These alternatives are mutually exclusive because, by definition, households can only have one *main* source of lighting. The model is based on the random utility function, where individuals make decisions by comparing the levels of utility associated with each possible alternative. In classical demand theory, the problem of consumer choice is usually described as a problem of utility maximization under a limited budget, with a utility function characterizing the consumer's preferences for consuming varying amounts of each type of commodity.

Table 2
COMPARISON OF HOUSEHOLD INCOME AND EDUCATION AMONG MAIN LIGHTING
SOURCE ADOPTERS

HH monthly income in thousands PKR	Contrast	Std. Err.	<i>t</i>	P><i>t</i>	[95% CI]	
Solar energy vs Dirty fuel	5.695	1.691	3.370	0.002	1.732	9.658
Grid Electricity vs Dirty fuel	15.178	1.454	10.440	0.000	11.769	18.587
Grid Electricity vs Solar energy	9.483	0.918	10.330	0.000	7.332	11.633
HH head's education (schooling years)						
Solar energy vs Dirty fuel	1.028	0.265	3.890	0.000	0.408	1.648
Grid Electricity vs Dirty fuel	3.529	0.228	15.510	0.000	2.996	4.063
Grid Electricity vs Solar energy	2.501	0.144	17.420	0.000	2.165	2.838

The MLM is widely used in estimating the log odds of household energy choices (Irfan et al., 2021). Alternative methods, such as instrumental variable regression, can address endogeneity issues (Irfan et al., 2023). However, the lack of a suitable instrument remains a limitation of this analysis.

The model assumes that households select an energy source that maximizes their utility. Let a household p , from n total households in the sample, select an energy source j from m mutually exclusive sources. The utility function U_p of an energy source X_j can be written as:

$$U_p = f(X_j) + e_{jp} \quad (1)$$

where:

- $j = 1, 2, 3, \dots, m$
- and $p = 1, 2, 3, \dots, n$

and e_{jp} is the error term following an i.i.d. extreme value distribution. The CDF of each error term is given by $[F(e_{jp}) = \exp\{-e^{-e_{jp}}\}]$. Finally, we have:

$$\Pr [Cl = j] = \exp^{\beta_j X_i} / 1 + \sum_{j=0}^m \exp^{\beta_j X_i} \quad (2)$$

where $\Pr [Cl = j]$ is the probability of choosing energy source j , with one of the energy sources as a reference category (in our application, we use dirty fuel as reference the category), j is the number of energy sources (total 3) in the choice set, $j = 0$ for the reference energy source (dirty fuels in our case), and X_i is a vector of explanatory variables.

The MLM relies on the assumption of the Independence of Irrelevant Alternatives (IIA), i.e., that the relative odds of the choices are independent of the number

of alternatives is one of the main limitations of the MLM. Nevertheless, as we don't have choice specific variables in our data sets, we could not apply relatively more flexible models such as the mixed logit model. Moreover, while non-parametric approaches can better estimate the odds of selecting an item, such models are better fit for time-variant data sets, i.e., panel or time series data. However, as the PSLM only provides cross-sectional data, MLM is the best available model for estimating the odds of choosing a main lighting source in this context.

We then use the estimates from the MLM to simulate the levels of socioeconomic factors necessary to ensure 50 percent of households would adopt solar energy for lighting, holding other factors constant. Specifically, we run seven simulations for each of top five variables (household income, household head's education, household head's age, number of rooms in the dwelling, and family size), using the *nnet* and *tidylog* packages in R.

4. Results and Discussion

Table 3 presents the results of the MLM, where the selection of dirty fuels is taken as the reference category first in Panels A and B (i.e., all odds ratio comparisons are the odds in comparison with dirty fuels), and then solar energy is taken as the reference category in Panels C and D, specifically to observe household preferences between grid-sourced electricity and solar energy.

As expected, household income is positively associated with both cleaner energy sources (solar and grid-sourced electricity), as shown in Panels A and B of Table 3. The odds of adopting solar energy and grid-sourced electricity over dirty fuels are 1.02 and 1.04 times higher, respectively, for each PRK 1,000 (USD 7.2)³ increase in income. Likewise, education of the household head is also positively associated with the adoption of cleaner energy sources. The odds of selecting solar energy as the main energy source are 1.04 times higher than dirty fuel adoption for each additional year of education. These results corroborate the findings of the extant literature, with respect to the positive association between cleaner energy and income and education (Jan et al., 2020; Tong et al., 2015, and Rahut et al., 2018).

