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Willingness to Adopt Solar-driven Drip Irrigation Systems: An Investigation in Ganj, Chakri

Bashir Ahmad[1], Naveed Ahmed [2], Alamzeb Awan[3], Shabana Akhtar[4]

[1] Director CEWRI, Climate Energy and Water Research Institute (CEWRI), National Agriculture Research Center (NARC), Islamabad, Pakistan. Email: dr.bashir70@gmail.com

[2] M.Phil. Scholar, Department of Environmental Economics, Pakistan Institute of Development Economics, QAU Campus, Islamabad, Pakistan. Email: mnaveedahmed176@gmail.com

[3] M.Phil. Scholar, Department of Environmental Economics, Pakistan Institute of Development Economics, QAU Campus, Islamabad, Pakistan. Email: alamzebawan11@gmail.com

[4] M.Phil. Scholar, Department of Economics and Finance, Pakistan Institute of Development Economics, QAU Campus, Islamabad, Pakistan. Email: shabanazeb11@gmail.com

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ABSTRACT

Rainwater and underground aquifers are the main sources of irrigation in the Soan River Basin in the Potohar region. Due to climate change, low precipitation rates shrink the underground aquifers and intensify the water and energy demand for irrigation. This study aimed to address water scarcity and energy shortage issues by measuring farmers' willingness to adopt solar-driven drip irrigation systems (SDDIS) in Union Council Ganj, Chakri, District Rawalpindi, Pakistan. The logit model was used to determine the willingness to uptake SDDIS. A survey tool was used to gather data from 141 randomly sampled farmers. The important factors affecting the adoption decision include age, status of the individual in family, number of land parcels, ownership status of the land, depth of water, agriculture as a primary source of income, the demonstration effect on adoption, knowledge of how to use, and the influence of government subsidies on adoption. The research suggests that the government should extend its project to raise awareness among the population about on-farm water and energy-efficient technologies by developing further demonstration sites for farmers. In addition, the authorities should increase grants to help farmers adopt SDDIS.

Corresponding Author's Email: mnaveedahmed176@gmail.com

1. Introduction

The agriculture sector of Pakistan comprises 24.04% of the GDP, and 37.4% of the total labor force works in this sector (Government of Pakistan, 2023). However, agriculture demands a large quantity of water for irrigation. Due to climate change, water availability is rapidly declining day by day. The country is classified among the highly water-scarce economies because of its unjustifiable utilization of underground water reserves by pumping for flood irrigation in the agriculture sector (Muzammil, Zahid, & Breuer, 2020). Therefore, it is crucial to manage water for irrigation purposes in the country. Low-income states like Pakistan face severe energy shortfalls. On the other hand, farmers bear substantial costs for using diesel and electricity to extract underground water (Xin, Bin Dost, Akram, & Watto, 2022). The farmers generally have limited resources and are therefore unable to bear borewell's operational and maintenance costs. Given these circumstances, it can be foreseen that the agriculture sector will encounter huge difficulties in managing irrigation water in the future. Thus, a proactive strategy requires the development of solutions that can effectively minimize irrigation costs (Shafeeque & Bibi, 2023). SDDIS and other such technologies recognized as 'state of the art', encourage and support the use of water in justified amounts and notably decrease energy and irrigation expenses (Siyal & Gerbens-Leenes, 2022). Solar technology has the ability to provide farmers uninterrupted supply of water at cheaper rates. Solar technology gains popularity due to its long lifespan. Consequently, farmers are more likely to be attracted towards solar energy.

