Socioeconomic Challenges Faced by Farmer in Adopting Solar-Powered Irrigation in Hafizabad District

Muhammad Awais Ashfaq*, Hasan Zulfiqar, Tehreem

Institute of Agricultural and Resource Economics, University of Agriculture, Faisalabad, Pakistan

***Corresponding Author**

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ABSTRACT

This study investigates the socioeconomic challenges making it hard for farmers to adopt solar-powered irrigation systems (SPIS) in Hafizabad District, Punjab, Pakistan. Given the increasing energy costs, growing water scarcity, and increasing environmental problems , SPIS presents a promising and sustainable solution for agricultural practices. These systems can help farmers reduce irrigation costs, improve water management, and minimize environmental degradation. However, smallholder farmers face significant barriers such as high initial installation costs, limited access to credit, lack of technical knowledge, insufficient training opportunities, and weak institutional support. The study utilized data collected through structured questionnaires from 102 farmers, applying descriptive statistics, cross-tabulations, and binary logistic regression analysis to identify the key determinants of SPIS adoption. The findings reveal that farmers experiencing acute water shortages are more likely to adopt SPIS, while high upfront costs, limited financial aid, and low awareness levels serve as major constraints. Moreover, factors such as education, farm size, and participation in farmer associations also significantly influence adoption decisions. The study suggests a combination of targeted policy interventions, including the provision of interest-free loans, targeted subsidies, technical assistance programs, and enhanced extension services to promote the use of SPIS. The research offers practical recommendations for policymakers, financial institutions, and development agencies to encourage widespread adoption of clean energy technologies in Pakistan’s agriculture sector.

Keywords: Solar energy, agriculture, financial barriers, farmer perceptions, renewable energy adoption

INTRODUCTION

Still a pillar of the national economy, agriculture in Pakistan generates almost 19% of the GDP and engages roughly 38.5% of the workforce (Pakistan Economic Survey, 2023). This economic contribution is driven by Punjab, the most agriculturally productive province. But the industry has several structural problems, including increasing fuel prices, water shortages, and declining access to energy for irrigation. Because of their operating expenses and environmental effects (Iqbal et al., 2020), conventional diesel- or electric-powered irrigation systems have become ever more unsustainable.

Solar-powered irrigation systems (SPIS) have become front-runners as a practical substitute, providing off-grid, renewable energy solutions in reaction. These systems power pumps with solar panels, therefore guaranteeing a dependable water supply for crops free from dependence on fossil fuels or power grids (Rehman and Saeed, 2017). With solar irradiance potential ranging from 5 to 7 kWh/m²/day, Pakistan is well suited for SPIS adoption, especially in areas such as Hafizabad, where agriculture is groundwater-based (Ashraf et al., 2018). Among smallholder farmers, SPIS adoption is still quite low notwithstanding the apparent technical and environmental benefits. Key obstacles are lack of access to cheap credit, poor technological awareness, and insufficient policy support, as well as high initial installation costs (Shah et al., 2018; Latif and Shah, 2021).

Recent studies reinforce that the transition to SPIS not only addresses sustainability challenges but also has the potential to improve crop yields and reduce long-term operational costs (Farooq et al., 2020). However, adoption rates remain uneven due to disparities in landholding size, education levels, and farmers’ exposure to solar technologies (Ahmed and Qasim, 2019). Moreover, the absence of integrated extension services and technical maintenance networks continues to discourage widespread uptake, particularly in semi-rural zones like Hafizabad (Naeem et al., 2021). These systemic barriers underline the necessity for localized interventions that blend financial subsidies with training programs to bridge the gap between technology availability and farmer capability. As this study will demonstrate, overcoming such obstacles requires both economic facilitation and institutional reinforcement.

In many instances, farmers are reluctant to spend on unfamiliar technologies without clear demonstrations or organizational support systems (Kamran et al., 2022). Through primary data from 102 farmers, this study aims to explore the economic and institutional influences on SPIS adoption in Hafizabad District. By examining this data, the paper offers empirical evidence on the importance of education, awareness, financing options, and governmental action in determining adoption behavior. The results seek to inform targeted policy changes that might advance solar energy adoption in Pakistan's agriculture sector, hence supporting climate resilience and sustainable irrigation.

LITERATURE REVIEW

Many studies have underlined how solar-powered irrigation could help to boost agricultural output and sustainability in water-scarce areas. Most people also recognize, nevertheless, that there are ingrained obstacles limiting broad adoption.

