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Nexus Between Energy Poverty and Technological Innovations: A Pathway for Addressing Energy Sustainability

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Pakistan has experienced energy poverty, as most of the people live in rural areas. Poor people are stereotyped as collecting the firewood and using the unclean energy sources to meet their residential energy needs. As a result, respondents in the provinces with the highest rates of energy poverty set a high priority on this research. Structured interviews were used to conduct the research in rural parts of Punjab and Sindh provinces. Due to the apparent country's large population and rapid industrialization, conventional energy sources cannot meet the country's present energy needs. Results revealed that energy poverty in rural areas had exposed the residents to security problems such as health dangers, fire accidents, time poverty, financial poverty, illiteracy, and other issues at various levels of severity. As a result, alternative energy sources must be explored. This research aims to determine the best renewable energy choice for Pakistan's rural areas. In terms of pricing, life duration, operation, and maintenance costs, the results show that solar energy is the best renewable energy source for Pakistan. The key barriers that continue to promote energy poverty have been identified. Finally, the study suggests policy recommendation for public and private sectors to overcome energy related barriers to alleviate energy poverty in rural areas by utilizing maximum solar energy.

Keywords: energy poverty, firewood, solar power, assessment, alleviation, Pakistan

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1 INTRODUCTION

Energy is crucial to advancing contemporary economic and social development and welfare (Owusu and Asumadu-Sarkodie, 2016). All human activities, including education, health care, and agriculture, require energy to work properly. Without appropriate energy usage, a nation cannot develop. It is regarded as the most crucial aspect of its economy (Naseem and Khan, 2015). Electricity is the backbone of a country's economic and social growth. However, 1.1 billion people worldwide do not have access to electricity (Warner and Jones, 2017). This energy-related poverty is termed "energy poverty" worldwide (Halkos and Gkampoura, 2021a). World Economic Forum (2010) defines the lack of access to sustainable and cheap renewable energy services as energy poverty (Sher et al., 2014). Energy poverty is defined as a person who does not have access to at least 35 kg of liquid LPG per year for cooking and 120 kW-hours of electricity per capita per year for illumination (Sher et al., 2014). Energy poverty affects the rural areas of the developing country's population. Even it also affects the developed countries such as Europe (Bollino and Botti, 2017). The majority of the people affected by this scenario live in rural zones of Sub-Saharan Africa(SSA) and South Asia (Das et al., 2016).

Worldwide energy consumption is predictable to be five times greater than current statistics due to growing technical industrial developments and larger electrical grids (Longe, 2021). The struggle against energy poverty is becoming crucially influential as the world's population grows by slightly more than one billion people over the coming 13 years, reaching 8.6 billion in 2030, 9.8 billion in 2050, and 11.2 billion by 2100 (United Nations), (Hassani et al., 2019). However, to meet rising energy demand, the energy industry could not increase the capacity of polluting power plants. Otherwise, the global average surface temperature would be rise by 2°C. (Geggel, 2017), resulting in dangerous climate change and the extinction of some flora and animals, among other things. To decrease global energy poverty, we must promote the usage of renewable energy sources to meet the world's ever-increasing energy demands. According to NASA's Goddard Institute for Space Studies (GISS), 2020 reports being 1.02°C degrees Celsius warmer than the 1951–1980 baseline (NASA) (Longe, 2021). As a result, global energy poverty should alleviate through renewable, affordable, and long-term energy sources. Women are frequently stigmatized as being responsible for providing and utilizing filthy energy in their homes. As a result, they collect and consume firewood, kerosene, coal, and animal dung regularly (Das et al., 2016; Bollino and Botti, 2017; Hassani et al., 2019; Longe, 2021; United Nations).Residential smog is caused by inefficient burning of dirty energy sources within homes, and it is estimated that it affects four million people each year (Longe, 2021).Modern cooking fuels enable mothers and children to live a healthy lifestyle (Mahmood and Shah, 2017).

Pakistan is still a developing nation, confronts with societal and ecological problems. A large percentage of Pakistan's population lives in rural regions, and mostly lack access to electricity. Furthermore, the country's growing population leading the higher energy demand. The country's current electricity demand is 25,000 MW, but the country's power supply is just 17,000 MW, resulting in an 8000 MW deficit (Raheem et al., 2016a). As a result, the electricity shortage in metropolitan areas is 12 h per day, while in rural regions, it is 18 h per day (Mirjat et al., 2017). The situation is riskier in Punjab's rural districts, where power outages sometimes last several days. Pakistan's electricity consumption is expected to rise to 40,000 MW (MW) by 2030 (Rehman et al., 2017). Not only do people's lives suffer as a result of energy poverty, but so makes the country's economic progress.

Long-term shutdowns have impacted all sectors, including agriculture, manufacturing, transportation, and residential (Wakeel et al., 2016). Pakistan's energy structure is totally dependent on thermal power. Solar energy is the cost-effective technology on the planet. By the end of 2017, the IEA estimated that the global solar power capacity had reached 402 GW (Irfan et al., 2019a). Solar power has effective potential to overcome energy poverty (Papadopoulou et al., 2019), such as Pakistan is located in the sunbelt and receives a lot of radiation all year. It is necessary to utilize existing solar energy resources to address current challenges and overcome energy poverty. Governmental and non-governmental organization investment is essential to achieve its full energy (Bakhtiar and Ahmed, 2017). As observed by Lucknow, solar energy has both institutional and technological barriers that need to be overcome (Luckow et al., 2015). The European Commission has been conducting solar energy research programs for more than 2 decades to reduce the global warming (PALZ et al., 1994). Solar power access has the technical potential to generate electricity (Farooq and Kumar, 2013).Solar energy is an essential natural resource for Pakistan (Shaikh et al., 2013).

No doubt, many researchers have assessed energy poverty but mostly in western countries. Current research tried to determine the energy poverty in Pakistan. This research aims to find out the underdeveloped areas of Pakistan where energy poverty is at an extreme level and suggest the policy recommendations that would contribute to national energy mitigation plans to alleviate the energy poverty. It will promote the slandered life at the community and national levels. It is a unique approach to access energy poverty by exploring the people who experience it the most in rural areas of Punjab and Sindh. Male and female respondents participated in the survey. The data reveal a strong relationship between energy poverty and the multifaceted poverty that individuals in rural areas face in terms of health, time, literacy, and the economy. The survey consequences provide the beneficial information for any entity (Governmental and Non-governmental organizations) to alleviate the energy poverty in rural areas of Pakistan. Just access to energy poverty in urban areas does not mean fulfilling energy sustainability at the national level. Both rural, urban, and suburban areas are part of the country. All of these areas need energy development. So, further researchers should also identify and access those areas where energy poverty is at an extreme level. Due to the COVID19 outbreak, selected rural areas from only two Pakistani provinces to design a solution model at both the provincial and national levels. And try to motivate the rural residents towards renewable energy (e.g., Solar Power) because solar energy is renewable energy and affordable energy. In addition, as far as the author is aware, no previous research has covered an in-depth analysis of energy poverty in these selected areas of Pakistan as contribute the novelty in this current research. The remaining part of this paper is structured as follows: **Section 1** consisted of a literature review including the energy poverty access at a national and global level. And this section also describes the potential of solar power to alleviate energy poverty at the national and international levels. The research methodology describes in **Section 2**, and **Section 3** consisted of result a discussion. Barriers to alleviating energy poverty in rural areas in **Section 4**. The recommendations from the research findings and the conclusion are presented in **Sections 5** of this paper, respectively. **Section 6** discusses the limitations and future research directions.

2 LITERATURE REVIEW ACCESS TO ENERGY POVERTY

Several research articles, books, and news reports give a detailed insight to access the energy poverty at the national and global levels. The findings from the literature are presented below:

TABLE 1 | Energy poverty in rural areas at the global level.

Country	Africa	Sub-saharan africa	Development asia	Latin America	% In rural areas
Lack of electricity	587million	585million	779 million	31million	1.227billion 85%
Relying on biomass	657million	653million	1.937million	85million	2.679 billion 82

TABLE 2 | Power installed capacity sources.