However, the installation cost of SDDIS systems is relatively higher than that of conventional irrigation systems (Guno & Agaton, 2022). This is a major obstacle to farmers' adoption of technology, even in water-scarce regions. According to a cost-benefit analysis, there are many other factors that can have an impact on farmers' technology adoption decisions (Bathaei & Štreimikienė, 2023). For instance, their socioeconomic profile can significantly affect their adoption decisions. Xiuling, Qian, Lipeng, and Sarkar (2023) have pointed out that farmers meant exposure to practical demonstrations of the energy and water efficient technologies which can go a long way in their adoption. Thus, whether farmers will opt for SDDIS at a cheaper price with government subsidization is also inquired. Thus, this scenario has to be investigated. Regarding the technology dissemination, Pakistan Agriculture Research Council (PARC) tried to exhibit these technologies in some places in the study area. Theoretically, these sites were to domesticate and construct a favorable image of SDDIS among the farmer target audience. It is this step that may help to facilitate the process of this solution and reveal significant implications for policy (Falchetta, Semeria, Tuninetti, Giordano, Pachauri, & Byers, 2023). This study seeks to establish the farmers' receptiveness towards SDDIS in order to determine the level of acceptance of the new technology. It provides policy implications for the Government that can help increase the protection of groundwater through encouraging the application of efficient irrigation tools. The research findings are useful to PARC to assess the Extension need and impact of PARC's project in the study area and its applicability of extending the project in other rain-fed areas. In addition, this research will benefit the empirical literature regarding the willingness to adopt SDDIS in the Potohar region.

SDDIS have pervaded among the farmers especially those who are in a serious water and energy deficit in their irrigation needs. A literature review of the changes in new technologies is a growing research focus. The structure focuses on social, economical, technical with environment factors which gives pros and cons of the adoption by the farmers. A study from the Kenya found out that high installation cost, lack of finance, and low level of awareness of the technology was the key factors that restrained of its adoption of SDDIS. It also proposes that offering possible associated financial products together with the irrigation equipment, and setting up learning through functional model sites also enhance the rates of utilization (Solar-Powered Irrigation Systems, n. d.). Similarly, a study in Bangladesh analyzes the financial viability and environmental advantages of solar-powered irrigation technology. The study reveals that although the initial investment is high, the long-term benefits, such as the rate of return on investment, lower irrigation costs, and reduced greenhouse gas emissions, significantly affect adoption (Frontiers | Adoption impact of solar based irrigation facility by water-scarce northwestern areas farmers in Bangladesh: Evidence from panel data analysis, 2023).

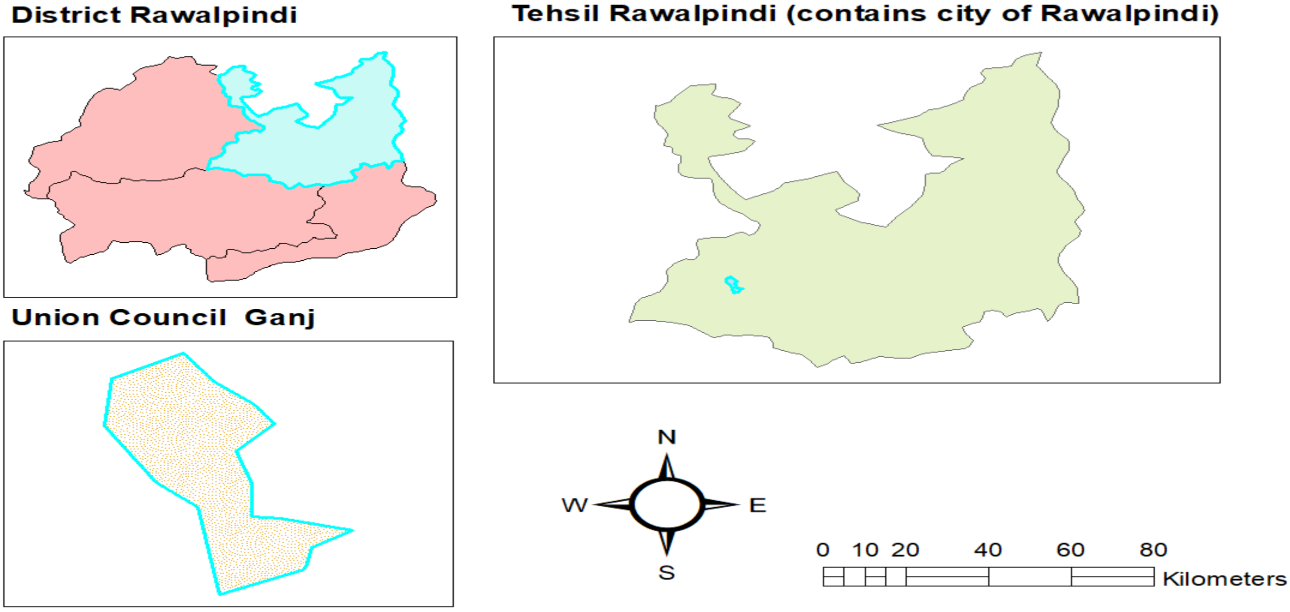
In Africa, study shows that solar irrigation increases the production of agricultural crops and emerges as a solution against climate change. It is also recommended to reduce the initial cost of installation; there must be a focus on developing lower-cost but high-performance irrigation solutions (Falchetta et al., 2023). In view of Pakistan, research suggests that effective government policies along with technical support can increase the adoption rate of solar-powered drip irrigation systems (Solar irrigation in Pakistan: A situation analysis report, 2021, October 21). This research aims to analyze the critical variables influencing farmers' willingness to adopt SDDIS in the Potohar region. This research emphasizes the determinants affecting the adoption of water- and energy-efficient solar technology in the Soan River Basin of the Potohar region in Punjab, Pakistan. Additionally, it explores the optimal financial policies the government should implement to encourage the use of drip irrigation in these rain-fed areas. The study also investigates the impact of practical demonstrations of SDDIS on farmers' adoption decisions. Ultimately, it is anticipated that this study will help identify factors that play a role in adoption decisions. Furthermore, the government should learn from this study how to promote SDDIS in rain-fed areas.

