**Comparative Analysis of Constraints faced by Solar Water Pump Adopters and Non Adopters in Haryana and Rajasthan, India**

**Abstract:**

The shift towards Solar-Powered Water Pumping Systems (SWPS) presents significant potential for sustainable agricultural advancement in India, especially in regions facing water scarcity and energy shortages. This research examines the barriers impacting the uptake of SWPS in Haryana and Rajasthan—two prominent states in solar pump deployment. A comparative study was performed utilizing data from 240 farmers (120 who adopted and 120 who did not) across six intentionally chosen districts. Findings indicate that the decision to adopt is shaped by a mix of technical, financial, extension-related, farm-level, operational, environmental, and socio-personal barriers. Among those who adopted, technical issues such as the absence of standardization and insufficient post-installation support were notable, whereas non-adopters were mainly impeded by high upfront costs, limited access to credit, and a lack of awareness. Gaps in extension services, particularly the lack of demonstrations and follow-up assistance, were evident in both groups. Comparisons between states revealed that adopters in Haryana encountered significantly greater levels of constraints across various categories compared to those in Rajasthan, indicating dissatisfaction post-adoption and gaps in implementation. Conversely, non-adopters in both states reported similar obstacles, highlighting pervasive structural challenges. The research emphasizes the necessity for tailored interventions, including quality assurance, timely subsidies, improved extension services, and awareness initiatives. Tackling these multifaceted constraints is crucial for promoting the fair and effective integration of solar technology in Indian agriculture.

**Keywords:** SWPS, Renewable Energy, Technology Constraints, Sustainable Irrigation, Haryana, Rajasthan, Policy Interventions

**Introduction:**

The transition to renewable energy is essential for sustainable agricultural development, particularly in water-scarce and energy-deficient regions. Among various renewable technologies, solar-powered water pumping systems have emerged as a viable alternative to conventional diesel and grid-electricity pumps. These systems utilize solar photovoltaic (PV) panels to harness solar energy, offering a clean, cost-effective, and low-maintenance solution for irrigation, livestock watering, and potable water supply. The relevance of solar pumps has grown with increasing fuel prices, erratic electricity supply, and environmental concerns linked to traditional energy sources (Harishankar *et al.,* 2014). India, with its vast solar potential estimated at over 750 GW by the National Institute of Solar Energy has made significant strides in solar energy adoption. Government initiatives such as the PM-KUSUM scheme provide substantial subsidies to encourage solar pump installations. States like Rajasthan and Haryana have seen large-scale adoption due to proactive policies and high solar radiation availability. Rajasthan leads with over 3.7 lakh installations, while Haryana has deployed nearly 88,000 solar pumps between 2020 and 2023.

Despite policy support, adoption rates vary across regions due to socio-economic, infrastructural, and behavioral factors. Therefore, understanding the dynamics behind the adoption of solar-powered pumps is critical. This study aims to conduct a comparative analysis of adopters and non-adopters in Rajasthan and Haryana—two agriculturally significant states facing common challenges such as declining groundwater levels and unreliable power supply (Shubham *et al.,* 2022). The findings will support targeted policy interventions, foster sustainable irrigation practices, and contribute to national goals for clean energy and agricultural resilience.

