

Gender-responsive solar energy for sustainable rural livelihoods: Lessons in productive use from Mandla district, India

Summary

Across South Asia, governments have invested heavily in solar irrigation to reduce diesel dependence, improve farmers' access to water, and build climate resilience. Yet many solar irrigation systems remain underutilized for significant parts of the year. Once irrigation demand falls, valuable clean energy goes unused while communities continue to struggle with limited livelihood opportunities and the high costs of maintaining irrigation infrastructure.

This presents an untapped opportunity.

Instead of viewing solar pumps solely as irrigation assets, they can become community energy hubs that power local enterprises, generate income, strengthen women's leadership, and improve the long-term sustainability of rural infrastructure.

Under the Swiss Agency for Development and Cooperation (SDC)-funded **Solar Energy for Agricultural Resilience** (SoLAR) project, the International Water Management Institute (IWMI), together with PRADAN (Professional Assistance for Development Action), tested this approach in tribal communities in Chimkatola (85 households, 51.4 ha) and Kevlari (180 households, 38.6 ha) villages of Mandla district, Madhya Pradesh.

The model combines: Solar lift irrigation (6.75 kWp solar PV array with a 7.5 HP pump - generating an estimated ~8,457 kWh/year); women-led Water User Associations (WUAs with 15 members in Chimkatola, 14 in Kevlari)); and solar-powered 5 HP rice milling to demonstrate how productive use of surplus energy can improve both livelihoods and financial sustainability



A woman farmer cleans a solar panel site in Kevlari, Mandla district, Madhya Pradesh. (photo: Tanmoy Bhaduri/IWMI)



Two 6.75 kilowatt-peak (kWp) solar systems generate ~8,457 kWh/year each



Women earned up to USD 423/season from vegetables, plus USD 153-190 in WUA water-sale



USD 60/year saved in electricity costs; Positive NPVs (USD 984-4,566) and <5-year payback through reduced upfront capital costs



15,000+ agricultural pump connections in Mandla district alone show the scale-up potential



Policy should support integrated Water-Energy-Food systems rather than standalone irrigation assets

The challenge: why solar irrigation alone is not enough

Solar irrigation has transformed access to water for thousands of farmers. However, many community systems continue to face common challenges - as the Mandla pilot's own numbers show.

Financial sustainability

Revenue from water tariffs alone is often insufficient. At Mandla, tariffs of USD 0.43/hour (members) and USD 0.63/hour (non-members) generated only USD 153-190 per site in year one - well short of the USD 23.39/month benchmark needed to cover loan repayment and system maintenance fully.

Limited rural enterprises

Most solar irrigation projects stop at pumping water. At Mandla, rice milling used only around 1% of total seasonal solar generation. A dedicated 2.5 kWp mill could unlock up to 825 milling hours/season and USD 846/year in revenue. With the current set-up, only 28% of village demand (270 quintals) is met.

Women's limited ownership of energy assets

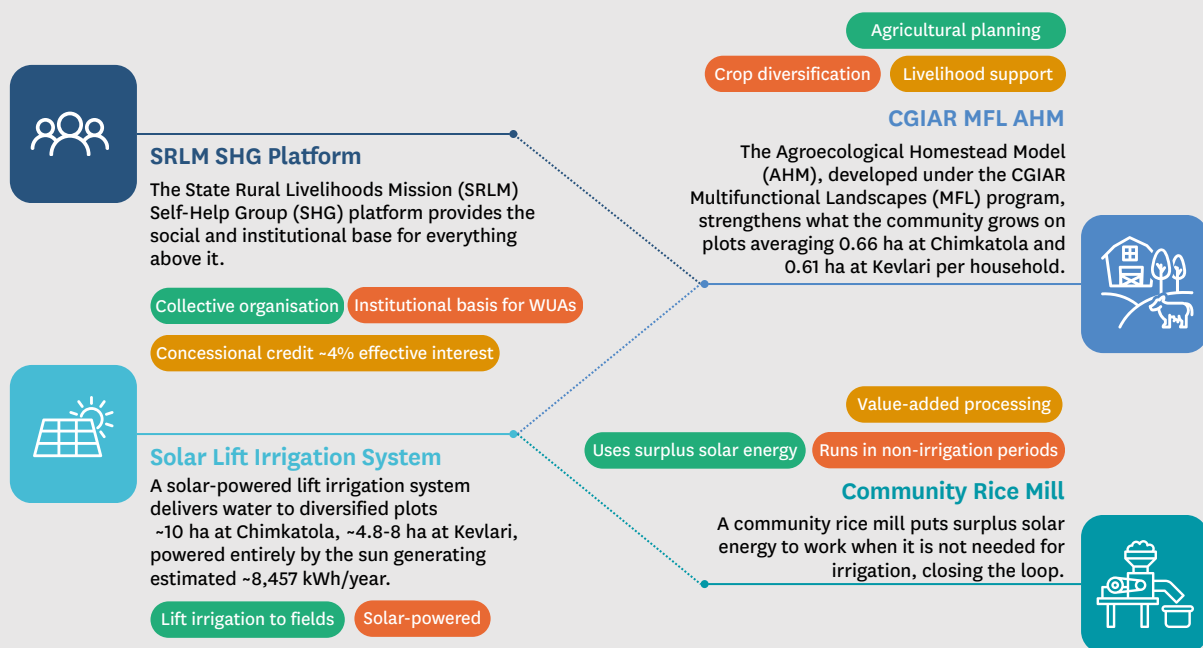
Although women contribute significantly to agriculture, they rarely manage productive energy infrastructure. At Mandla, women hold 100% of WUA seats (15 members in Chimkatola, 14 in Kevlari) - evidence that this can change with the right institutional design.