Fiscal year	Thermal	Hydroelectric	Nuclear	Renewable	Total generation
2014–15	58,635	32,563	4,996	803	96,997
2015–16	61,448	34,272	3,854	1,549	101,123
2016–17	66,468	31,786	5,868	2,937	107,059
2017–18	79,649	28,239	8,720	3,907	120,715
2018–19	61,003	24,931	2,903	7,941	96,792
2019–20	56,320	29,799	7,941	2,322	96,382
2020-21	61,052	31,357	8,038	2,294	102,742

2.1. Energy Poverty Access at Global

The United Nations' 7th Sustainable Development Goal, introduced in 2015, focuses on maintaining that everyone should have access to sustainable energy sources, such as poverty. Inefficient energy access is also a significant issue worldwide (Carlsen and Bruggemann, 2021). To maintain a healthy lifestyle, everyone needs access to power and clean cooking fuel. Eastern and southern European countries are classically identified as having the highest levels of energy poverty, while Scandinavian countries have the lowest levels. According to Thomson and Snell's research, Bulgaria have the highest levels of energy poverty in 2007 (Thomson and Snell, 2013). Energy poverty conditions worsened when the effects of the economic crisis were visible, particularly in Bulgaria, which experienced high levels of energy poverty from 2004 to 2019 (Halkos and Gkampoura, 2021b). Ethiopia, like many African countries, was experiencing severe energy poverty. On the other hand, Egypt and Morocco have low levels of energy poverty (Halkos and Gkampoura, 2021a).

In Latin America, energy poverty is particularly severe in Haiti, Guatemala, and Honduras. Although, Mexico have low ratio of energy poverty, but still they are facing higher problems with their population's access to energy facilities (Santillán et al., 2020). In Asian countries, energy poverty had badly effected Afghanistan and Bangladesh, India and Pakistan (Abbas et al., 2020). China has advanced economically compared to other Asian countries, resulting in a considerable reduction in energy poverty. However, energy-related problems persist in several country regions (for example, the Yellow River's middle reaches) (Wang et al., 2015). (International Energy Agency, 2010), and **Table 2** shows power installed capacity sources (Irfan et al., 2020).

Table 1 depicts the energy poverty in rural areas at the global level (International Energy Agency, 2010), and **Table 2** shows power installed capacity sources (Irfan et al., 2020).

Energy poverty indicates a socio-economic problem that is not the same as "poverty" in the traditional sense. Energy poverty at the residential level means a lack of access to energy resources such as appropriate electricity or technical devices for cooking, heating, and lighting in underdeveloped countries. Traditional home appliances, including wood and biofuels, have been used for cooking and heating (Maxim et al., 2016).In the late 1970s, the phrase "fuel poverty" was first used to describe households with disproportionately high fuel expenses than the rest of the population (Liddell et al., 2012).In 1990, the total final energy consumption was 6,267,177 kilotons, and in 2018, it was 9,937,703 ktoe. It considers the global population growth, which has increased from 5.28 billion in 1990 to 7.59 billion in 2018. It is evident that world energy consumption has grown per capita and that the world's energy use has reached extremely high levels. In 2015, fossil fuels accounted for 79.7% of total global energy use, whereas renewable energy sources accounted for 18.05%. Industry and the transportation sector consume the highest energy at the global level. In 2018, the residential sector consumed 2,109,205 ktoe, and it is the third-largest energy consumer sector. Globally, energy poverty has had a significant influence on the residential sector. In comparison, limited energy access cannot fulfill basic human needs (Halkos and Gkampoura, 2021a).

Fuel poverty is caused by a combination of variables, including low income, increased energy bills, and poor home conditions (Boardman, 1991). Energy poverty affects about 100 million individuals in Europe (Brunner et al., 2012), almost 1.2 billion people lack the access to power at global level (Maxim et al., 2016). Bouzarovski (Bouzarovski, 2014) mentions additional terms for the same purpose, such as "domestic energy deprivation" or "energy precariousness." Households in this category spend more than 10% of their income on energy (Isherwood and Hancock, 1979). Bouzarovski defines it as "a scenario in which a household lacks a socially and materially required level of energy services in the home" (Bouzarovski,

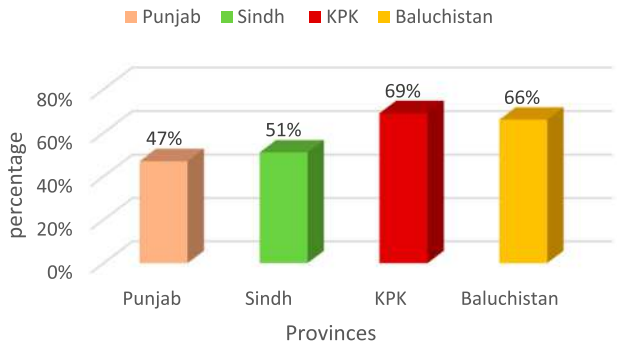

FIGURE 1 | Comparison of energy poverty at provincial level (Sher et al., 2014).

2014). The Millennium Development Goals (MDGs) could not be accomplished without first tackling energy problems. A reliable energy source such as solar power requires sustainable development and energy poverty alleviation (Adenle, 2020).Energy is a vibrant element of sustainability, such as more effective use of energy results in cost savings and a higher quality of life (Maxim et al., 2016). A growing population means a greater need for energy. Advanced energy availability, for example, creates a foundation for better labor force employment. It expands job opportunities and boosts pay, leading to a more excellent standard of living (Markandya et al., 2016). According to Boardman's research, the cold seasons have a higher death rate than the other seasons, partly attributable to low indoor temperature (Rudge, 2012). According to previous studies, people feel anxious when paying their unaffordable energy bills (Brunner et al., 2012). Despite the progress made in Asia, it is critical to promote policies to alleviate energy poverty and ensure that as many people as possible have access to essential energy services (Halkos and Gkampoura, 2021a).

2.2 Energy Poverty at the National Level

The global demand for energy has risen dramatically, and Pakistan has no exception. Pakistan is also facing the energy poverty, which is impeding the country's progress and harming the lives of its citizens. Pakistan's major sectors, such as agriculture, transportation and residential, all require a constant supply of energy. All of Pakistan's provinces are affected by energy poverty (Javed, 2016).

In 2017, another researcher described energy poverty in rural areas of Pakistan. There is a large rural-urban gap. In urban and rural Punjab, the share of energy-poor families (H) is 18.5% and 70.7%, respectively. Sindh's ratio is 14.4%–80.3%, KP's is 24.3–74.6%, and Baluchistan's is 31.3%–84.9%. In urban Punjab, the intensity of deprivation (A) is 36.6%, compared to 43.5% in rural Punjab. In urban Sindh, deprivation is 37.5%, and in rural Sindh, it is 48.6%. The equivalent A values for urban and rural KP are 36.2% and 47.6%, respectively, and 47.0% and 57.6% for urban and rural Baluchistan (see **Figure 1**). The author stated that most energy poverty is caused by the insufficiency of contemporary cooking fuels at the household level. Conventional fuels are used in 67% of Pakistani homes. In rural KP, the use of modern fuels is relatively low, with 91% relying on traditional fuels. In rural areas, particularly in rural KPK and Baluchistan, the MEPI's mobility factor is more important. The lack of a refrigerator in 64% of houses and a television or radio in 36% of households indicates decreased power usage for entertainment and services like cooking and heating (Mahmood and Shah, 2017).

Pakistan's existing energy system is based on fossil fuels. 86.5 percent of the country's energy demands are met by thermal energy (Irfan et al., 2019a), (Ahmed et al., 2016).The use of fossil fuels on a large scale has hindered economic progress. Still, it has also resulted in several ecological problems. Furthermore, natural resources are decreasing due to the excessive use of traditional energy. As a result, a new energy economy will need to be built. In this future economy, solar energy will lead to sustain energy requirements, and also reducing the price of imported fossil fuel (Sharma et al., 2012). Pakistan's energy consumption is growing at more than 9% per year. Pakistan's energy consumption will rise eight-fold by 2030 and twenty-fold by 2050 (Noureen, 2014).

As a result, the government is exploring alternate and sustainable energy sources to help address these issues. For electricity generation, Pakistan has tremendous contemporary energy potential. Wind energy has a potential of 346 GW (GW), whereas solar energy has a potential of 2900 GW, hydropower has a potential of 6 GW, and biomass has a potential of 5 GW (Solangi et al., 2019). Punjab's provincial government is successfully generating electricity through renewable energy. Despite the government's best efforts, the province's rural areas remain underserved due to four fundamental factors. First, rural areas account for 37% of Punjab's population, with 7432 villages still without electricity (Irfan et al., 2019b). These areas are far dispersed and disconnected from the national grid. Connecting these places to the national grid is both uneconomical and prohibitively costly. Second, in rural regions, electricity consumption is just 50 to 100 W per home, which is comparatively low than metropolitan areas (Bhutto et al., 2012). Because tiny dwellings usually only have one room, maximum two electric fans and a few lights are generally sufficient. It is very costly to supply on-grid transmission to these settlements (Arefin et al., 2018).