2. Materials and Methods

2.1. Study Area

The National Agriculture Research Centre (NARC), a scientific research institute focused on supporting the agriculture sector, is part of the Pakistan Agriculture Research Council (PARC), a council that sets priorities for research in the country. NARC has established pilot sites in Union Council Ganj, Rawalpindi District, to promote efficient water and energy use in agriculture. These sites were developed as part of the Himalayan Adaptation, Water, and Resilience Project (Exposure Visit to HI-AWARE Climate Smart Training and Learning Pilot Site at Chakri—ICIMOD, n.d.). Ganj Union Council was chosen for the study because it is close to the Soan River in the Potohar region. This location is characterized by limited groundwater resources and restricted access to electricity for irrigation. As a result, SDDIS are particularly advantageous for improving energy and water efficiency in this area.

Figure 1: Study Area



Historically, farmers employed animals to take water from wells, while also utilizing power and fuel to pull water through pumps for agricultural purposes. Nevertheless, the accessibility of water for crops is restricted due to exorbitant fuel expenses and undependable energy provisions. SDDIS, which incurs no running costs, offer a viable substitute for electric and diesel-powered pumps, effectively meeting the requirements for both water and energy in agricultural irrigation.

2.2. Sampling

The current study utilized a well-designed questionnaire to gather field data from farmers. Farmers were selected randomly, and information was collected from the farmers through interviews. Prior to commencing each question-and-answer session, the field survey taker requested the farmer's consent to complete the questionnaire. Additionally, they provided a clear explanation of the final objective and intended utilization of the gathered data. The farmers selected for the survey had the choice to leave the survey at any time, and they participated voluntarily. The data on the important factors is listed in Table 1.

Table 1: Variables Used in the Study

Sr. No	variable	Variable type	Code/ Response
1	Years of Education	Variable Type	Number of years
2	Age in Years	Scale variable	Number of years
3	Status of an Individual in the Family	Scale variable	Head=1, Member=2
4	Satisfaction with the Current Irrigation System	Dichotomous variable	Satisfaction Level (1-5)
5	Number of Land Parcels	Categorical variable	Number of parcels
6	Area of Field (kanals)	Scale variable	Size of farm in kanals
7	Ownership Status of the Land	Scale variable	Owner=1, Cultivator=0
8	Depth of Water	Dichotomous variable	Shallow=1, Deep=0
9	Agriculture as a Primary Source of Income	Dichotomous variable	Yes=1, No=0
10	Family Size	Dichotomous variable	No. of family members