**Material and Methods:**

The current research was conducted in the states of Haryana and Rajasthan to evaluate the knowledge, attitudes, and training requirements of farmers regarding Solar-Powered Water Pumping Systems (SPWPs). A multi-stage sampling method was utilized for the selection of the study area. In the initial stage, three districts from each state were purposefully chosen based on the highest number of SPWP installations. The districts selected from Haryana were Yamunanagar (Zone-I), Hisar (Zone-II), and Jhajjar (Zone-III), while in Rajasthan, the chosen districts included Sriganganagar, Bikaner, and Jaipur. These districts were identified in collaboration with the Department of New and Renewable Energy in Haryana and the relevant authorities in Rajasthan. In the second stage, two villages were randomly chosen from each of the six identified districts, resulting in a total of 12 villages. From Hisar district, the selected villages were Ludas and Nangthala; from Jhajjar, Madana Kala and Amadalpur; and from Yamunanagar, Naharpur and Tigri. In Rajasthan, Fakirawali and Ganeshgarh were selected from Sriganganagar; Rojha and Pemasar from Bikaner; and Hirnoda and Renwal from Jaipur. In the final stage, a total of 40 farmers were chosen from each district, consisting of 20 adopters and 20 non-adopters of SPWPs. This resulted in a total sample size of 240 farmers, with 10 adopters and 10 non-adopters selected from each village. Data were gathered through personal interviews conducted at the respondents’ farms or residences to ensure the reliability and accuracy of the information. The constraints were categorized under seven categories such as, technical, financial, extension, farm level, Operational & maintenance, Environmental and Social-personal & psychological constraints. The responses were obtained on a three-point continuum signifying the degree of that particular constraint, i.e., very serious, serious and not so serious. Also, mean per cent score for each of the constraint was obtained by dividing the total obtained score with the maximum possible score of the particular statement. The ranking of constraints was done based on the mean per cent score, obtained for each constraint. Furthermore, an independent sample t-test was conducted to find out if there was a significant difference in the degree of constraints faced by respondents from Haryana and Rajasthan in adoption of SWPS.

**Result:**

**Constraints Faced by SWPS Adopters and Non-Adopters in Haryana and Rajasthan**

The adoption of Solar Water Pumping Systems (SWPS) in Haryana and Rajasthan is influenced by diverse constraints spanning technical, financial, extension, operational, environmental, farm-level, and socio-personal dimensions. A comparative analysis between adopters and non-adopters reveals both commonalities and state-specific variations in the intensity of these challenges.

Technical constraints were prominent across both groups. Adopters in Haryana (MPS 82.22) and Rajasthan (MPS 77.78) identified the lack of standardization and quality assurance of solar components as their top concern, reflecting apprehensions about durability and performance. Meanwhile, non-adopters in both states were primarily deterred by non-availability of spare parts and repair difficulties—early-stage hurdles to technology uptake. Financial constraints remained a dominant barrier. Adopters in Haryana reported high initial investment (MPS 86.67) and insufficient personal capital (MPS 78.89) as key issues, with Rajasthan showing similar trends (MPS 84.44 and 80.00, respectively). Among non-adopters, especially in Rajasthan, the lack of credit (MPS 87.78) and inability to afford the system (MPS 88.89) emerged as the most critical impediments. Extension-related constraints were unanimously highlighted. Lack of demonstrations by extension agencies ranked highest among adopters in both states (MPS 90.00). Non-adopters similarly cited inadequate exposure to the technology and absence of follow-up support as major limitations, underlining the weak extension and awareness mechanisms. Farm-level challenges differed by context. In Haryana, adopters pointed to small landholdings and low income as key barriers, while non-adopters shared similar concerns. In Rajasthan, both groups emphasized issues like deep water tables and saline water, suggesting that natural resource limitations diminish the utility of solar pumps even after adoption. Operational and maintenance issues were more severe for adopters. Poor after-sales service (Haryana MPS 85.56; Rajasthan MPS 81.67) and need for additional infrastructure like storage tanks (MPS ~80.00 in both states) were frequently cited. Non-adopters faced delays in installation, lack of operational knowledge, and absence of trained technicians. Environmental constraints were universal. Adopters and non-adopters alike mentioned poor performance during cloudy days and short winter hours as persistent issues, although such factors were seen as external and less critical compared to economic and institutional barriers. Socio-personal constraints particularly among non-adopters centered on unfavorable attitudes of older farmers, lack of awareness, and limited education. In Haryana, non-adopters highlighted negative mindsets (MPS 82.22) and poor education (MPS 78.89), while in Rajasthan, lack of awareness (MPS 85.00) remained a dominant factor.

**Comparison of constraints faced by respondents in Haryana and Rajasthan**

A comparative study examining the challenges encountered by SWPS adopters and non-adopters in Haryana and Rajasthan indicated that adopters experienced notable differences (at the 1% significance level) in terms of technical, financial, extension, and environmental constraints, with farmers in Haryana reporting greater challenges compared to their counterparts in Rajasthan. Conversely, for non-adopters, there were no statistically significant differences observed in any of the constraint categories between the two states, suggesting a relatively consistent perception of constraints among non-adopters.