Due to the remoteness of the areas and the absence of infrastructure, renewable energy projects are not viable. Meanwhile, generating electricity with diesel generators is uneconomical due to the high cost of delivering oil to remote areas. As a result, grid-connected electricity is unlikely to be available in the future (Mirza et al., 2009). Finally, the country's economic situation is precarious, and it cannot afford to import expensive fossil fuels, particularly oil, to solve its energy concerns. As a result, the government has chosen to shut down some current renewable energy initiatives that have hampered the adoption of renewable energy technology. The Punjab province has been suffering the higher energy problems due to the government's decision since freshly begun projects are shut down entirely (Irfan et al., 2019b).

Pakistan is a developing country with significantly lower per capita energy consumption than comparable countries. It is essential to analyze the present situation and determine which

TABLE 3 | NEPRA approved a 25-years solar PPA in 2016.

Category	>1 ≤ 20 MW	>20 ≤ 50 MW	>50 ≤ 100 MW
Northern Pakistan - Levelized Tariff (US Cents/kWh	11.5327	11.4460	11.3560
Southern Pakistan- Levelized Tariff (US Cents/kWh)	10.8920	10.8101	10.7251

areas require immediate attention. According to Awan, Sher, and Abbas (2013), the country has been experiencing higher levels of energy poverty. According to Awan et al. (2013), energy poverty affects 54.6% of households. Rural areas have a greater rate of energy poverty than metropolitan ones (Mahmood and Shah, 2017). According to Mirza and Szirmai (2010), extreme level energy poverty affects 91.7% of rural households in Punjab (Mirza and Szirmai, 2010). Due to growing population, a significant quantity of energy is required to keep everything running smoothly (Fatai et al., 2004). However, there is an energy supply shortfall, and Pakistan is experiencing its most profound energy problems. The disparity between power demand and supply has widened in recent years, most noticeable during the summer (Irfan et al., 2019a). Complete power outages lasted 10–12 h in urban areas and 16–18 h in rural areas (Farooq and Shakoor, 2013; Ghafoor and Munir, 2015; Ghafoor et al., 2016).

2.3 Potential of Solar Power to Alleviate the Energy Poverty

Solar energy has potential and true alternative energy options among several renewable energy technologies. As an example, mostly rural communities use fuelwood for household purposes because the risk of deforestation produces environmental issues and a difficult trade-off. Pakistan has a total landmass of 79,610, 000 ha (ha), but just 1,686,000 ha of forest (Irfan et al., 2020).Pakistan is located in sunbelt, has the potential of solar energy. To promote the off-grid solar power to produce the electricity in rural areas (Bataineh et al., 2014; Haghighat Mamaghani et al., 2016; Irfan et al., 2019c). Due to its high solar irradiation (Wakeel et al., 2016), the province enjoys more than 300 sunny days per year and receives 2 MW h/m2. Asian Development Bank reported that off-grid solar power is cost-effective, quick installation, and improves the socio-economic condition (Irfan et al., 2019b). Various scholars have recommended off-grid solar power in rural areas (Ghafoor and Munir, 2015), (Haghighat Mamaghani et al., 2016). Moreover, several additional studies have demonstrated that an off-grid solar PV system is the most environmentally friendly and cost-effective energy option for rural people. As a result of developing the solar PV system, people's living conditions have improved (Sandwell et al., 2016), (Mishra and Behera, 2016) (Irfan et al., 2019b). The solar PV system is safe for human health, reduces carbon emissions, and produces no noise (Hosenuzzaman et al., 2015).The solar house has significantly enhanced internal settings and boosted thermal comfort for residents. Solar house can be an effective way to alleviate rural households' energy poverty (Liu et al., 2018). Strong political determination, appropriate policy frameworks, and a proactive ecosystem with businesses are all necessary for a successful transition to off-grid solar-based regimes for rural and remote inhabitants (Yadav et al., 2019). According to the Alternative Energy Development Board (AEDB), 35 projects with a total capacity of 1111.4 MW are in the works under the AEDB's policies and processes. Ten developers have been accepted for FITs (or upfront tariffs as they are known in Pakistan), and three of them have signed power purchase agreements with the public off-taker. **Table 3** below shows the FITs for a 25-years Solar PPA approved by NEPRA in 2016 (Tait and Alam, 2019).

3 RESEARCH METHODOLOGY

This study used hybrid research approaches to understand better the respondents' subjective viewpoints on the current topic. This study aimed to explore the perspectives on the subject to describe qualitative and quantitative results that could lead to practical policy recommendations for addressing energy poverty in Pakistan's rural areas. Structured interviews with predefined questions were developed for all respondents to accomplish this quickly, with an opportunity for each person to convey their ideas. Because the work focuses on energy poverty, the interviews were only from rural areas where energy poverty was extremely high. So, this research used purposive and snowball sampling techniques to collect subjective reality from the study. The research process is mentioned in **Figure 2**. The study area was chosen from the two provinces (Punjab and Sindh). In Punjab and Sindh, interviews were done in underdeveloped areas with the highest rate of energy poverty. However, in the Punjab province, more interviews were conducted. Interviews were done in Punjab's undeveloped districts, which included Bahawalpur, Multan, Dara Ghazi Khan, Faisalabad, Lahore, and Sargodha, as well as Sindh's Larkana, Sukkur, Nawab Shah, Hyderabad, Mir Pur Khas, and Karahi. Each division had two districts' data collection. In Punjab, data collecting duration was 6 weeks, while in Sindh it was 9 weeks. Accessing participants for the empirical investigation was problematic due to COVID-19. As a result, data collection takes up more time. The researcher could not use conventional survey technique of distributing questionnaires in this study due to the COVID-19 pandemic in the country and the limitations imposed by the government to stop the virus's spread (such as limiting human face-to-face contact). As a result, the questions were created in Google Forms and filled out based on the residents' responses. Two parts make up the form. Part A was designed for statistical measurement. The respondents were granted the right to respond in their own arguments with brief discussions in Part B, consisted of a qualitative analysis. As a

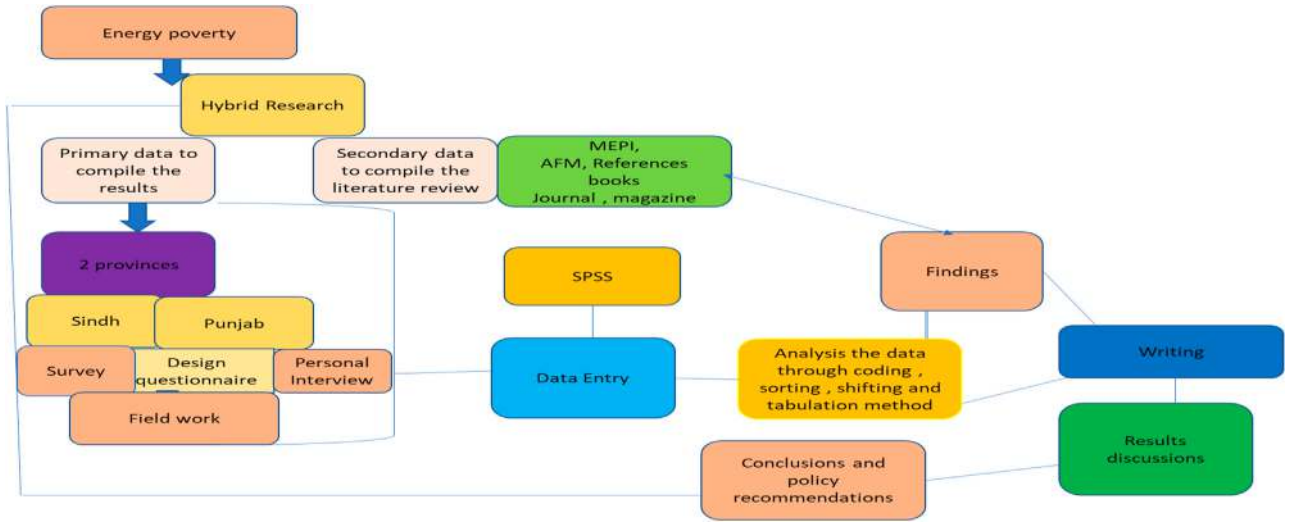

FIGURE 2 | Research process.

TABLE 4 | Demographics of the respondents.