In Sindh and Punjab, Rehman and Saeed (2017) discovered that adoption depended mostly on landholding size and tenure security. Because of access to credit and collateral, larger landholders were more inclined to invest in solar technology; tenants and smallholders remained excluded. Bukhari and Ahmed (2018) likewise stressed institutional failures, noting that interdepartmental delays, poor coordination, and a lack of monitoring systems resulted in inefficient execution of solar promotion programs.

High initial expenses and little awareness severely impacted the uptake of high-efficiency irrigation systems in Punjab, according to Ashraf et al. (2017). Shah et al. (2018) conducted direct farmer interviews and noted that poor policy outreach and high maintenance costs combined with a lack of public knowledge prevented SPIS spread, therefore supporting their results. According to Latif and Shah (2021), smallholder farmers often saw solar irrigation systems as dangerous due to the lack of after-sales support, insufficient warranties, and poor service networks in remote regions. This impression discouraged long-term investments.

Similarly, Imran and Farooq (2019) emphasized the need for incorporating SPIS into national extension services, arguing that adoption could be raised if field agents were educated to provide technical direction and assistance. More recently, Habibullah and Faheem (2022) evaluated post-installation performance and found that technical failures and a shortage of local technician availability hindered ongoing usage of SPIS, even among first adopters. Further stressing that behavioral inertia—farmers' unwillingness to change from conventional systems and distrust of private vendors—also contributes to poor adoption rates, Kamran et al. (2022).

Nawaz and Anwar (2021) compared the role of government policies and institutional frameworks in enhancing the use of solar power irrigation systems in the region of Punjab. They discovered that there was a high degree of technical viability and interest of farmers, but due to poor coordination between the agricultural departments and energy agencies, policy was poorly implemented. The researchers made it obvious that subsidizing is not all; unless accompanied with regular support services, demonstration on the field and easy loan process, the subsidizing will not be effective in the long run. They also made it report that there was a relatively high uptake in areas where the local government had active renewable energy officers. Their study supports the belief that inefficiencies in institutions are normally slower on the uptake than technological constraints.

Yasir et al. (2022) examined the socioeconomic impact of the adoption of SPIS by smallholder farmers in southern Punjab. They indicated that their findings indicated that farmers who have adopted SPIS have realized a significant reduction in the expenses used on diesel, higher crop achievements, and higher cropping intensities. In addition, the research indicated that solar irrigation decreased reliance on unreliable electricity, thus providing better management and farming at the right times. Nevertheless, the authors were also quick to observe that the high up-front cost and the unawareness remained huge impediments to the popularization. The research reflects powerfully on the idea that SPIS has the potential to improve economic sustainability as well as environmental sustainability where barriers to access are corrected.

Collectively, these studies highlight that SPIS provides long-term advantages, but adoption is hampered not by technology alone but by the socioeconomic environment surrounding rural farmers. This study adds to the body of knowledge by presenting local empirical data from Hafizabad with a focus on practical insights for policy and institutional change.

METHODOLOGY

This study uses a quantitative survey-based methodology. A location known for its dependence on groundwater and strong agricultural output, Hafizabad District in Punjab, was the site of the research. To guarantee representation across small, medium, and large farm sizes, stratified random sampling was applied. Using an interview questionnaire, interviews with 102 farmers were carried out. Through in-person surveys, primary data were gathered. Demographics, farm practices, knowledge of solar systems, and expected obstacles were covered in the questionnaire parts.

Data Analysis Techniques:

Descriptive statistics

Binary logistic regression to determine the factors significantly influencing SPIS adoption

Key Variables

Independent: Age, education, farm size, ownership status, awareness, government support, access to credit

Dependent: Adoption of SPIS (Yes/No)

RESULTS AND DISCUSSION

The analysis of data collected from 102 farmers in Hafizabad District provides valuable insights into the socioeconomic realities influencing the adoption of solar-powered irrigation systems (SPIS). The demographic profile of respondents revealed that 98% of them were males and that 61% were between 36 and 50 years old. With 45% having either no formal education or just primary-level education, educational accomplishment differed. The farm size distribution showed that 52% of respondents ran tiny farms of less than 12 acres, therefore emphasizing the prevalence of smallholders in the agricultural scene of the region.

The degree of education was a major factor affecting the adoption of SPIS. Farmers with more education attained substantially greater adoption rates, as shown in the table. Just 20% of those without any formal education had embraced SPIS; among those with graduate-level education, the rate rose to 60%. This pattern highlights how education influences technological awareness, risk perception, and the capacity to engage with financial or institutional systems that enable SPIS adoption. These results support those of Latif and Shah (2021), who claimed that better-educated farmers are more amenable to clean energy developments and more inclined to look for technical advice.

