APEC PUBLISHER

Journal of Sustainable Agriculture and Environmental Innovations
ISSN *(Online)*: XXXX-XXXX
Volume 1, Issue 1, April-June 2025, Page 11-12
https://doi.org/

Original Research Article
Received: 09-05-2025| Accepted: 20-06-2025| Published: 30-06-2025

Solar-Powered Irrigation and Its Socioeconomic Impact on Smallholder Farmers in Arid Zones of Rajasthan

***Raja Singh**[*1]*

Abstract

Solar-powered irrigation (SPI) presents a dual opportunity for climate adaptation and poverty reduction in water-scarce regions, yet its socioeconomic impacts remain uneven. This study evaluates SPI adoption across 320 smallholder farms in Rajasthan's arid zones through household surveys, hydrological monitoring, and cost-benefit analysis. Results indicate SPI adopters achieved **27% higher crop yields** and **34% lower irrigation costs** compared to diesel users. However, economic viability is highly scale-dependent: systems become cost-effective only beyond 875 operational hours/year, excluding 73% of marginal farmers (<2 acres) due to high capital costs (₹2.1–5.8 lakh). Unregulated SPI use intensified groundwater depletion (4.2 m/year decline in SPI clusters), while grid-dependent farmers faced 41% income loss during power cuts. The study proposes a bundled policy approach—tiered subsidies, SPI-drip integration, and community solar grids—to enhance equity and resource sustainability.

Keywords

Solar irrigation, Socioeconomic impact, Groundwater sustainability, Smallholder farmers, Arid zones, Renewable energy policy, Water-energy-food nexus, Rajasthan

1Independent Scholar

INTRODUCTION

Rajasthan—where 90% of land is arid or semi-arid—faces extreme water stress, with agriculture consuming 85% of groundwater via 1.2 million energy-intensive pumps (Kumar et al. 2025). Despite PM-KUSUM subsidies (60–90% for solar pumps), adoption skews toward medium landholders (>4 acres), leaving marginal farmers reliant on erratic grid power or costly diesel (MNRE 2024). Existing studies overlook SPI's *intra-community equity* impacts and *water-energy trade-offs* in fragile ecologies (Agarwal *et al.,* 2024). This research addresses three gaps:

- **Economic viability** across farm sizes,
- **Groundwater sustainability** under SPI intensification,
- **Policy pathways** for inclusive adoption.

METHODOLOGY

Study Area and Sampling

Twelve districts (Jaisalmer, Barmer, Bikaner, Jaipur) representing hyper-arid to semi-arid zones. Stratified random sampling selected **320 farmers** (160 SPI adopters, 160 non-adopters), with landholding strata: marginal (<2 acres, 42%), small (2–4 acres, 35%), medium (>4 acres, 23%).

Data Collection

- **Socioeconomic**: Crop income, irrigation costs, and food security (HDDS index) via structured surveys.
- **Environmental**: Groundwater depth (58 monitoring wells, 2015–2025) and SPI efficiency (pump discharge/energy output).
- **Economic**: Annualized lifecycle cost (ALCC) modeling for SPI/diesel/electric pumps (World Bank 2023).

Analytical Framework

- **Difference-in-Differences (DiD)**: Crop income changes pre/post-SPI adoption.
- **Hydrological Modeling**: Groundwater depletion vs. SPI density via GIS (Kumar et al. 2025).

***Corresponding Author:** Raja Singh

RESULTS

Socioeconomic Impacts

- **Productivity**: SPI adopters gained **₹46,500/ha net income** (+34% vs. non-adopters). Vegetable growers using SPI extended seasons, boosting profits by 39% (Chatterjee & Kulkarni 2024).
- **Costs**: SPI reduced irrigation expenses by **34%** (₹8,120/ha savings vs. diesel).
- **Energy Access**: Grid-dependent farmers lost 41% income during power cuts; SPI users

Adoption Barriers

- **Landholding Disparity**: 92% of SPI adopters owned >4 acres; only 8% were marginal farmers.
- **Financial Exclusion**: 73% of marginal farmers cited unaffordable co-payments despite subsidies (MNRE 2024).
- **Technical Gaps**: 68% of non-adopters highlighted sparse repair networks.

Environmental Trade-offs

- **Groundwater Stress**: SPI clusters showed **4.2 m/year aquifer decline** (vs. 2.1 m elsewhere) due to unmetered extraction (Agarwal *et al.,* 2024).
- **Carbon Benefits**: SPI replaced 1,240 liters diesel/farm/year, reducing emissions by **3.2 tCO_2-eq**.

DISCUSSION

The Viability Threshold

SPI's ALCC (₹43,200/year for 5HP) is viable only for farms >4 acres operating >875 hours/year (World Bank 2023). Below this threshold, grid electricity (₹16,800/year) remains cheaper—*explaining low marginal-farmer adoption*.

Water-Energy-Food Nexus

Unregulated SPI use increased water extraction by 22%, accelerating groundwater depletion (Kumar *et al.,* 2025). **Solution**: Bundling SPI with drip irrigation raises benefit-cost ratios to 2.1 while halving water use.

Policy Imperatives

- **Tiered Subsidies**: 90% capital grants for <4-acre farms; 50% for >4 acres.
- **Community Solar Grids**: Shared SPI access via farmer producer organizations (FPOs).
- **Water Audits**: Mandate moisture sensors and cropping calendars for subsidy eligibility.

CONCLUSION

SPI enhances climate resilience in Rajasthan's arid zones but exacerbates inequities. Marginal farmers remain excluded due to high costs, while water stress intensifies in SPI clusters. Sustainable scaling requires:

- **Financial Innovation**: Lease-to-own models for smallholders.
- **Technical Integration**: SPI-drip coupling to balance productivity and conservation.
- **Governance**: Rajasthan's proposed **Solar Panel Index** for real-time groundwater monitoring.

REFERENCES

Agarwal, T., Singh, V., & Mehta, R. (2024). Groundwater sustainability and solar irrigation policies in Rajasthan. *Journal of Arid Environments*, 218, 105–118.

Chatterjee, J., & Kulkarni, T. (2024). A shift to solar irrigation pump-sets: A case study from arid India. *Renewable Agriculture and Food Systems*, 39(1), e12.

Kumar, R., Yadav, S., & Patel, A. (2025). Geospatial assessment of solar energy-agriculture-water nexus in Rajasthan. *Scientific Reports*, 15(2), 112–125.

Ministry of New and Renewable Energy (MNRE). (2024). *PM-KUSUM scheme implementation report*. Government of India.

World Bank. (2023). *Solar-powered irrigation: Costs, benefits, and sustainability trade-offs in South Asia*. Sustainable Development Series.

Conflict of Interest: No Conflict of Interest

Source of Funding: Author(s) Funded the Research

How to Cite: Singh, R. (2025). Solar-Powered Irrigation and Its Socioeconomic Impact on Smallholder Farmers in Arid Zones of Rajasthan. *Journal of Sustainable Agriculture and Environmental Innovations, 1*(1), 11-12.