**Discussion:**

The implementation of Solar Water Pumping Systems (SWPS) in the regions of Haryana and Rajasthan is shaped by a multifaceted interaction of technical, financial, institutional, and socio-environmental challenges. This research reinforces the notion that the adoption of technology in agriculture is seldom motivated by a singular factor; rather, it is influenced by a variety of interconnected obstacles (Rogers, 2003; Feder *et al.,* 1985). Technical difficulties were significant for both those who adopted the technology and those who did not, encompassing inadequate infrastructure, inferior equipment, and insufficient post-installation assistance (Yadav *et al.,* 2024; Vinay *et al*., 2022). In Haryana, adopters particularly raised concerns regarding quality assurance, while non-adopters highlighted the absence of spare parts and technical support services (Gupta, V., & Singh, S. P. 2025). Financial limitations surfaced as the most significant impediment for non-adopters, particularly in Rajasthan, where high initial costs and restricted access to credit were prevalent (Sathish *et al.,*2024; Kumar et al., 2023). Even among adopters, persistent financial challenges were reported, primarily due to delays in receiving subsidies. Gaps in extension services and awareness were widespread, characterized by a lack of demonstrations and follow-up support,

**Table 1: Constraints Perceived by the SWPS Adopter and Non-adopter Farmers in Haryana and Rajasthan**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S. No.** | **Technical constraints** | **Haryana** | | | | **Rajasthan** | | | |
| **SWPS Adopters**  **(n=60)** | | **SWPS Non-adopters**  **(n=60)** | | **SWPS Adopters**  **(n=60)** | | **SWPS Non-adopters**  **(n=60)** | |
| **MPS** | **Rank** | **MPS** | **Rank** | **MPS** | **Rank** | **MPS** | **Rank** |
| 1. | Spare parts are not available in market. | 33.33 | IV | 74.44 | II | 43.33 | IV | 65.56 | II |
| 2. | Difficulty in getting equipment repaired. | 48.33 | III | 73.89 | III | 55.00 | III | 63.33 | III |
| 3. | Non availability of quality spare parts. | 51.11 | II | 72.78 | IV | 61.11 | II | 67.78 | I |
| 4. | Lack of codes and standards to guarantee quality SPV panels and equipment. | 82.22 | I | 85.00 | I | 77.78 | I | 60.00 | IV |
| **Financial constraints** | | | | | | | | | |
| 5. | Insufficient subsidy | 76.67 | III | 72.78 | V | 71.11 | VI | 78.89 | V |
| 6. | Excessive initial investment | 86.67 | 1 | 63.33 | VII | 80.00 | III | 81.11 | IV |
| 7. | High interest rate and short term loans | 72.78 | IV | 83.33 | III | 76.11 | IV | 83.33 | III |
| 8. | Lack of credit facilities | 65.56 | VII | 87.78 | I | 82.22 | II | 87.78 | II |
| 9 | Lack of money to purchase a solar system | 78.89 | II | 85.00 | II | 84.44 | I | 88.89 | I |
| 10 | Maintenance is costly | 68.89 | VI | 68.89 | VI | 68.89 | VII | 71.11 | VII |
| 11 | High cost of solar pump equipments | 70.00 | V | 73.33 | IV | 74.44 | V | 73.33 | VI |
| 12 | Excessive operational cost | 57.22 | VIII | 45.00 | VIII | 57.22 | VIII | 56.11 | VIII |
| **Extension constraints** | | | | | | | | | |
| 13. | Lack of exposure of solar pump technology | 74.44 | VII | 80.00 | I | 70.00 | VII | 76.67 | III |
| 14. | Lack of demonstrations by KVKs/ Agriculture/Horticulture Department | 90.00 | I | 68.33 | V | 90.00 | I | 83.89 | I |
| 15. | Lack of administrative assistance | 85 | III | 66.67 | VI | 73.89 | VI | 73.33 | IV |