Table 1: year of education and SPIS Adoption

Year of education	SPIS Adoption: NO	SPIS Adoption: YES	Total
Uneducated	8	22	30
1-5	19	3	22
6-8	12	5	17
9-10	0	15	15
11-12	0	10	10
Above	1	7	8
Total	40	62	102

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Financial willingness also came to be a key determining feature. 62% of participants stated they would embrace SPIS given financial aid. This great level of latent demand shows that the affordability of the initial investment is the actual obstacle, not a lack of interest or perceived benefit. These findings reinforce Shah et al. (2018), which underlined the affordability gap as a major barrier to renewable energy uptake in rural agricultural areas.

Table 2: Financial challenges and SPIS Adoption

Financial challenges	SPIS Adoption: NO	SPIS Adoption: YES	Total
High initial cost	36	18	54
Lack of credit	4	12	16
Lack of subsidies	0	23	23
Other	0	9	9
Total	40	62	102

A cross-tabulation study further verified the strong association between institutional outreach exposure and adoption as well as ownership status. Owner-cultivators were much more inclined to embrace SPIS than tenant farmers were, mostly because of their long-term interest in land productivity and access to official credit. Moreover, farmers who had gone to government awareness workshops or had gotten informational brochures showed rather higher SPIS adoption rates. This underscores how critical institutional interaction and trust are in public projects.

Table 3: Farm size (in acres) and SPIS Adoption

Farm size (in acres)	SPIS Adoption: NO	SPIS Adoption: YES	Total
Less than 9	8	6	14
10-20	12	35	47
21-30	14	16	30
Above 30	6	5	11
Total	40	62	102

Relationship Between Ownership Type and Adoption of Solar-Powered Systems:

It elucidates how the cross-tabulation looks into the relationship existing between land ownership type and adoption of the solar irrigation systems. Considering that 102 were the respondents, out of which 62 had adapted to using solar irrigation systems, the remaining 40 respondents had not adopted these systems. Of non-adopters, 34 are landowners (n = 34), 4 are sharecroppers (n = 4), and 2 are tenants (n = 2). On the other side, there are 47 owners, 9 sharecroppers, and 6 tenants under the adopter.

Deeper statistical insight came through logistic regression analysis. Those who thought acute water shortages were 2.7 times more likely to use SPIS than those who did not regard water availability as a concern. Access to financial institutions—that is, owning a bank account—also had a positive and statistically significant influence, raising the adoption probability by 1.9 times. Government interaction via extension services and educational achievement both exhibited positive coefficients, hence confirming the qualitative findings from field interviews.

Table 4: Regression

	B	S.E.	Wald	df	Sig.	Exp(B)
Age	16.673	4507.493	0.000	1	0.997	17415018.56
Family size	-3.837	4.909	1.337	1	0.920	3.613
Year of education	3.629	1.701	2.645	1	0.046	0.533
Marital status	2.35	4.43	0.000	2	1.000	32.58
Bank account	-0.641	1.045	0.375	1	0.540	0.527
No. of child attending school	1.576	3.113	0.000	1	1.000	4.833
Farm size	0.111	0.391	0.081	1	0.776	1.118

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Monthly cost	0.00	0.23	0.000	1	1.000	1.00
Loan with low interest	-3.739	0.912	16.787	1	<0.001	0.024
Willingness with financial support	-2.927	1.245	5.525	1	0.019	0.054
Water availability issue	3.135	1.493	4.407	1	0.036	22.994
Constant	1.911	1.195	2.560	1	0.110	6.575

As shown in table 4. A logistic regression analysis was used to examine the influence of different socioeconomic factors on the adoption of solar-powered irrigation systems in Hafizabad District. The coefficients (B) report the direction of the relationship, while the significance value (Sig.) specifies whether the variable has a statistically significant relationship.

Farm Size (in Acres)

B = 0.111, Sig. = 0.776

A positive coefficient indicates a positive association between farmers and the adoption of solar-powered irrigation and size of the farm, but the effect was statistically insignificant ($p > .05$). This suggests that farm size has no meaningful influence on the farmers in this sample's decision to adopt solar systems.

Monthly Cost

B = 0.000, Sig. = 1.000

The coefficient is essentially zero, showing no relation between monthly cost or the decision to adopt. The p-value of 1.000 indicates that monthly cost has no statistical impact on adoption behavior.