Households with male household heads have 3.57 times higher odds of choosing solar energy compared to households with female household heads. This is surprisingly inconsistent with Irfan et al. (2021), who found that female headed households were more likely to adopt cleaner fuels for cooking. Perhaps, energy sources for cooking are more salient for females, and the costs of dirty fuels in terms of indoor air pollution are concentrated on women and children in the household, and so female-headed households are more likely to adopt cleaner fuels.

³ <https://www.ceicdata.com/en/indicator/pakistan/exchange-rate-against-usd> This study uses 2018-19 data, therefore, we use January 2019 USD to PKR rate (1USD = 138.7 PKR).

Table 3
RESULTS OF MULTINOMIAL LOGIT MODEL^a

Panel A: Solar Energy (vs. Dirty Fuels as Reference)						
Main Lighting Source	Odds Ratio	Std. Err.	z	P> z 	[95% CI]	
Household monthly Income (PKR thousands)	1.025	0.006	4.40	0.000	1.014	1.036
Household head's education (schooling years)	1.045	0.017	2.76	0.006	1.013	1.078
Household head's age	0.993	0.004	-1.71	0.087	0.985	1.001
Household head's gender (Male)	3.566	1.677	2.70	0.007	1.418	8.965
Family size	0.992	0.020	-0.43	0.670	0.954	1.031
Number of rooms in dwelling	1.739	0.106	9.09	0.000	1.544	1.960
Region (Urban)	0.992	0.230	-0.03	0.973	0.631	1.561
Agricultural occupation (Yes)	0.488	0.053	-6.57	0.000	0.394	0.605
Constant	0.285	0.144	-2.49	0.013	0.106	0.766
Panel B: Grid-sourced Electricity (vs. Dirty Fuels as Reference)						
Main Lighting Source	Odds Ratio	Std. Err.	z	P> z 	[95% CI]	
Household monthly Income (PKR thousands)	1.043	0.005	8.17	0.000	1.033	1.054
Household head's education (schooling years)	1.124	0.016	8.10	0.000	1.092	1.156
Household head's age	1.005	0.004	1.50	0.134	0.998	1.012
Household head's gender (Male)	0.806	0.253	-0.69	0.492	0.435	1.492
Family size	0.891	0.016	-6.37	0.000	0.860	0.923
Number of rooms in dwelling	1.656	0.095	8.77	0.000	1.480	1.854
Region (Urban)	5.565	1.150	8.31	0.000	3.712	8.342
Agricultural occupation (Yes)	0.451	0.042	-8.54	0.000	0.376	0.542
Constant	9.542	3.373	6.38	0.000	4.773	19.076
Panel C: Dirty Fuels (vs. Solar Energy as Reference)						
Main Lighting Source	Odds Ratio	Std. Err.	z	P> z 	[95% CI]	
Household monthly Income (PKR thousands)	0.976	0.005	-4.40	0.000	0.965	0.986
Household head's education (schooling years)	0.957	0.015	-2.76	0.006	0.928	0.987
Household head's age	1.007	0.004	1.71	0.087	0.999	1.015
Household head's gender (Male)	0.280	0.132	-2.70	0.007	0.112	0.705
Family size	1.008	0.020	0.43	0.670	0.970	1.048
Number of rooms in dwelling	0.575	0.035	-9.09	0.000	0.510	0.648
Region (Urban)	1.008	0.233	0.030	0.973	0.640	1.586
Agricultural occupation (Yes)	2.047	0.223	6.57	0.000	1.653	2.535
Constant	3.508	1.770	2.49	0.013	1.305	9.428

(continued)

Table 3 (continued)
RESULTS OF MULTINOMIAL LOGIT MODEL^a

Panel D: Grid-sourced Electricity (vs. Solar Energy as Reference)						
Main Lighting Source	Odds Ratio	Std. Err.	z	P> z 	[95% CI]	
Household monthly Income (PKR thousands)	1.018	0.002	8.15	0.000	1.014	1.023
Household head's education (schooling years)	1.075	0.008	9.82	0.000	1.060	1.091
Household head's age	1.012	0.002	5.43	0.000	1.008	1.017
Household head's gender (Male)	0.226	0.081	-4.14	0.000	0.112	0.457
Family size	0.899	0.008	-11.49	0.000	0.883	0.915
Number of rooms in dwelling	0.952	0.021	-2.17	0.030	0.911	0.995
Region (Urban)	5.608	0.599	16.14	0.000	4.549	6.914
Agricultural occupation (Yes)	0.924	0.059	-1.23	0.219	0.815	1.048
Constant	33.468	12.437	9.45	0.000	16.156	69.333

Number of obs = 23,906
Prob > chi2 = 0.0000
Pseudo R2 = 0.1220

^aThe results in Panels A and B are from a multinomial logit model with dirty fuels as the reference category. The results in Panels C and D are from a multinomial logit model with solar energy as the reference category.