Gender	Province	Age	Respondents	%
Male and Female	Punjab	0–17	112	11.2
		18–30	213	21.3
		31–50	249	24.9
		51and above	66	
	Sindh	0–17	94	9.4
		18–30	102	10.2
		31–50	115	11.5
		51and above	49	4.9
	Total		1000	100

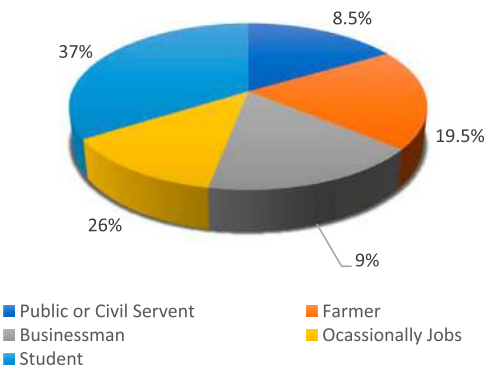

FIGURE 3 | Employment statics.

result, they were free to voice themselves, and the interviewers could record their responses (See **Supplementary Appendix**).

Depicts the demographics of all respondents (see **Table 4**). Structured interviews were conducted among 1000 respondents who used polluted energy sources for lighting, cooking, and heating in the divisions of Sindh and Punjab stated above.

Also shows the age groups of the respondents in the provinces that were considered. The survey's results can be verified because of the vast number of respondents who have been exposed to unclean energy.

4 RESULT AND DISCUSSIONS

This section contains the survey findings from the two provinces visited for this study for Parts A and B of the questionnaire (as shown in **Supplementary Appendix Table 10**).

4.1 Results From Survey questions—part A

Error! Reference source not found. shows that the residential respondents in these country areas were of different ages. The survey lasted 9 weeks, with 6 weeks spent in Punjab and 3 weeks in Sindh. The average household size ranged from five to six people. Including both provinces, only 20.5% of respondents were under 18 years old, while 79.5% were older than 18 years old. According to the current employment statistics shown in **Figures 3**, **9** % of respondents run their own business, 8.5% were civil workers, 37% were students, and 19.5% were agriculturalists. The remaining 26% work part-time and rely on landlords for their livelihood. The respondents were also totally dependent on agriculture cultivation, with only a minority relying on wages, pensions, and grants.

This study proves that energy poverty cannot be alleviated by low income. Respondent's income level was also a great determinant of their energy choice. Furthermore, as seen in **Table 5**, most households (29.5%) earned less than Rs 5000 per month. Only 11%, which comprises government officials and company owners, earned more than Rs 20,000. However, they cannot take advantage of sustainable energy due to a lack of awareness. The results indicate that people live in financial

TABLE 5 | Levels of monthly household income.

Monthly income	Respondent percentage (%)
0-5000	29.5
5001-10,000	31
10,001-15,000	16
15,001-20,000	12.5
Above 20,000	11

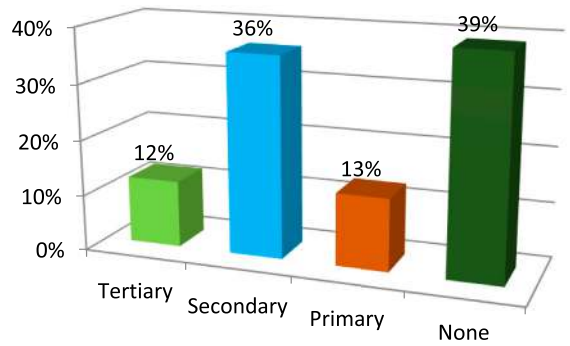

FIGURE 4 | Highest educational level obtained by respondents.

poverty, which depict their energy poverty and impact their choice of sustainable energy. According to current statistics, 60.5% earned less than Rs15,000, and just 23.5% earned more than Rs15,000. But it could not give the offer to enjoy clean energy. As previously mentioned (Clancy et al., 2003), (Wang and Jiang, 2017), their financial situation influenced their energy choice. When looking at household structure as an indicator of income, it is evident that non-poor households prefer to use clean energy (such as solar) for illumination. In contrast, poor households prefer to use solid fuel (Dash et al., 2018). The lowest quartile is the most affected by energy poverty compared to the richest quartile (Awan et al., 2022). Improvements in financial inclusion have the potential to alleviate energy poverty (Koomson and Danquah, 2021).

Figure 4 depicts the distribution level of high educational qualification achieved by respondents, indicating that around 61% of all ages are educated. This helped us during the survey because most of them understood the questions and responded correctly in English or their native languages (Urdu, Saraki, Punjabi, Sindhi, etc.). Furthermore, if given the opportunity, this would contribute to their acceptance, adaption, and usage of renewable energy.

Both provinces (Sindh and Punjab) are included. The majority of the undeveloped regions lacked adequate illumination. Respondents claimed they face load-shedding for 12–14 h each day, with some days being without power for up to 24 h. Previously published work by (Valasai et al., 2017) showed that Pakistan is suffering from chronic electricity shortages, which have resulted in forced power outages ranging from 8 to 12 h per day in urban areas and up to 18 h per day in rural regions over the last decade. Due to lack of energy, 94% of rural

TABLE 6 | Energy use for lighting during load shedding.

Energy source for Lighting	Respondents	%
Batteries	420	42
Candles	678	67.8
Firewood	321	32.1
Solar Energy	47	4.7

residents relied on one or two lights in their homes. This power does not satisfy them. Most respondents stated that they had a flawed energy system but paid extra bills. As a consequence of rising energy costs and lower monthly income, they choose to live without electricity. **Table 6** shows that only 4.7% of rural households have access to solar energy. Rural inhabitants should be encouraged to use solar lamps for lighting to improve their energy quality and prevent them from using energy sources. Previous work by (Irfan et al., 2019b)showed that off-grid solar power is the supportable solution for rural areas because of its net energy, low life-cycle cost, and ecological quality. It would also allow people to work, study, and spend time with their families and online job facilities. Furthermore, 96.3% were excited about moving from filthy energy sources to clean energy sources using adequate renewable energy with the aid of government and non-government organizations. So that they can purchase solar lamps during load shedding, it is a potential prospect for the government or an independent power company to provide solar access to these energy-poor areas. Because at the time of the survey, they did not have convenient access to clean energy. The majority of them were entirely unaware of the benefits of renewable energy, highlighting the need for increased renewable energy awareness in rural areas. In Pakistan, Firewood and candles are the most vulnerable, so the government should implement policies and facilitate people in purchasing the positively effective energy sources (solar lamps, solar cooking stoves, and solar heaters). As mentioned earlier in (Urmee et al., 2009) showed that renewable energy-based rural electrification initiatives need policies and strategies. In addition, number of studies indicate that an off-grid solar PV system is the most environmentally friendly and cost-effective energy option for rural electrification (Irfan et al., 2019b), (Akikur et al., 2013). The government should create a national energy research program. Prioritize R&D investment for home-based, energy-efficient solar energy devices. University students and research groups should conduct studies to develop current, cost-effective solar energy equipment for home and commercial users (Irfan et al., 2019a).

Table 6, **Table 7**, **Table 8** indicates that many respondents use more than one energy source to fulfill their energy demand, such as lighting, cooking, water heating, and space heating.

4.1.1 Lightning

Both provinces (Sindh and Punjab) are included. The majority of the undeveloped regions lacked adequate illumination. Respondents claimed they face load-shedding for 12 to 14 h

TABLE 7 | Energy sources for cooking.

Sources	Respondents	%
Animal Dung	167	16.7%
Coal	253	25.3%
Firewood	886	88.6%
Solar Energy	-	-
Gas/LPG	105	10.5%

TABLE 8 | Energy sources for space heating and water heating.