11	Demonstration Effect on Adoption of Technology	Scale variable	Yes=1, No=0
12	Influence of Government Subsidy on Adoption of Technology	Dichotomous variable	Yes=1, No=0
13	How to Use Solar Driven-Drip Irrigation Systems	Dichotomous variable	Yes=1, No=0
14	Adoption of Solar-Driven Pump	Dichotomous variable	Yes=1, No=0
15	Adoption of Solar-Driven Pump with a Drip Irrigation System	Dichotomous variable	Yes=1, No=0

Data were obtained from locations near the experimental sites of the National Agriculture Research Centre (NARC), situated within a 5-kilometer radius of four settlements: Gung, Saroba, Gahi Syedan, and Gaangal, all of which are adjacent to the Soan River. These communities comprise nearly 2,600 farmers. Given that the project team has already conducted farmer training and awareness campaigns in these villages, and considering the close proximity of all trial locations, it is logical to gather data from these areas. The population consists of approximately 2,600 farms, as previously stated. Our sample size is around 141, based on a confidence level of 90% and a margin of error of 10% calculated using the Zscore. Thus, 141 farmers were chosen at random. Data is available publicly on the Zenodo at https://doi.org/10.5281/zenodo.12689154. Moreover, a file containing STATA commands for replicating the results of the study is also available.

2.3. Methods

Replacing electricity and diesel-powered pumps with SDDIS can be a viable option for farming communities in the study area because it provides both energy and water efficiency to local farmers. It is important to investigate if farmers are open to using this technology because of the high cost of electricity and the water shortage in the chosen study location. This question is the focus of the current investigation.

Figure 2: Replacement of Persian Wheel with SDPs

The actual cost of a solar-driven pump (SDPs) is 100,000 PKR, and the cost of drip irrigation per acre is 275,000 PKR on average (*Frequently Asked Questions | On Farm Water Management*, n.d.). The total cost of a SDDIS is 375,000 PKR. However, after a 75% subsidy from the Punjab government Subsidies for Farmers | On Farm Water Management (n.d.), the cost of a SDDIS was reduced to approximately 94,000 PKR. Farmers were offered the option to purchase a SDPs pump for 25,000 PKR without drip irrigation and a SDDIS for 8 kanals for 94,000 PKR with subsidies. The farmers' responses were recorded as "1" for "willing to adopt" and "0" for "unwilling to adopt." Products 1 and 2 were SDPs and SDDIS, respectively, and their willingness to adopt each was recorded in the survey. Classical linear models, such as ordinary least squares (OLS), may produce inconsistent estimators when the dependent variable is binary (Gujarati & Porter, 2009). One potential solution to this problem is to employ maximum likelihood estimation (MLE). However, heteroscedasticity can be another issue arising from using the MLE method. This problem can be addressed by utilizing Logit or Probit models with flexible functions (Finite-Sample Properties of the Maximum Likelihood Estimator for the Binary Logit Model with Random Covariates | Statistical Papers, n.d.). The Logit and Probit models are functionally equivalent, so choosing one over the other does not make much difference. However, the Logit model simplifies mathematical expressions, and its output, the odds ratios, is more easily understood than those from the Probit model (Identification and decompositions in probit and logit models | Empirical Economics, n.d.).

Farmers' perceptions of new technology significantly influence their willingness to adopt a SDDIS. Assuming a linear relationship between benefits and utility, farmers would prefer new technologies over older ones if they improved financial returns. Energy costs are a major component of the overall cost of irrigation for farmers. Installing a SDDIS can save money and water while improving irrigation efficiency. Finally, determining farmers' openness to using SDPs with drip irrigation systems is crucial for achieving the research goal of understanding their willingness to adopt these technologies. The main objective of this research is therefore to identify central performance indicators that influence SDDIS usage. To accomplish this objective, we need farmers' feedback. In the first question, we ask farmers whether they are willing to adopt SDPs (product 1), which is relatively low-priced at 25000 rupees. The adoption variable in this case is considered a categorical variable. The decision to implement the technology is at the discretion of the farmer. In another question, we ask farmers about their willingness to adopt SDDIS (product 2), which are priced relatively higher at 94,000 rupees compared to product 1. Questionnaires were used to gather feedback from farmers residing in the research region. There are two dependent variables that measure farmers' desire to use SDPs standalone or SDDIS. These variables are classified as binary or dichotomous based on the nature of the questions asked in the questionnaire. By first asking about the willingness to adopt a low-price product, SDPs, and then a high price product, SDDIS, we can understand perceived value and benefits of integrated systems SDDIS versus standalone systems SDPs (Akram, Jin, Li, Changan, & Aiman, 2018). Also, since the independent variables may be highly correlated, there can be a problem of multicollinearity during the estimation of coefficients in which the variance of such estimates is increased. A variance inflation factor below the threshold level ensures the reliability and robustness of the model and provides credible study findings (Overcoming the Inconsistences of the Variance Inflation Factor: This not only gives direction to the way VIF can be redefined to give an indicator of the severity of multicollinearity but also offers statistical test to identify the presence troubling multicollinearity, A Redefined VIF and a Test to Detect Statistical Troubling Multicollinearity | Request PDF available: [Accessed January 2023]. The research will make sure that all the VIF values used will not be greater than the acceptable limit.