While for lighting energy sources, solar energy is better to reduce the cost, and it may make male heads to adopt cost effective energy sources (renewable energy sources e.g., solar energy) because usually male counterparts bear the household's overall expenditures.

Moreover, households with a larger dwelling (greater number of rooms) have significantly higher odds of adopting cleaner fuels. Our estimates show that each additional room is associated with 1.74 times higher odds of choosing solar energy rather than dirty fuels. This is likely capturing a wealth effect, with wealthier households better able to afford the up-front costs associated with solar photovoltaic adoption. However, if a household is involved in the agricultural occupation, then the chances of adopting cleaner fuels is reduced. Possibly, if a household is involved in an agricultural occupation, they can access freely available energy sources such as wood and crop residues (both of which are dirty fuels). Hence, they don't need to pay for lighting, and this can lead to an increase in the adoption of dirty fuels and decrease in the use of cleaner fuels.

Surprisingly, the region being urban does not affect the adoption of solar energy significantly. Conceivably, solar plants require little space to install (can be installed on the roof tops) or do not require transmission lines and therefore the region being urban or rural becomes irrelevant. On the other hand, the region being urban is significantly and positively associated with the adoption of grid-sourced

electricity because the urban region has access (transmission) to electricity. The odds of adopting grid-sourced electricity as compared to dirty fuels for the households that are in urban areas are 5.6 times higher than that of rural households.

Moreover, comparing preferences between solar energy and grid-sourced electricity in Panel D of Table 3, our estimates show that, as income and education rise, the odds of adopting grid-sourced electricity increase by 1.02 and 1.08 times, respectively, in comparison to solar energy. In other words, taking all the results in Table 3 together, grid-sourced electricity can be considered as the most preferred lighting source.

4.1 Simple Simulations: The previous analysis suggests that as household income and education of household heads increase (as we would expect to happen over time), both solar adoption and grid-sourced electricity adoption would increase at the expense of dirty fuels. However, at the same time, solar adoption would decrease in favor of grid-sourced electricity. To evaluate the net impact of increases in household income and education on main lighting source adoption, simulations were run using MLM, where the value of one variable was changed (income, or education) holding the rest of the variables constant. The results are laid out in the figures for better visualization. The results in tabular form are included in the appendix. We focus attention on the proportion of households that adopt solar energy or continue to use dirty fuels. The probability of using grid-sourced electricity for lighting remains more than 92 percent in all the scenarios in all simulations. The probabilities of dirty fuel and solar energy vary between 0 and 5 percent.

In the first simulation, we assumed income was increased gradually (10,000 PKR in each scenario), holding all other variables constant for each household. As shown in Figure 1, the adoption of dirty fuels and solar energy decline as income increases, while the probability of grid-sourced electricity adoption increases (shown in figure 3). However, interestingly, dirty fuel use decreases more than solar energy use. Overall, based on this simulation it is clear that higher incomes would lead to lower adoption of solar energy for lighting in Pakistan.

Simulation 2 is presented in Figure 2, where the education of the household head was increased in each scenario (two-year increments),⁴ holding the value of all other variables constant. As for income, both dirty fuel use and solar energy use decrease with higher education, and consequently grid-sourced electricity adoption increases (shown in figure 3). This simulation confirms that, along with income, higher household education would lead to lower adoption of solar energy for lighting.

Figure 3 presents the results of household grid-sourced electricity use from first and second simulations. The probability of using electricity for every additional

⁴ We minorized the maximum level of education and kept it to a maximum of 20 years of schooling (equivalent to holding a doctoral degree).