Energy sources	Respondents	%
Animal Dung	321	32%
Coal	355	35.5%
Firewood	766	76.6%
LPG	-	-
Electric and Solar Heater	-	-

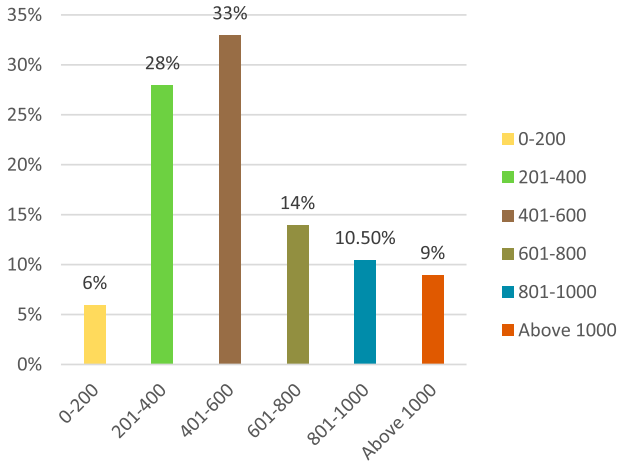

FIGURE 5 | Household monthly average energy expenditure.

each day, with some days being without power for up to 24 h. Previously published work by[69] showed that Pakistan is suffering from chronic electricity shortages, which have resulted in forced power outages ranging from 8 to 12 h per day in urban areas and up to 18 h per day in rural regions over the last decade. Due to lack of energy, 94% of rural residents relied on one or two lights in their homes. This power does not satisfy them. Most respondents stated that they had a flawed energy system but paid extra bills. As a consequence of rising energy costs and lower monthly income, they choose to live without electricity. **Table 6** shows that only 4.7% of rural households have access to solar energy. Rural inhabitants should be encouraged to use solar lamps for lighting to improve their energy quality and prevent them from using energy sources. Previous work by [46] showed that off-grid solar power is the supportable solution for rural areas because of its net energy, low life-cycle cost, and ecological quality. It would also allow people to work, study, and spend time with their families and online job facilities. Furthermore, 96.3 % were excited about moving from filthy energy sources to clean energy sources using adequate renewable energy with the aid of government and non-government organizations. So that they can purchase solar lamps during load shedding, it is a potential prospect for the government or an independent power company to provide solar access to these energy-poor areas. Because at the time of the survey, they did not have convenient access to clean energy. The majority of them were entirely unaware of the benefits of renewable energy, highlighting the need for increased renewable energy awareness in rural areas. In Pakistan, Firewood and candles are the most vulnerable, so the government should implement policies and facilitate people in purchasing the positively effective energy sources (solar lamps, solar cooking stoves, and solar heaters). As mentioned earlier in [70] showed that renewable energy-based rural electrification initiatives need policies and strategies. In addition, number of studies indicate that an off-grid solar PV system is the most environmentally friendly and cost-effective energy option for rural electrification[46], [71]. The government should create a national energy research program. Prioritize R&D investment for home-based, energy-efficient solar energy devices. University students and research groups should conduct studies to develop current, cost-effective solar energy equipment for home and commercial users[17].

4.1.2 Cooking

Firewood is the primary source of cooking energy. **Figure 5** depicts the average monthly energy cost for consumers. According to the findings, 33% of respondents claimed to spend more than Rs 600 per month on energy to buy wood. Only 9% of those surveyed said they spent more than Rs 1000 on firewood. As seen in many developing countries, people's reliance on firewood as a key energy source is producing serious deforestation concerns. Reliable data on firewood use rates are required to build afforestation initiatives and control deforestation, as previously also mentioned by (Fox, 1984)–(Bakehe and Hassan, 2022).

Table 7, just 10.5% of people in rural areas have access to LPG gas, while 88.5% depend on firewood and other forms of energy to cook. Many inhabitants did not cook the meal because they lived below the poverty line. Generally, these types of respondents work for landlords or as baggers. Most respondents do not have a chimney or a smoke hood in their kitchen and cook food in their backyard. They used it for the entire year and cooked twice a day using firewood. Most respondents said they spend more than 10% of their income purchasing firewood. 76% of respondents stated they want to improve the energy system. It is very polluted. 69% indicated this fuel source is entirely unsafe in stormy and windy seasons. Previously research work by (Longe, 2021) showed that 98% responded they would be willing to switch from dirty to clean energy sources if they had access to electricity. However, 95% of those respondents stated they would welcome the solar energy as a source of electric power. It is a positive sign for the government or a private organization interested in providing electricity to these communities. However, some respondents

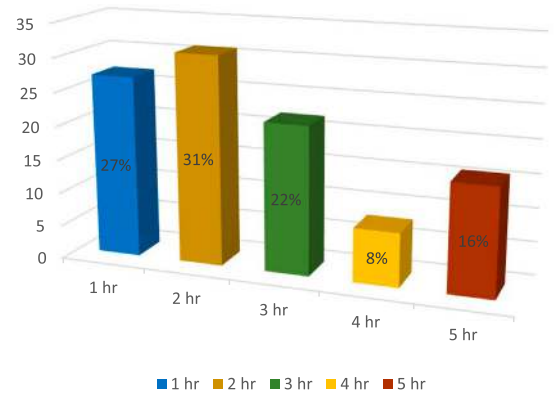

FIGURE 6 | Time spent fetching firewood per day by the respondents.

desired only wood since they claimed they did not have enough money to enjoy a lavish lifestyle. The government should install LPG meters and solar panels in rural communities. In order to properly implement the new solar home system policy, the Pakistani government must build solar power plants, increase solar panel installation, and provide financing and complete information to conduct independent research. In addition, approximately 90% of respondents believe that the government should take the lead in developing the SHS sector, as previously also mentioned by (Zhou et al., 2017). **Figure 6** illustrates that most individuals (31%) spend 2 h per day going to the forest to collect firewood for domestic energy usage. This time could have been better spent on other productive activities to boost their income and improve their living conditions. Previous work by (Agea et al., 2010)showed that Firewood collectors traveled 8–12 km and spent 4–6 h collecting firewood each day.

The accessibility of high-quality firewood in the bushes and forests has decreased due to deforestation. These magnificent forests are in danger of extinction because they are not consciously replanted after being destroyed. Obtaining and using firewood will be more challenging if there is no access to renewable energy sources. The rate of deforestation will be high. In many developing countries, people's reliance on firewood as a key energy source is producing serious deforestation concerns. Reliable data on firewood use rates are required to build afforestation initiatives and control deforestation, as previously also mentioned by (Fox, 1984; Bhatt and Sachan, 2004; Adeoye and Ayeni, 2011; Bakehe and Hassan, 2022).

4.1.3 Space Heating

During the winter, 94% of respondents reported they did not have enough heat in their homes and were exposed to harsh cold for 3–4 months. They cannot keep their rooms warm due to a lack of energy resources. Due to a shortage of electric and solar heaters, they heated their home with an open fire. As previously also mentioned by (Jaber, 2002; Jaber et al., 2008; Papathanasopoulou, 2010), fossil fuel combustion is widely used in household space and water heating, contributing significantly to environmental pollution and carbon dioxide emissions. **Table 8** shows the energy sources used to keep respondents warm during the winter months. Even in this technological era, people still use animal dung and coal for space heating and to heat water for showering. For example, 32% reported using animal dung to heat their residences and water. Firewood was utilized for the same purpose by 76.6% of such respondents. Mostly said that they suffered injuries due to an open fire system. Earlier work in (Reyes et al., 2015) showed that energy poverty significantly influences people's health and living conditions. Increased indoor CO2 emissions in the morning and evening hours pose major health risks to households due to intensive firewood use. Therefore, significant public awareness and pollution control actions should be proposed to improve the rural population's indoor air quality and health (Tika Ram and Hom Bahadur, 2020).

4.1.4 Cooling

Summer lasts for about 5–6 months. From April to September, the temperature is unbearably humid (Archer and Fowler, 2008). As a result, they take showers three to four times a day to cool off their bodies. Due to poverty and flirty energy, they cannot enjoy a contemporary and hearty lifestyle. However, they are confronted with various issues. In hot weather, 80% of people feel aggressive. Summer has the highest rate of aggressive crime, whereas winter has the lowest rate, as previously mentioned by (Butke and Sheridan, 2010). Only 20% of respondents said they felt normal. Due to their large family and limited appliances, they cannot obtain sufficient cooling air. 99.5% of rural households lacked an exhaust system in their kitchen, resulting in indoor pollution. Earlier work by (Jerneck and Olsson, 2013)showed that cooking using solid fuels over an open fire causes incomplete combustion and indoor air pollution, which causes respiratory and other illnesses, as well as around two million premature deaths each year. Smoke-free kitchens should be established to promote health and well-being while reducing carbon emissions. Green technology innovation improves the economy and reduces the CO2 emissions (Razzaq et al., 2021). Furthermore, 61.5% of respondents stated that they do not own any electric cooling appliances. Such as **Figure 7**, 47.5 % said they get cooled water by using clay pots, as they lacked the money to purchase a refrigerator. 14% of respondents said they buy ice from a shop and keep their water cold in a cool box. Just 10% have an electric refrigerator for storing food and cold water, but none have used a solar refrigerator. 68% clearly stated that their home is not cool enough during summer, such as previous research mentioned by (Zahid and Rasul, 2010) showed that the weather in Punjab and Sindh remain scorching during summer.56% do not utilize electric equipment to cool their homes; as **Figure 8** Shows, 31% used electric fans to cool their rooms. Only 13% of rural areas used air conditioners.21% have used homemade fanes.23% of people open their doors and windows to get some fresh air.