Preference for a Loan with Low Interest

B = -3.739, Sig. < 0.001

The negative coefficient shows a strong negative association. Farmers that have a preference for a low-interest loan are considerably less likely to adopt solar systems on their own. This may imply they have a dependency on support from outside sources or have constraints in their finances—since $p < 0.001$, the relationship is highly statistically significant.

Willingness with Financial Support

B = -2.927, Sig. = 0.019

There is a negative relationship between willingness to provide financial support and solar system adoption. This suggests that farmers can be willing, only if there is financial support provided, to adopt the system on their own. The significance level $p = 0.019$ suggests that this is a statistically significant factor.

Bank Account (1 = Yes)

B = -0.641, Sig. = 0.540

Though the relationship is negative, this result is not statistically significant ($p = 0.540$). Hence, having a bank account does not significantly influence the adoption decision in this study.

Water Availability Issues (1 = Yes)

B = 3.135, Sig. = 0.036

This variable has a positive and statistically significant impact on solar adoption, as the positive coefficient indicates that farmers who are experiencing issues related to water availability are more likely to adopt solar-powered irrigation systems. This finding seems logical, as solar systems could potentially guarantee a stable supply of water.

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Year of Education

B = 3.629, Sig. = 0.046

The positive coefficient indicates that education positively influences the decision to adopt solar technology. The result is statistically significant (p = 0.046), suggesting that educated farmers are more likely to understand, trust, and adopt innovative irrigation technologies like solar systems.

Age

B = 16.673, Sig. = 0.997

The coefficient has an extremely large value, but the significance value (p) of 997 reveals that there is no statistical relationship between the age and the adoption of solar systems. This outcome can be evidence of the data irregularities or the outliers, and age is not a reliable predictor in this model.

Family Size (Total Household Members)

B = -3.837, Sig. = 0.920

This variable has a negative coefficient, though it does not achieve a significant result (p = 0.920). Therefore, the size of a family does not yield much influence in the decision to adopt the use of solar-powered irrigation plants in the research topic in question.

Marital Status

B = 2.350, Sig. = 1.000

Although the coefficient was positive, marital status did not have any significant effect on the probability of solar adoption (p = 1.000). It implies that marital status does not have any correlation with the technology adoption behavior in this instance.

Number of Children Attending School

B = 1.576, Sig. = 1.000

The coefficient of this variable is positive, but the p-value (1.000) shows that it is irrelevant in association with the solar adoption. Therefore, the level of school- going children in a household does not influence the farmer opting towards the use of solar irrigation technology.

Along with the statistical data, qualitative input from participants pointed out a few often experienced obstacles. At 78%, farmers cited SPIS installation's high initial cost; 65% mentioned lack of inexpensive credit access; and 58% said inadequate technical knowledge or training. Another little but significant portion (29%) pointed to distrust in private vendors, hence stressing the need for transparent procurement methods and controlled service providers. These problems match results by Ashraf et al. (2018) and Kamran et al. (2022), who found that institutional trust and service quality are important in long-term adoption and performance.

Together the results show that though technical knowledge of SPIS is present in Hafizabad, socioeconomic, financial, and institutional issues prevent its actual use. The data offered confirms that advancing solar irrigation in Pakistan calls for more than just equipment availability; it calls for an enabling environment enabled by policy, education, and easy financing.

RECOMMENDATION

Targeted and coordinated policy efforts are necessary to increase the acceptance of solar-powered irrigation systems (SPIS) in Hafizabad. First of all, the government ought to launch soft credit programs or interest-free loans, especially for small and medium-sized farmers. 62% of those polled were ready to adopt SPIS if financial assistance was offered. Affordability would be greatly improved by flexible payment plans matching crop cycles.

Second, at the grassroots level, awareness and technical training initiatives should be extended. According to the research, farmers with more education and government outreach were more inclined to embrace SPIS. Extension divisions should work with licensed solar companies to show demonstrations and offer after-sales assistance.

Third, the institutional procedures need simplifying. A centralized subsidy platform with quick approval timelines and clearly stated eligibility criteria should be introduced. To avoid abuse, only government-certified vendors should also be authorized to engage in public subsidy schemes.

Finally, especially for tenant farmers or those with tiny landholdings, community-based SPIS ownership models should be promoted. These group plans help to fairly spread access to solar technology and lower personal investment expenses. Implementing these procedures would help to solve the major institutional and economic obstacles discovered in this research as well as promote more widespread adoption of sustainable irrigation methods in Pakistan's agricultural industry.

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