| 16. | Lack of motivational programme for adoption of solar pump | 79.44 | V | 76.11 | II | 79.44 | V | 68.89 | VI |
| 17. | Lack of knowledge of extension agencies | 87.22 | II | 66.11 | VII | 87.22 | II | 79.44 | II |
| 18. | Lack of motivational programme for adoption of solar pump | 81.67 | IV | 65.00 | VIII | 81.67 | IV | 71.67 | V |
| 19. | No follow up services by the supplier | 76.11 | VI | 75.00 | IV | 83.89 | III | 64.44 | VIII |
| 20. | Lack of information regarding the profitability of solar pump | 70.56 | VIII | 62.78 | IX | 66.11 | VIII | 67.22 | VII |
| 21. | Absence of feedback programme | 65.00 | IX | 57.78 | X | 58.33 | X | 57.78 | X |
| 22. | Absence of fellow farmer’s co-operations | 62.22 | X | 73.88 | III | 62.22 | IX | 60.56 | IX |
| **Farm level constraints** | | | | | | | | | |
| 23. | Lack of package of practice for solar pump irrigation farming system | 63.33 | IV | 76.67 | III | 75.56 | III | 70.56 | V |
| 24. | Saline ground water | 43.89 | VI | 62.78 | V | 78.33 | II | 83.33 | II |
| 25. | Higher depth of water table | 46.11 | V | 58.33 | VI | 84.44 | I | 87.22 | I |
| 26. | Inadequate farm income | 75.00 | I | 80.56 | II | 66.11 | V | 75.00 | IV |
| 27. | Small scale landholding | 72.78 | II | 87.22 | I | 70.56 | IV | 78.89 | III |
| 27. | Fear of robbery of solar panel | 72.22 | III | 72.22 | IV | 61.11 | VI | 63.33 | VI |
| **Operational and maintenance constraints** | | | | | | | | | |
| 28. | Requires specific skill in operation and maintenance | 70.00 | IV | 83.33 | III | 77.78 | III | 86.11 | II |
| 29. | Delay from installations | 56.67 | VI | 78.33 | IV | 61.11 | VI | 74.44 | V |
| 30. | Lack of skilled personnel or training schemes | 71.67 | III | 75.00 | V | 71.67 | V | 82.22 | III |
| 31. | Breakdown of solar pump use system | 45.56 | VII | 45.56 | VII | 54.44 | VII | 64.44 | VI |
| 32. | Lack of knowledge about solar system | 60.00 | V | 84.44 | II | 73.33 | IV | 60.00 | VII |
| 33. | Poor after sale services by the solar panel service providers | 85.56 | I | 71.11 | VI | 81.67 | II | 77.78 | IV |
| 34. | Water tank and additional water lifting facilities are required to get efficient irrigation potential | 80.56 | II | 90.00 | I | 85.56 | I | 90.00 | I |
| **Environmental constraints** | | | | | | | | | |
| 35. | Working hours are less during winter season | 92.22 | II | 93.33 | II | 82.22 | II | 86.67 | I |
| 36. | It does not work in cloudy/rainy days | 95.00 | I | 95.00 | I | 85.00 | I | 81.67 | II |
| 37. | Suitable place for establishing of solar pump are not available (weather or climate condition) | 33.33 | III | 33.33 | III | 33.33 | III | 33.33 | III |
| **Social-personal and psychological constraints** | | | | | | | | | |
| 38. | Lack of awareness regarding solar water pump programme | 47.22 | IV | 73.33 | III | 47.22 | III | 85.00 | I |
| 39. | Lack of motivation | 64.44 | II | 71.11 | IV | 53.89 | II | 73.33 | IV |
| 40. | Unfavourable attitude of old aged farmers towards solar water pump programme | 68.89 | I | 82.22 | I | 46.11 | IV | 81.11 | II |
| 41. | Insufficiency of education among farmers for using solar water pump programme | 46.67 | V | 78.89 | II | 57.78 | I | 76.67 | III |
| 42. | Selfish motives of agriculture officer | 48.33 | III | 66.11 | VI | 45.00 | V | 69.44 | V |
| 43. | Lack of interest in solar water pump programme | 33.33 | VI | 62.22 | VII | 33.33 | VI | 62.22 | VII |
| 44. | Inadequacy of support of family members | 33.33 | VII | 67.78 | V | 33.33 | VII | 65.56 | VI |