4.1.5 Education and Communication

According to data from both provinces, 48% are illiterate, with only 52% of their children pursuing higher education. But they are facing various challenges, including the fact that most youngsters stated they did not have the internet to communicate with their teachers during COVID 19. **Table 9** shows that 8.9% of respondents have Android phones and 28.7%

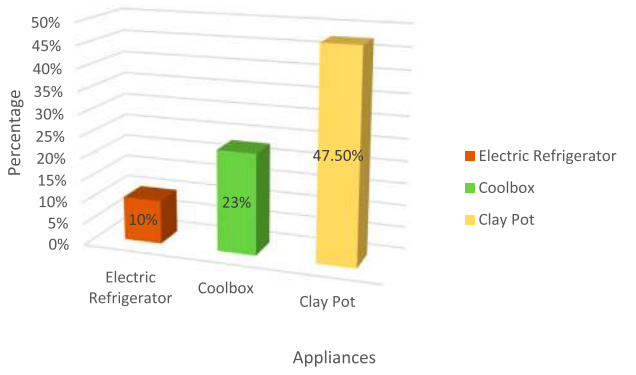

FIGURE 7 | Electric and non-electric appliances.

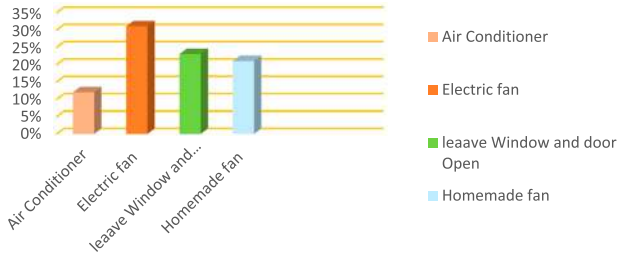

FIGURE 8 | Sources to cool the residence.

have smartphones. Due to long-term vocations, parents claim that their children are uninterested in going to school. They could not afford an Android or the internet at home, and they did not even have an alternative system to maintain their children's education. Mostly, parents were depressed and opposed to extended vacations. Most parents expressed their unwillingness to send their children back to school. Radio is being used by 31.1% for news and entertainment. Only 17.2% of people have a television in their house. However, they only use it for 1–2 h due to the energy crisis. Earlier work by (- Pandemic, Mamica, G ł owacki, Makie ł a) showed that energy poverty influences student academic performance during COVID-19 outbreaks. Students from electrified homes are more competitive and academically successful than students from non-electrified homes. The responders in both provinces sadly demanded that the government should promote energy production in rural areas. Due to increasing load-shedding at night, their children seem unable to devote more time to study, with 37.8% of students devoting 4 hours to study, as shown in.

Figure 9 Many organizations in these areas have promised access to clean energy. Unfortunately, they are still unable to complete their projects. However, many respondents supported renewable energy, but still not being implemented due to low monthly income and higher household expenses.

TABLE 9 | Sources of information and communication.

Sources	Respondents	Percentage%
TV	172	17.2
Smart Phone	287	28.7
Android Mobile	89	8.9
Radio	311	31.1
None	141	14.1%

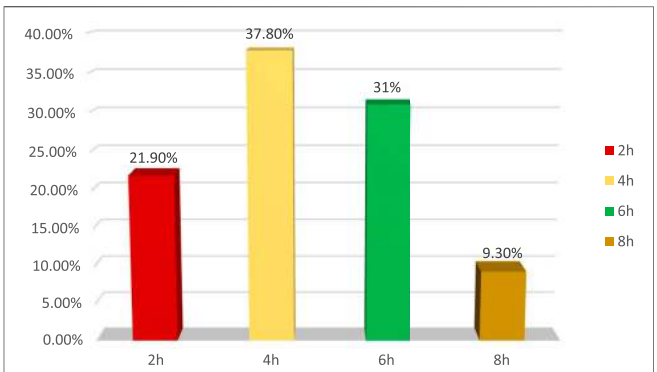

FIGURE 9 | Student study time duration.

4.2 Results From Survey questions—part B

This section's central purpose is to analyze energy poverty-related issues in-depth. However, due to space and length constraints in this article, only ten respondents per question are chosen, and related conversations are described in this section.

4.2.1 Responses

i. It is difficult for girls to cut firewood when they are experiencing menstrual cramps.
ii. My children don't take bathe before going to school because of the cold water. This is a horrible thing, especially for women who might be experiencing their monthly cycles on those days.
iii. Since my family and I do not work, cooking with firewood is too expensive.
iv. We don't have any other energy source for cooking or heating, so that I couldn't refute the firewood.
v. *Occasionally, I get annoyed by firewood.*
vi. It was initially uncomfortable. But now that I'm used to it, I feel firewood is faster than animal dung.
vii. It irritates me because it requires the maximum amount of time. My children collect wood from the forest due to a low monthly income, and they can't devote time to their studies.
viii. As it's our tradition, I always prefer to cook with firewood.
ix. It's a problem because teenagers prefer to buy firewood for their homes rather than travel to the forest, which we can't always afford. They suffer from an inferiority complex.
x. I always prefer alternative energy sources instead of firewood.

Despite the fact that most respondents are dissatisfied with their use of firewood, they continue to do so because they cannot afford to purchase alternative energy sources. It is difficult for girls to cut firewood when experiencing menstrual cramps. They could not refute the firewood due to the lack of contemporary energy sources like Solar Heater or LPG. Occasionally, they get annoyed by firewood. It irritates them because it requires the maximum amount of time for cooking, as previously mentioned in (Bhatt and Sachan, 2004); (Katuwal and Bohara, 2009). Due to financial constraints, some households cannot even afford firewood. Students are particularly affected by this traditional energy source, wasting their time fetching firewood. It's a big problem for young people because they prefer to buy firewood for their homes rather than travel to the forest. Most parents can't always afford it. Their children suffer from inferiority complexes. Minor responses were satisfied with firewood and claimed that using firewood is traditional. So, they never leave it.

4.2.2 Responses

i. Fetching firewood from the forest is extremely dangerous. My children had faced kidnapping.
ii. My relative was bitten by a snake and died while fetching firewood.
iii. It is perilous for one's life. I get hurt in the bushes sometimes.
iv. Many snakes have tried to bite me. I'm afraid to go into the forests to collect firewood.
v. Going into the forest alone is risky, as rape cases have been reported in our area.
vi. In the bushes, it's risky. Some trees are hazardous due to their prickles, while others are harmful due to unknown fluids that leak out and hurt the eyes.
vii. Honey bees attacked me three times as I was cutting firewood. These last few days were horrible because I had to face too much pain.
viii. It is challenging to cut forests, especially in the summer. We mostly face the wild animals in the bushes.
ix. *I get burns on my skin when I cook with fire. In the forest, I also had several encounters with wild animals. This conventional energy does not accord with me.*
x. We always encounter the deadliest animals in the bush, such as snakes and dogs. Some rapists also attack our little girl on the way to and from the jungle.

According to these responses, every responder faces various threats associated with gathering and consuming the firewood, such as health issues (lungs problem, cough, skin allergy etc.) and criminality (rape, kidnapping, etc.). It is extremely dangerous for one's life. Due to using firewood, they have skin problems, such as rashes on their faces. They are injured in the bushes due to unknown fluids leaking out and injuring their eyes. Deaths have occurred as a result of snake bites and due to some other wild animals. Women are worried about going into the forest to collect firewood. Because going into the forest alone is dangerous, as there have been many reports of attempted rapes of young girls. Therefore, replacing conventional energy with contemporary energy will contribute to improving lifestyles. Safe and clean energy contribution will also decrease crime rates like kidnapping, raping, murder, etc. This has also been supported by work in (Longe, 2021; Chowdhury et al., 2008; Ochola et al., 2018; Adei et al., 2019; Nduwayezu et al., 2021).

4.2.3 Responses

i. It affects their academic performance because sometimes they are getting late to school due spending the more time in wooded areas where they collect firewood.
ii. Due to load shedding at night, reading near a firewood fire is incredibly unsafe for youngsters. When they tried to study in the light of a fire, they occasionally burned pages of books.
iii. My children have less time to do their homework.
iv. When most of the children are studying, my children collect firewood in the bushes. It makes me quite unhappy.
v. On rainy days, cooking with moist firewood takes too much time. My children eat late. This condition creates the aggressive behavior among child.
vi. My children spend 4 hours a day fetching firewood because the forest is too far away from our house.
vii. It's a time-consuming process. I get up at 4 a.m. to prepare breakfast for my school-going children. When my children are 5 minutes late for school, the teacher often punishes them.
viii. Cooking with firewood is more efficient than cooking with gas. We prefer to buy firewood from a woodchopper because getting it from the jungle takes too much time.
ix. Firewood cooks faster, but fetching it from the jungle requires too much energy. It is not suitable for girls during their menstrual cycles.
x. My children enjoy playing in the bushes and arrive late at home. They do not fully concentrate on their schoolwork. According to their teacher, my children's academic performance is very poor.