3. Results

3.1. Multicollinearity Analysis of Independent Variables

The VIF for several independent variable is shown in the following table, which is used to analyze the regression. These values indicate the intensity of multicollinearity amongst the predictors. If the VIF value is lower than 10 suggests low multicollinearity, meaning the variables are not highly correlated with each other. In this analysis, all VIF values are below 2, indicating that multicollinearity is not an issue in this model. The mean VIF is 1.136, further supporting that the predictors are sufficiently independent of each other. This ensures the reliability and validity of the regression coefficients.

Table 2: Variance Inflating Factor for Independent variables

	VIF	1/VIF
Age	1.374	.728
Education	1.345	.744
Family size	1.147	.872
How to use solar-driven drip irrigation system	1.139	.878
Depth of Underground Water	1.133	.883
Status of an Individual in the Family	1.126	.888
Number of Land Parcels	1.097	.912
Demonstration effect on adoption	1.088	.919
Agriculture as a Primary source of income	1.078	.927
Size of farm in kanals	1.077	.929

Ownership Status of Land	1.063	.941
Satisfaction with the current Irrigation System	1.059	.944
Influence of Government Subsidy on Adoption	1.048	.954
Mean VIF	1.136	1.18

3.2. Regression Results

There were two logit models run to see the adoption of a SDPs and a SDDIS. The overall performance of logit models 1 and 2 is satisfactory. Both of the models are statistically significant and perform well. However, Model 2 is superior compared to Model 1 because it explains more variance in the data, making it a more robust model for predicting outcomes. The Wald chi-square test shows a value of 51.986 for Model 1 and 36.136 for Model 2, both of which are statistically significant. Moreover, it shows that at least one independent variable is significantly affecting the adoption of SDPs and SDDIS in both models. In addition, the pseudo-R-squared values indicate that model 1 explains 29.4% and model 2 explains 36.5% of the variability in the endogenous variables, showing a reasonable fit for the logistic regression model because pseudo-R-squared values are typically low compared to R-squared values in linear regression models (Ozili, 2023). The logit model output shows the significance and direction of each variable's impact on the dependent variable and is presented for two different models: Model 1 (adoption of SDPs) and Model 2 (adoption of SDDIS). Education does not significantly influence the dependent variable in either model. Age has a positive and significant effect in Model 2 (0.070*), while its effect in Model 1 is positive but not significant (0.032). The " Status of an Individual in the Family " variable has a significant negative impact in both models, with a stronger effect in Model 2 (-2.316**) compared to Model 1 (-1.363*). Satisfaction with irrigation management does not show significant influence in either model. The size of the land parcel has however a positive and important coefficient in both models, with a slightly higher coefficient in Model 2 (0.357*) compared to Model 1 (0.285*). Farm size does not significantly affect the dependent variable in either model. Ownership status of land shows a positive and significant impact in both models, being more pronounced in Model 2 (3.753***) than in Model 1 (3.046**). The depth of underground water has a significant negative effect in both models, with a slightly stronger impact in Model 1 (-1.236**) than in Model 2 (-1.096*). Agriculture as the primary source of income positively influences the dependent variable significantly in both models, with a greater effect in Model 2 (2.326***) compared to Model 1 (1.681*). Family size does not significantly affect the dependent variable in either model. The demonstration effect is significant and positive in both models, with a stronger effect in Model 2 (1.541*) compared to Model 1 (1.152*). Government subsidy influence is positive and significant in both models, with a slightly higher coefficient in Model 2 (2.303*) than in Model 1 (2.093**). Knowledge of how to use solar pumps has a positive and significant impact in both models, with a higher coefficient in Model 2 (1.110*) compared to Model 1 (0.962*).