Figure 1
INCOME'S EFFECT ON DIRTY FUEL (DF) AND SOLAR ENERGY (SO) ADOPTION

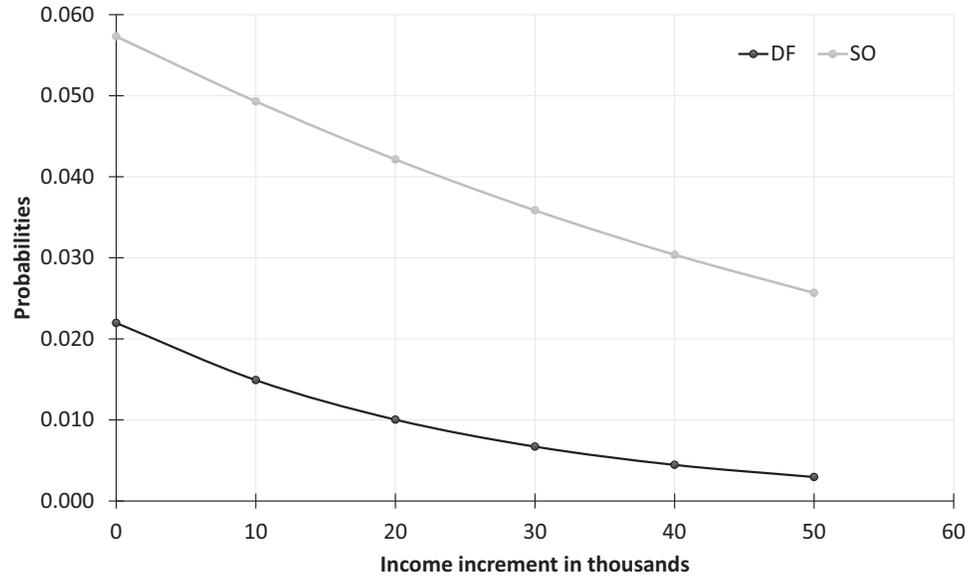


Figure 2
EDUCATION'S EFFECT ON DIRTY FUEL (DF) AND SOLAR ENERGY (SO) ADOPTION

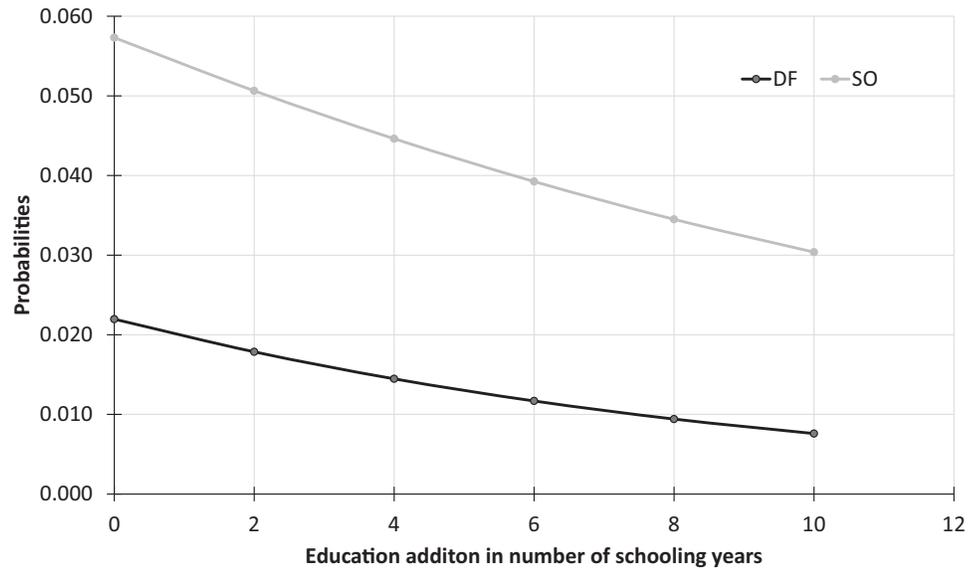
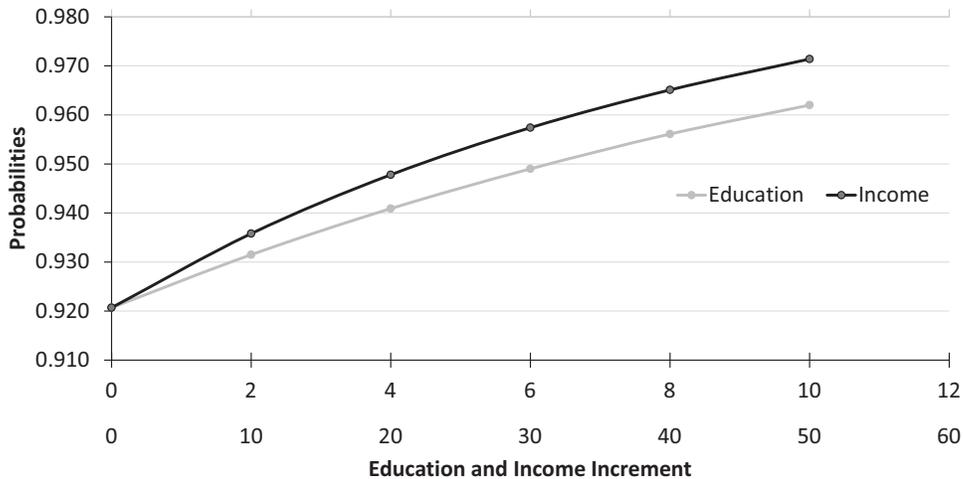