According to the respondents, obtaining and using firewood has a negative impact on children's academic performance. Students are frequently late to class because they enjoy playing in the bushes. It is clear that firewood consumption negatively impacts the students' productive time. Instead, they may put this valuable time to good use by improving their educational activities. Unfortunately, academic achievement has been poor. Furthermore, during COVID-19, load shedding limits their potential to communicate with their teachers online as mentioned earlier in (Longe, 2021), (- Pandemic, Mamica, G ł owacki, Makie ł a), (Kiri et al., 2022). The literacy gap will worsen if this energy poverty continues. As a result, there is an urgent need to address energy poverty in Pakistan's rural areas. Some of the first responders are unaware of the risks associated with using firewood. The government should focus on public knowledge of the dangers of using firewood in these energy poor areas. The best solution is to encourage renewable energy consumption rather than conventional energy as previously mentioned in (Farooq and Shakoor, 2013; Omer, 2008; Akintande et al., 2020; Shahbaz et al., 2020).

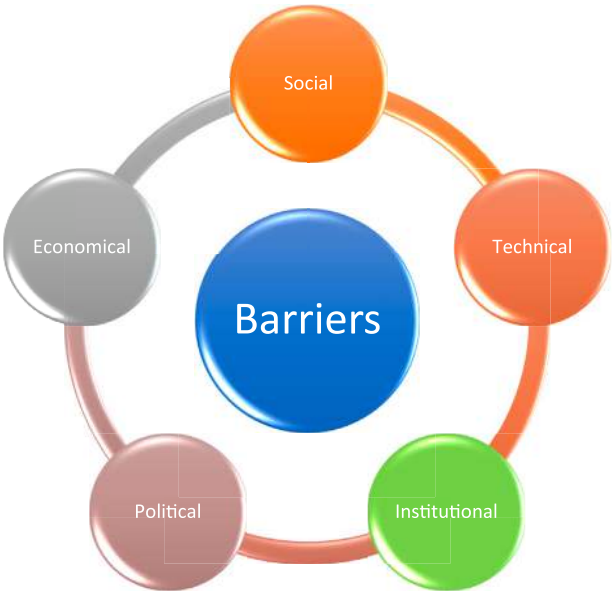

FIGURE 10 | Barriers lead to energy poverty.

5 BARRIERS TO ALLEVIATE THE ENERGY POVERTY IN RURAL AREAS

Although the Pakistani government has recently launched many projects to accelerate the deployment of solar energy to tackle energy poverty, the sector still confronts many barriers. As seen in **Figure 10**, some of these roadblocks are social, political, technological, and economical.

5.1 Economic Barriers

Contemporary energy sustainability is being hampered by a lack of capital and import tariff subsidies to boost local manufacturing (Abdullahi et al., 2017). Financial restraints and loan arrangements for solar energy projects, particularly at the local level, impede the smooth growth of the solar market and, on the other hand, the structure of consumer service infrastructure. The initial costs of launching a new solar energy plant are too high. Due to a lack of government subsidies, banks are reluctant to lend money to large-scale projects (Irfan et al., 2019a; Mirza et al., 2009). Low income, high-energy prices, and inefficient energy use are the primary causes of energy poverty. Like under-developed countries, developed countries also face energy poverty dilemmas due to financial constraints (Maxim et al., 2016). Low-income and inefficient energy housing stocks have resulted in high rates of energy poverty (Healy and Clinch, 2004). Due to high energy prices, energy poverty is defined as a lack of energy affordability (Brunner et al., 2013). These barriers make it very difficult to adopt and maintain sustainable energy to alleviate energy poverty in rural areas. Economic policy uncertainty has a big and negative impact on climate change (Zahra and Badeeb, 2022). Policymakers should achieve the optimal level of decentralization in order to encourage energy innovation. Inadequate fiscal decentralisation hampers public support for sustainable energy technology. The negative effects of fiscal decentralisation are minimised in nations with higher public energy RD&D expenditures (Kassouri, 2022). Improving environmental quality and fiscal management are the most critical policies for sustainability development (Sun and Razzaq, 2022). Fiscal decentralisation boosts environmental sustainability by increasing green investment and the transition to renewable energy (Sun et al., 2022a). Renewable energy development is a very important component of green economic growth (Zhao et al., 2022; Sun et al., 2022b). Inefficient resource policies can exacerbate energy poverty (Li et al., 2021). The disparity between revenue and expenditure decentralisation causes a vertical fiscal imbalance, dramatically affecting energy and environmental performance. To reduce energy and environmental efficiency losses, boost the fiscal reform and eliminating vertical fiscal imbalances (Lin and Zhou, 2021).

5.2 Technological Barriers

A lack of training facilities and a weak framework for entrepreneurship growth are technical barriers that promote energy poverty (Luthra et al., 2015). First, there is no national processing plant for solar cells, reliance on western technology for crucial parts and equipment. Dependency on western workers to build and run huge solar energy plants illustrates unreliable local technology. Second, inadequate R and D activities; in Pakistan, there is no known national institution for the R and D of the solar sector. Unauthentic solar maps are used to assess the strength of Sun radiation (Naqvi et al., 2018); (Irfan et al., 2019a). Lack of high-quality equipment, difficulty in providing maintenance, and logistical issues such as shipping and installation are significant barriers (Sovacool, 2012). All of these barriers impede the alleviation of energy poverty (Pasqualetti, 2011). One of the most effective approaches to achieve the transition to a worldwide clean energy system is through energy technology innovation. The impact of government energy technology research, development, and demonstration (RD&D) budgets on cleaner energy supply and carbon footprints, which is the fundamental input of energy technology advancements (CFP). The contribution of renewable energy to total primary energy supply is used to determine a greener energy supply (RE) (Altıntaş and Kassouri, 2020). The use of renewable energy reduces carbon emissions significantly (Sun et al., 2022c).

5.3 Social Barriers

Lack of consumer understanding of modern energy, particularly solar energy potential, and public rejection of new technology are key barriers (Akinwale et al., 2014). Solar energy is underutilized, especially in rural areas. There is a lack of consumer education, awareness, and demonstration at the domestic level. Local communities have shown strong opposition to some solar energy projects. Residents have no idea how to fix problems on their own if they arise unexpectedly. People continue to rely on traditional forms of electricity, which creates a significant barrier for new solar energy projects. Solar power project development is hampered by a scarcity of experts and human resources. Residents are unaware of the benefits of solar energy. There are no community demonstration projects, and developers of

solar energy projects are under-trained (Javed, 2016), (Irfan et al., 2019b). The barrier also negatively impacts market projection, cultural and religious faith disputes, and economic progress and sustainability (Abdullahi et al., 2017).

5.4 Political Barriers

Long-term planning and the political willpower to develop renewable energy are absent (Luthra et al., 2015). Energy poverty is also caused by a lack of government subsidies and incentives (Iqbal, 2018). The government's policies are unclear. There is no feed-in tariff scheme in place. Traditional energy sources are prioritized, while renewable energy is not subject to any structural regulations. Fossil fuels receive more subsidies than solar energy and other renewable energy sources (Irfan et al., 2019a), (Raheem et al., 2016b). Another problem occurs as a result of the provincial government's approval need for energy costs. On the other hand, provincial governors are unwilling to take political risks by adopting a higher energy tariff. Despite technological advances that make renewables more economically viable, this political challenge prevents governments from adopting renewable energy sources. As a result, on-grid electricity generation attracts most private sector investment rather than off-grid energy generation (Setyowati, 2020). These barriers impede strategic work for renewable energy such as solar energy development and sustainability. The government should attempt to shift from fossil fuels to renewable energies to reduce CO2 emissions, installing solar panels on verandas for low-income residents. The most major motive for installing solar PVs in their homes is determined to be lower electricity bills. Government energy policies and financial incentives influence low-income households' adoption of residential solar PVs (Lee and Shepley, 2020).