Table 3: Combine Results for both Logit Regression Models

Variable	**consider product 1**	**consider product 2**
Education	0.016 (0.054)	0.036 (0.077)
Age	0.032 (0.018)	0.070* (0.028)
Status of an Individual in the Family	-1.363* (0.620)	-2.316** (0.730)
Satisfaction with the current irrigation system	0.617 (1.339)	0.710 (1.157)
No. of land parcels	0.285* (0.122)	0.357* (0.165)
Size of farm (kanals)	-0.002 (0.002)	0.004 (0.002)
Tenurial status	3.046** (1.027)	3.753*** (1.119)
Depth of underground water	-1.236** (0.427)	-1.096* (0.489)
Agriculture as primary source of income	1.681* (0.678)	2.326*** (0.678)
Family size	0.012 (0.069)	0.084 (0.076)
Demonstration effect on adoption	1.152* (0.485)	1.541* (0.604)
Influence of Government Subsidy on Adoption	2.093** (0.713)	2.303* (0.894)
How to use solar-driven pump with drip irrigation system	0.962* (0.381)	1.110* (0.451)
Constant	-7.050** (2.179)	-9.449** (3.601)
N	141	141
r2_p	0.294	0.365
ll	-65.578	-40.880
chi2	51.986	36.136

*Standard errors * p<0.05, ** p<0.01, *** p<0.*00

3.3. Adoption Rate

The tabulation below shows that among those who adopted the SDPs, 88 also adopted the SDDIS, while only 1 did not. Conversely, among those who did not adopt the SDPs, 23 adopted the SDDIS, and 29 did not. The Pearson Chi-squared test result (Chi2 = 58.52, Prob = 0.0000) indicates a significant association between adopting SDPs and combined SDDIS. Even though the price of product 2 is higher, farmers are more willing to adopt it because it is subsidized, and they have higher utility savings on their energy and water costs. This suggests that offering SDPs (product 1) increases the adoption rate of SDDIS (product 2).

Table 4: Cross-Tabulation of Adoption Rates

consider product 1 (solar-driven pumps)	**consider product 2 (solar-driven pumps and drip irrigation system)**		
	0	1	Total
0	29	23	52
1	1	88	89
Total	30	111	141
Pearson Chi2 = 58.52 Prob = 0.0000			

4. Discussion

The coefficients generated from the logit models reveal a number of different variables that may affect the probabilities of adopting the said behaviors. In Model 2 the relevant coefficient for age is positive and statistically significant, 0. 070 Thus, the results revealed that the age of the farmers had a positive influence towards adopting the SDDIS; that is, the older farmers are more inclined to accept the change. This may be due to the fact that as people age, they gain experience and a better grasp of the advantages of the technology, which increases their likelihood of engaging in it (Miran, Tamoor, Kiren, Raza, Hussain, & Kim, 2022). Furthermore, elderly people may have greater stability and resources, which facilitates change implementation. In Model 1 and Model 2, the variable status of individual in family exhibits a substantial and negative influence, with coefficients of -1.363 and -2.316, respectively. This study implies that those who have a low position in the hierarchy of their families will not be able to start it. This can be due to lower autonomy in decision making or limitations on access to assets in the family which are critical for the adoption of technology (Lundberg & Pollak, 2008). The findings of this study reveal that the amount of the land Parcels is positively and strongly related to the likelihood of adoption decision; Coefficient for Model 1 & Model 2 = 0. 285 and 0. 357, respectively. They have more land which can be translated to mean they have more resources and economic stability hence the ease to implement SDPs and SDDIS. Also, the possession of land may be associated with a broader social status and receive the technical support and necessary information to use innovations (Persad et al., 2011).