Figure 3
INCOME AND EDUCATION'S EFFECT ON ELECTRICITY ADOPTION



10,000 PKR income and two years of schooling is consistently more than 92%. The key result from this simulation, along with the simulations presented in Figures 1 and 2, is that increasing income and education would lead to greater adoption of electricity and not greater solar energy adoption.

The simulation analysis suggests that if a household's income reaches 40,000 PKR per month, the probability of adopting dirty fuel drops to less than 1%, solar energy to 3%, and grid-sourced electricity to slightly above 96%. Similarly, if the household head's education exceeds 10 years, the probability of choosing dirty fuel for lighting decreases to below 1%, solar energy to 3%, and grid-sourced electricity to around 97%.

5. Conclusion

Provision of affordable and clean energy is enshrined in Sustainable Development Goal 7. However, almost half of the world continues to use dirty fuels to meet their energy requirements. The consumption of dirty fuels not only damages the environment but contributes to climate change and also adversely burdens the country's health and economic situation. Almost every country is striving hard to shift from dirty fuel consumption to cleaner fuels or zero carbon emission fuels. However, like many other developing countries, Pakistan is still dependent on dirty fuel consumption (firewood, crop residues, animal dung, coal, and kerosene oil) and its grid electricity production is heavily dependent on oil (roughly 63%).

Nevertheless, Pakistan has good potential to produce solar and hydroelectric energy and adopting solar energy could be a suitable option to have renewable, sustainable, and affordable energy, especially for rural areas where the transmission cost of grid-sourced electricity is high.

However, the adoption of solar photovoltaic energy systems in Pakistan has not gained momentum, despite World Bank and Asian Development support, perhaps because of poor diffusion policy and lack of research in this area. For instance, PSLM 2018-19 is the first dataset that includes data about household solar energy usage in Pakistan. Therefore, understanding the contributors to solar energy adoption is not well understood. Hence, we applied MLM to estimate the odds of adopting main lighting source and explored the main socioeconomic factors which are associated with the adoption of main lighting energy source. We found that higher income education, number of rooms in a dwelling, and gender being male were positively associated with the adoption of solar energy in comparison to dirty fuels.

We further ran simulations to calculate the probabilities of all the main lighting sources. The simulations showed that grid-sourced electricity will remain the most preferred lighting source in Pakistan. The odds of adopting grid-sourced electricity for each additional unit of income, education, and number of rooms are slightly higher than solar energy. Moreover, the probability of choosing grid-sourced electricity as main lighting source remains higher than 92% in all scenarios. However, as stated above, grid electricity production is mainly dependent on oil. Perhaps, switching electricity production from fossil fuels to cleaner and renewable energy sources such as hydroelectric, solar, and wind may significantly reduce the detrimental environmental and health effects as well as reduce the oil import burden on the country. However, electricity connections to rural households require massive transmission costs, which may be avoided by adopting solar photovoltaic panels. Perhaps, providing a subsidy for the adoption of solar energy in rural areas would be more cost-effective than large-scale electricity transmission to those areas. Further research should explore these options in detail. Nevertheless, Pakistan needs to formulate a clear policy on the production and diffusion of renewable and sustainable energy sources.