**Table 2: Comparison of constraints faced by respondents in Haryana and Rajasthan**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Constraints Category | SWPS Adopter | | | | SWPS Non-Adopter | | | |
| Mean Haryana | Mean Rajasthan | Mean Difference | t-Value | Mean Haryana | Mean Rajasthan | Mean Difference | t-Value |
| Technical constraints | 3.02 | 2.53 | 0.49 | 2.138\*\* | 4.08 | 3.9 | 0.18 | 0.368 NS |
| Financial constraints | 2.58 | 2.80 | 0.22 | 3.023\*\* | 3.09 | 3.02 | 0.07 | 0.475 NS |
| Extension constraints | 3.07 | 2.79 | 0.28 | 3.037\*\* | 3.78 | 3.2 | 0.58 | 0.289 NS |
| Farm level constraints | 3.22 | 3.01 | 0.21 | 0.473NS | 4.58 | 4.3 | 0.28 | 0.382 NS |
| Operational and maintenance constraints | 2.96 | 2.77 | 0.19 | 0.294 NS | 3.89 | 3.7 | 0.19 | 0.427 NS |
| Environmental constraints | 3.42 | 2.80 | 0.62 | 2.853\*\* | 4.64 | 3.96 | 0.68 | 0.471 NS |
| Social-personal and psychological constraints | 2.78 | 2.50 | 0.28 | 0.432 NS | 3.25 | 3.04 | 0.21 | 0.361 NS |

**(NS = Non Significant, \*\* = Significant at 0.01 level of significance)**

which aligns with the findings of (Santra *et al*., 2021) and indicates inadequate institutional support systems. Issues specific to location also played a role in influencing adoption: the small landholdings and low income in Haryana diminished feasibility, while Rajasthan encountered ecological difficulties such as deep water tables and salinity (Singh, G. & Gandhi, V. 2024). Adopters experienced operational challenges, including a shortage of maintenance services and the necessity for additional infrastructure (Roy, S., & Mohapatra, S. 2022). Although environmental issues were not heavily emphasized, concerns regarding efficiency during overcast days and winter months indicate a potential need for hybrid or battery-assisted systems (Kumar *et al.,* 2022; Kumar *et al.,* 2024). Socio-personal elements—such as age, educational background, and risk perception—further constrained adoption among non-adopters, in accordance with Rogers' diffusion theory. State-level comparison revealed that adopters in Haryana reported higher constraint levels across multiple dimensions, possibly due to unmet expectations post-adoption (Kumar *et al.,* 2024). Non-adopters, however, showed similar constraint perceptions across both states, indicating common structural challenges like lack of credit, awareness, and extension services.

**Conclusion:**

The research highlights that the implementation of Solar Water Pumping Systems (SWPS) in Haryana and Rajasthan is influenced not only by the availability of technology but is also intricately linked to a combination of technical, financial, institutional, environmental, and socio-personal elements. The results indicate that both users who have adopted and those who have not encounter considerable obstacles, although the characteristics and severity of these challenges differ between states and user groups. Key barriers to adoption include technical inefficiencies, restricted financial access, insufficient extension services, and environmental constraints. While adopters in Haryana reported greater levels of constraints, indicating dissatisfaction and operational difficulties after installation, non-adopters in both states pointed out similar fundamental challenges such as a lack of credit options, limited awareness, and inadequate institutional support. These findings imply that a comprehensive, region-specific strategy is crucial for improving the adoption of SWPS. Policy measures should aim to enhance system quality, guarantee prompt subsidy payments, bolster extension services, and create technologies that are suitable for the local context—especially in areas facing ecological challenges. Furthermore, increasing awareness and tackling socio-personal reservations through focused capacity-building programs could help close the adoption gap. Addressing these interconnected issues is essential for fostering sustainable irrigation methods and promoting the integration of renewable energy in Indian agriculture.

**Competing Interests Disclaimer:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

**Disclaimer (Artificial intelligence)**

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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