Ownership status of land, has a significant beneficial impact in both models (Model 1: 3.046; Model 2: 3.753). Having land gives you security and a stake in improvements, which increases the chance of adoption. Due to the stable interest of farmers in their property, landowners are more inclined to make investments that will pay off in the long run (Olumba, Garrod, & Areal, 2024). The depth of underground water has a significant negative effect, with coefficients of -1.236 in Model 1 and -1.096 in Model 2. Deeper underground water levels likely present more challenges and higher costs for extraction, making it less feasible for individuals to adopt SDPs and SDDIS that depend on water resources. This barrier reduces the likelihood of adoption, especially in resource-constrained settings (Groundwater Governance and Adoption of Solar-Powered Irrigation Pumps: Experiences from the Eastern Gangetic Plains, 2020). Having agriculture as the primary occupation shows a positive and significant effect, with coefficients of 1.681 in Model 1 and 2.326 in Model 2 people who work in agriculture are more receptive to adopt SDPs with drip irrigation systems that are relevant to their line of work. Practices that increase sustainability and production have a direct impact on farmers, which influences them to adopt more advantageous technologies (Ejigu, 2021). A solar site's presence has a favorable and noteworthy impact; in Model 1, the coefficient is 1.152, and in Model 2, it is 1.541. Possessing a solar site in a nearby location offers demonstration effects, like lower energy bills and more dependable energy delivery, which promote the adoption of SDPs with SDDIS. The demonstration effect on the adoption of technology can also serve as evidence of the viability and advantages of solar technology, encouraging its further use (*Creating a Solar-Powered Drip Irrigation Optimal Performance Model (SDrOP) to Lower the Cost of Drip Irrigation Systems for Smallholder Farmers* | *Request PDF*, 2022). How to use solar driven-pumps and drip irrigation systems has a strong positive impact (coefficients of 2.303 in Model 2 and 2.093 in Model 1). Increased knowledge probably results in a greater understanding of the advantages and real-world uses of solar technology, giving people more self-assurance and capacity to adopt new technologies (Groundwater Governance and Adoption of Solar-Powered Irrigation Pumps: Experiences from the Eastern Gangetic Plains, 2020). The coefficients of the favorable and significant impact of knowledge about how a solar pump works are 0. 962 in Model 1 and 1 in Model 2. 110 in Model 2. The significant and positive result for the impact of Government Subsidies in both the SDP and SDDIS models is found to be 2. 093 in Model 1 and 2, although the magnitude of the current was higher in the current Model 2. 303 in Model 2. This means that the government financial support is effective in creating appropriate incentives to the farmers to adopt such technologies because of reduced initial costs.. Due to the heavy cost tag coupled with the fact that solar-powered irrigation systems are relatively expensive, subsidies remain paramount as a means to allow farmers go solar. Therefore, such actions as the prolongation and possible widening of subsidy initiatives could enhance sustainable irrigation systems among farmers (Kumar, Syan, Kaur, & Hundal, 2020).

5. Conclusion

This paper analyzed the acceptability of SDDIS by farmers in Union Council Ganj, Chakri, District Rawalpindi, Pakistan and established several factors affecting their staking decision as follows. Older farmers since they are more likely to have more capital as compared to young farmers together with more experience are most likely to make such investments. On the other hand, the lower the family status, and the less decision-making power, the less likely he is to adopt them. Number of land parcels owned and the status of land ownership significantly affects adoption if it is economically stable; the depth of underground water on the other hand hampers its adoption due to higher costs of extraction. Farmers primarily engaged in agriculture are more inclined towards adoption, given its direct benefits to their productivity and sustainability. The existence of demonstration locations and understanding about solar technology significantly increase adoption likelihood by offering practical examples and raising awareness. Government subsidies play an important role in making these technologies affordable. The study recommends that expanding government awareness programs and developing more demonstration sites can boost adoption rates. Addressing financial and informational hurdles through effective government involvement is critical for promoting sustainable farming practices in water-scarce areas, improving water management, and increasing energy efficiency. This study is based on a small geographical area. It can be replicated for all rain-fed areas of Pakistan. However, this would require substantial funding, which is not feasible for the current study.

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