REFERENCES

- Ahmar, M., F. Ali, Y. Jiang, Y. Wang, and K. Iqbal. 2022. "Determinants of Adoption and the Type of Solar PV Technology Adopted in Rural Pakistan." *Frontiers in Environmental Science* 10 (May). <https://doi.org/10.3389/fenvs.2022.895622>.
- Akhtar, S., M. K. Hashmi, I. Ahmad, and R. Raza. 2018. "Advances and Significance of Solar Reflectors in Solar Energy Technology in Pakistan." *Energy & Environment* 29 (4): 435–55. <https://doi.org/10.1177/0958305X18758487>.
- Aklin, M., P. Bayer, S. P. Harish, and J. Urpelainen. 2018. "Economics of Household Technology Adoption in Developing Countries: Evidence from Solar Technology Adoption in Rural India." *Energy Economics* 72 (May): 35–46. <https://doi.org/10.1016/j.eneco.2018.02.011>.

- Alipour, M., H. Salim, R. A. Stewart, and O. Sahin. 2020. "Predictors, Taxonomy of Predictors, and Correlations of Predictors with the Decision Behaviour of Residential Solar Photovoltaics Adoption: A Review." *Renewable and Sustainable Energy Reviews* 123 (May): 109749. <https://doi.org/10.1016/j.rser.2020.109749>.
- Asif, M. H., T. Zhongfu, A. Dilanchiev, M. Irfan, E. Eyvazov, and B. Ahmad. 2023. "Determining the Influencing Factors of Consumers' Attitude toward Renewable Energy Adoption in Developing Countries: A Roadmap toward Environmental Sustainability and Green Energy Technologies." *Environmental Science and Pollution Research* 30 (16): 47861–72. <https://doi.org/10.1007/s11356-023-25662-w>.
- Bashiri, A., and S. H. Alizadeh. 2018. "The Analysis of Demographics, Environmental and Knowledge Factors Affecting Prospective Residential PV System Adoption: A Study in Tehran." *Renewable and Sustainable Energy Reviews* 81 (January): 3131–39. <https://doi.org/10.1016/j.rser.2017.08.093>.
- Best, R., M. Marrone, and M. Linnenluecke. 2023. "Meta-Analysis of the Role of Equity Dimensions in Household Solar Panel Adoption." *Ecological Economics* 206 (April): 107754. <https://doi.org/10.1016/j.ecolecon.2023.107754>.
- . 2024. "Do Income and Capital Influence Household Solar Panel Investment? A Meta-Regression." *Energy Journal* 45 (4): 159–77. <https://doi.org/10.1177/01956574241284501>.
- Claudy, M. C., C. Michelsen, A. O'Driscoll, and M. R. Mullen. 2010. "Consumer Awareness in the Adoption of Microgeneration Technologies: An Empirical Investigation in the Republic of Ireland." *Renewable and Sustainable Energy Reviews* 14 (7): 2154–60. <https://doi.org/10.1016/j.rser.2010.03.028>.
- Guta, D. D. 2018. "Determinants of Household Adoption of Solar Energy Technology in Rural Ethiopia." *Journal of Cleaner Production* 204 (December): 193–204. <https://doi.org/10.1016/j.jclepro.2018.09.016>.
- Hasheem, M. J., S. Wang, N. Ye, M. Z. Farooq, and H. M. Shahid. 2022. "Factors Influencing Purchase Intention of Solar Photovoltaic Technology: An Extended Perspective of Technology Readiness Index and Theory of Planned Behaviour." *Cleaner and Responsible Consumption* 7 (December): 100079. <https://doi.org/10.1016/j.clrc.2022.100079>.
- Heltberg, R. 2005. "Factors Determining Household Fuel Choice in Guatemala." *Environment and Development Economics* 10 (3): 337–61. <https://doi.org/10.1017/S1355770X04001858>.
- Irfan, M., G. Hassan, and M. P. Cameron. 2021. "Can Income Growth Alone Increase Household Consumption of Cleaner Fuels? Evidence from Pakistan." *Economia Politica* 2: 121–46. <https://doi.org/10.3280/EFE2021-002006>.
- Irfan, M., M. P. Cameron, and G. Hassan. 2023. "The Causal Impact of Solid Fuel Use on Mortality – A Cross-Country Panel Analysis." *International Journal of Energy Economics and Policy* 13 (1). <https://doi.org/10.32479/ijeep.13498>.
- Irfan, M., Z.-Y. Zhao, A. Rehman, I. Ozturk, and H. Li. 2021. "Consumers' Intention-Based Influence Factors of Renewable Energy Adoption in Pakistan: A Structural Equation Modeling Approach." *Environmental Science and Pollution Research* 28 (1): 432–45. <https://doi.org/10.1007/s11356-020-10504-w>.
- Jan, I., W. Ullah, and M. Ashfaq. 2020. "Social Acceptability of Solar Photovoltaic System in Pakistan: Key Determinants and Policy Implications." *Journal of Cleaner Production* 274 (November): 123140. <https://doi.org/10.1016/j.jclepro.2020.123140>.
- Kamran, M. 2018. "Current Status and Future Success of Renewable Energy in Pakistan." *Renewable and Sustainable Energy Reviews* 82 (February): 609–17. <https://doi.org/10.1016/j.rser.2017.09.049>.
- Kamran, M., et al. 2019. "Socio-Economic Acceptance for Stand-Alone Solar PV Systems: Survey Evidence from Southern Punjab, Pakistan." *International Journal of Renewable Energy Research* 9 (1). Accessed March 9, 2025. <https://www.ijrer.com/index.php/ijrer/article/view/8904>.