5.5 Institutional Barriers

The illegal framework, administrative challenges, non-integration of the energy mix, non-participation of the private sector, inadequate R&D culture, and the non-interference of stakeholders are vital barriers that lead to energy poverty (Aliyu et al., 2015), (Fagbenle et al., 2011). Decentralization strategies also hamper rural renewable energy. Changes in ministerial leadership frequently drive changes in government policy and priorities. Far from mobilizing private climate finance, changes in regulatory frameworks have proved counterproductive to that goal. The private sector's investment in renewable energy has been hampered by regulatory uncertainty. This is evident in the decreased amount of investment in renewable energy throughout the years (Setyowati, 2020). The barriers result in uncertainty about solar energy assistance, a lack of communication mechanisms to reach institutional authorities for reform, and a negative perception of the technology (Abdullahi et al., 2017). In the current setting of the fourth industrial revolution, energy research and development (R&D) and environmental sustainability are usually referred to as two interrelated developments. R&D in the energy sector is critical in tackling global environmental and energy concerns because it is a main input of energy innovations. From the 50th to the 90th quantiles, energy efficiency research and development reduces CO2 emissions significantly, with the magnitude of the negative sign becoming more obvious at the highest quantile (90th). Policymakers are developing long-term energy research and development programmed that balance the environment while encouraging energy innovation (Bilgili et al., 2021).

6 CONCLUSIONS AND POLICY RECOMMENDATIONS

This research aims to explore energy poverty in Pakistan's rural areas, using data from two of the country's most populous provinces as a sample. Still, rural people facing the electricity problems. Due to to12-14h load-shedding, the respondents relied on candles for light and firewood and animal dung for cooking and space heating. The study also revealed that energy poverty is associated with insecurity, financial poverty, illiteracy, time poverty, physical hazards, and societal and political barriers. Due to a lack of affordability and clean energy, rural students have been unable to communicate with their teachers. As a result, energy is a must for online classes due to COVID-19. Solar energy is an affordable and clean energy source. Most rural areas agreed to install it in their home. However, they really cannot manage it due to their low salary. Hence, this paper proposes new policy changes to enhance access to inexpensive and sustainable energy in Pakistani rural families. Government should promote the off-grid microgrids to develop the highly centralized energy generation. And increased socio-economic awareness of the merits of renewable energy and the detriments of traditional energy, affordable energy tariffs, and income-based energy incentives have all been proposed as additional solutions to alleviate energy poverty in Pakistan's rural areas. The findings presented in this study explore an innovative method of alleviating energy poverty in Pakistan's rural areas. Energy poverty can be alleviated by implementing the right plan to access modern energy. Since 1997, policies have been developed but not fully implemented, and the issue of energy poverty has been debated. On a geographical level, Pakistan remains in the sunbelt. As a result, solar power is the most suitable energy source for dealing with it. Because without energy, existence is nothing more than taking a breath, and rural areas are still locked in the 14th century. Surprisingly, researchers have found that some rural people do not want electricity due to income poverty. As a result, both government and non-government organizations should concentrate their efforts in these areas, attempting to overcome energy poverty.

These results highlight the important energy development policies to reduce hazardous risk of energy poverty and also provide opportunity for rural people to improve their living conditions. It is crucial to provide sustainable solutions to the country's energy poverty. The recommendations in this section are based on the research findings. The following policy recommendations are highlighted to alleviate energy poverty as soon as possible by leveraging the best available technology. Off-grid solar power rural electrification

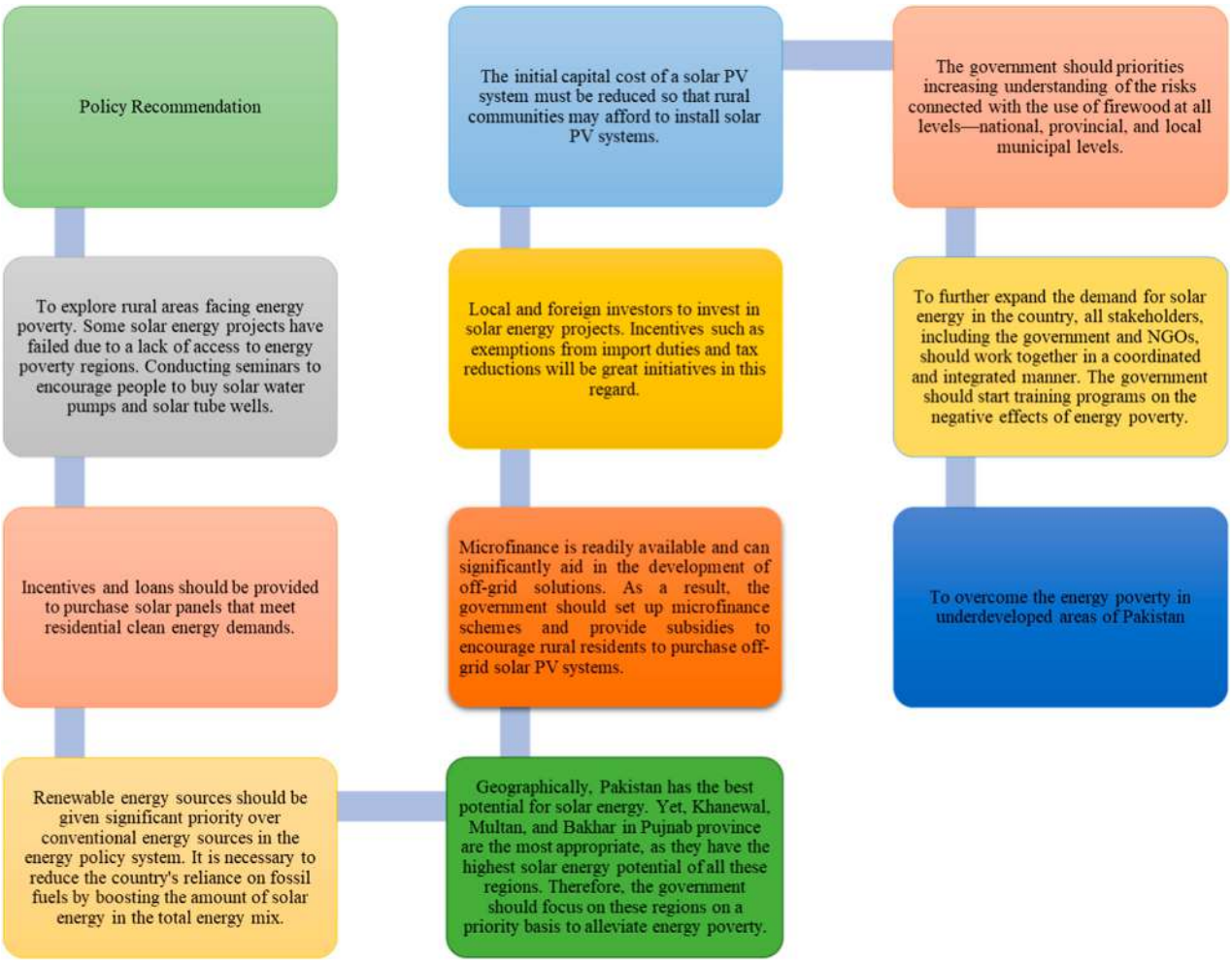

FIGURE 11 | Policy recommendations.

programs should be implemented in the Punjab and Sindh provinces to alleviate the energy poverty. Pakistan has a large amount of solar energy potential for electricity production**.** As a result, the relevant authorities should take the initiative and design well-organized policies to launch off-grid solar PV rural initiatives in Pakistan's underdeveloped regions to alleviate energy poverty. Solar power should be installed in underserved areas through public and commercial incentives. As a result, it is recommended that the government announce supportive policies to reduce energy poverty by maximizing solar energy use. **Figure 11** depicts the policy recommendation.

There are certain limitations to the study. Due to COVID-19, only two provinces of Pakistan were selected for the study. As a result, the research findings are inappropriate for Pakistan's other three provinces. Hopefully, future scholars can visit the remaining provinces to assess energy poverty more comfortably. Furthermore, researchers can propose a hybrid renewable energy system in the above-mentioned rural areas, such as solar power implementation. Above all, the government's participation is critical in assisting rural areas with hybrid systems and overcoming Pakistan's energy poverty. The current study averaged the data from two provinces. As a result, it could be considered a crucial future research direction.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by This research study was conducted according to the Declaration of Helsinki guidelines, and the Institutional Review Board of North China Electric Power University, China (protocol code 737–4 on 21 November

2021) has proved the study. . The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KB: writing—original draft, formal analysis, data handling, variable construction, and methodology. Z-YZ: supervision, funding acquisition FA: conceptualization, software, writing review and editing. AD: Writing review and editing. All authors have read and agreed to the published version of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.888080/full#supplementary-material

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