- Khan, M. A., and N. Latif. 2010. "Environmental Friendly Solar Energy in Pakistan's Scenario." *Renewable and Sustainable Energy Reviews* 14 (8): 2179–81. <https://doi.org/10.1016/j.rser.2010.03.016>.
- Komatsu, S., S. Kaneko, and P. P. Ghosh. 2011. "Are Micro-Benefits Negligible? The Implications of the Rapid Expansion of Solar Home Systems (SHS) in Rural Bangladesh for Sustainable Development." *Energy Policy* 39 (7): 4022–31. <https://doi.org/10.1016/j.enpol.2010.11.022>.
- Kumar, V., A. S. Syan, A. Kaur, and B. S. Hundal. 2020. "Determinants of Farmers' Decision to Adopt Solar Powered Pumps." *International Journal of Energy Sector Management* 14 (4): 707–27. <https://doi.org/10.1108/IJESM-04-2019-0022>.
- Lee, L. Y.-T. 2013. "Household Energy Mix in Uganda." *Energy Economics* 39 (September): 252–61. <https://doi.org/10.1016/j.eneco.2013.05.010>.
- Liang, X., X. Hu, T. Islam, and M. S. Mubarik. 2021. "Social Support, Source Credibility, Social Influence, and Solar Photovoltaic Panels Purchase Intention." *Environmental Science and Pollution Research* 28 (41): 57842–59. <https://doi.org/10.1007/s11356-021-14750-4>.
- Mirjat, N. H., M. A. Uqaili, K. Harijan, G. D. Valasai, F. Shaikh, and M. Waris. 2017. "A Review of Energy and Power Planning and Policies of Pakistan." *Renewable and Sustainable Energy Reviews* 79 (November): 110–27. <https://doi.org/10.1016/j.rser.2017.05.040>.
- Qureshi, T. M., K. Ullah, and M. J. Arentsen. 2017. "Factors Responsible for Solar PV Adoption at Household Level: A Case of Lahore, Pakistan." *Renewable and Sustainable Energy Reviews* 78 (October): 754–63. <https://doi.org/10.1016/j.rser.2017.04.020>.
- Rahut, D. B., K. A. Mottaleb, A. Ali, and J. B. Aryal. 2018. "The Use and Determinants of Solar Energy by Sub-Saharan African Households." *International Journal of Sustainable Energy* 37 (8): 718–35. <https://doi.org/10.1080/14786451.2017.1323897>.
- Ramachandran, K. V. 1956. "On the Tukey Test for the Equality of Means and the Hartley Test for the Equality of Variances." *Annals of Mathematical Statistics* 27 (3): 825–31. Accessed October 17, 2022. <https://www.jstor.org/stable/2237389>.
- Reddy, S., and J. P. Painuly. 2004. "Diffusion of Renewable Energy Technologies—Barriers and Stakeholders' Perspectives." *Renewable Energy* 29 (9): 1431–47. <https://doi.org/10.1016/j.renene.2003.12.003>.
- Schelly, C. 2014. "Residential Solar Electricity Adoption: What Motivates, and What Matters? A Case Study of Early Adopters." *Energy Research & Social Science* 2 (June): 183–91. <https://doi.org/10.1016/j.erss.2014.01.001>.
- Shahid, I. A., K. Ullah, C. A. Miller, M. Dawood, and M. I. Ahmed. 2022. "Rooftop Solar Adoption among Populations and Markets Outside the US and Europe—A Case from Pakistan." *Electricity Journal* 35 (3): 107090. <https://doi.org/10.1016/j.tej.2022.107090>.
- Shakeel, S. R., and S. ur Rahman. 2018. "Towards the Establishment of Renewable Energy Technologies' Market: An Assessment of Public Acceptance and Use in Pakistan." *Journal of Renewable and Sustainable Energy* 10 (4): 045907. <https://doi.org/10.1063/1.5033454>.
- Tate, G., A. Mbzibain, and S. Ali. 2012. "A Comparison of the Drivers Influencing Farmers' Adoption of Enterprises Associated with Renewable Energy." *Energy Policy* 49 (October): 400–409. <https://doi.org/10.1016/j.enpol.2012.06.043>.
- Tong, T. M., et al. 2015. "A Study of Factors That Influence the Adoption of Solar Powered Lanterns in a Rural Village in Kenya." <https://doi.org/10.1163/15691497-12341356>.
- United Nations. 2025. "THE 17 GOALS | Sustainable Development." Accessed March 9, 2025. <https://sdgs.un.org/goals>.
- Urpelainen, J., and S. Yoon. 2015. "Solar Home Systems for Rural India: Survey Evidence on Awareness and Willingness to Pay from Uttar Pradesh." *Energy for Sustainable Development* 24 (February): 70–78. <https://doi.org/10.1016/j.esd.2014.10.005>.

Wang, H., H. Zameer, and Y. Wang. 2018. "Energy Production System Optimization: Evidence from Pakistan." *Renewable and Sustainable Energy Reviews* 82 (February): 886–93. <https://doi.org/10.1016/j.rser.2017.09.089>.

Wang, J., and W. Azam. 2024. "Natural Resource Scarcity, Fossil Fuel Energy Consumption, and Total Greenhouse Gas Emissions in Top Emitting Countries." *Geoscience Frontiers* 15 (2): 101757. <https://doi.org/10.1016/j.gsf.2023.101757>.

Waris, I., I. Hameed, and R. Ali. 2022. "Predicting Household Sign Up for Solar Energy: An Empirical Study Based on the Extended Theory of Planned Behavior." *International Journal of Energy Sector Management* 17 (3): 455–73. <https://doi.org/10.1108/IJESM-06-2021-0010>.

World Bank. 2025. "Expanding Renewable Energy in Pakistan's Electricity Mix." Accessed March 9, 2025. <https://www.worldbank.org/en/news/feature/2020/11/09/a-renewable-energy-future-for-pakistans-power-system>.

Zakeri, B., et al. 2022. "Pandemic, War, and Global Energy Transitions." *Energies* 15 (17). <https://doi.org/10.3390/en15176114>.

Zhu, B., W. Zhang, J. Du, W. Zhou, T. Qiu, and Q. Li. 2011. "Adoption of Renewable Energy Technologies (RETs): A Survey on Rural Construction in China." *Technology in Society* 33 (3): 223–30. <https://doi.org/10.1016/j.techsoc.2011.09.002>.

APPENDIX

Table A1
INCOME'S EFFECT ON MAIN LIGHTING SOURCE ADOPTION^a

Household Income increment in Thousands	DF	SO	ELT	Total
0	0.022	0.057	0.921	1.0
10	0.015	0.049	0.936	1.0
20	0.010	0.042	0.948	1.0
30	0.007	0.036	0.957	1.0
40	0.004	0.030	0.965	1.0
50	0.003	0.026	0.971	1.0

^aAuthors' calculations, DF: Dirty Fuel, SO: Solar Energy, ELT: Grid-Electricity

Table A2
EDUCATION'S EFFECT ON MAIN LIGHTING SOURCE ADOPTION^a

Household head's education increment in schooling years	DF	SO	ELT	Total
0	0.022	0.057	0.921	1.0
2	0.018	0.051	0.932	1.0
4	0.014	0.045	0.941	1.0
6	0.012	0.039	0.949	1.0
8	0.009	0.035	0.956	1.0
10	0.008	0.030	0.962	1.0

^aAuthors' calculations, DF: Dirty Fuel, SO: Solar Energy, ELT: Grid-Electricity.

Table A3
INCOME AND EDUCATION INCREMENT EFFECT ON GRID-SOURCED
ELECTRICITY ADOPTION^a

Income (Monthly in thousands)	Education (schooling years)	ELT - Income	ELT - Education
0	0	0.921	0.921
10	2	0.936	0.932
20	4	0.948	0.941
30	6	0.957	0.949
40	8	0.965	0.956
50	10	0.971	0.962

^aAuthors' calculations, ELT: Grid-Electricity.