A woman farmer transports harvested paddy to the solar-powered community rice mill in Kevlari village, Madhya Pradesh. (photo: Tanmoy Bhaduri/IWMI)

A four-layer model of community-managed irrigation

Four interconnected layers, each building on the one below, that turn a stand-alone irrigation system into a community-managed productive energy enterprise



Scaling
From community pilot to district and national policy

Enabling conditions
Blended finance, productive-use integration beyond irrigation, and facilitation, training and capacity building

Replication potential
Replicated across 4 villages and PM-KUSUM B positioned as the national financing model



Yashoda Devi, a member of the Kevlari Water User Association, operates the community solar-powered rice mill in Kevlari village, Madhya Pradesh. (photo: Tanmoy Bhaduri/IWMI)



Members of the Chimkatola Water User Association record payments for irrigation services as part of the community-managed solar irrigation system. (photo: Tanmoy Bhaduri/IWMI)

Evidence from the pilot in Madhya Pradesh

The pilot implemented in Chimkatola and Kevlari villages in Mandla district, Madhya Pradesh, demonstrated that the productive use of solar irrigation systems can generate benefits that extend well beyond improved access to irrigation.

Reliable energy

Each 6.75 kWp / 7.5 HP system generates an estimated ~8,457 kWh/year (~25 kWh/day), irrigating ~10 ha at Chimkatola and ~4.8-8 ha at Kevlar reduced farmers' dependence on erratic electricity supplies and costly diesel pumps, while enabling greater crop diversification and improving agricultural productivity.

Women's leadership

Women-led WUAs, all from Scheduled Tribe households, set irrigation schedules, collect fees (Rs 40/hr members, Rs 60/hr non-members), and have already banked Rs 14,500 (Chimkatola) and Rs 18,000 (Kevlari) in water-sale revenue.

Better proximity

The installation of a solar-powered rice mill (USD 952 - financed by USD 105 community contribution, USD 582 project grant and USD 265 SRLM CCL loan) brought significant economic and social benefits. It reduced the need for farmers to travel long distances up to 15 km for milling services, lowered processing costs, saved time, and created new opportunities for local income generation.

Community ownership

Emerged as another key outcome of the pilot. Financial contributions from farmers encouraged better maintenance of the infrastructure, strengthened accountability, enabled faster repairs, and improved collective management of the system.

Lessons learnt

- Irrigation and milling still compete for the same array: milling used only ~1% of seasonal generation, underscoring the case for dedicated productive-use systems
- Importance of strengthening market linkages
- Investing in continuous capacity building to ensure the long-term sustainability and impact of productive-use interventions.

Policy implications

Scaling solar irrigation requires more than simply installing solar pumps. To deliver lasting economic, social, and environmental benefits, future programmes should integrate productive use, community institutions and supportive market ecosystems in their design.

■ **Shift to integrated community energy design.** Design systems as multi-use assets from the outset, not seasonal irrigation infrastructure alone, so the full ~8,457 kWh/year generated per site is put to work year-round. Designing the infrastructure to support local business grids alongside farming ensures maximizing the return on investment for the entire community.

■ **Incentivize local value-addition and solar-powered enterprises.** To ensure the financial sustainability of these community systems, policymakers should actively support the establishment of solar-powered rural enterprises. This includes providing targeted credit, training, and market linkages for high-yield productive uses such as agro-processing, rice milling, and cold storage. Promoting these value-addition activities directly translates clean energy access into sustainable household income.

■ **Invest in women-led institutions.** Strong community institutions are essential for the long-term success of solar irrigation. Strengthening SHGs and women-led WUAs can improve governance, financial management, operation and maintenance, and equitable access to irrigation and productive assets

■ **Strengthen rural value chains.** Investments in solar irrigation should be complemented by market access, enterprise development, business training, and technical support. Building these enabling conditions allows communities to fully realize the economic benefits of productive-use technologies and develop sustainable rural enterprises.

■ **Improve system design.** The Mandla pilot highlights the importance of appropriate technical design. Installing dedicated photovoltaic systems for productive-use activities, rather than sharing the same solar array with irrigation pumps, can reduce operational conflicts, increase equipment utilization, improve revenue generation, better market linkages and enhance the long-term financial viability of community solar irrigation systems.

“Initially, many women in the village were hesitant because even a small financial contribution felt risky for families already struggling with uncertain incomes and limited access to irrigation. But once farmers began seeing the benefits- reliable water access, healthier crops, reduced electricity costs, and better yields- one woman farmer earned around INR 40,000 (USD 415) from selling vegetables such as brinjal in the past season. Their confidence gradually grew. Today, more farmers are accessing irrigation water from the solar pump, and women are actively participating in managing and expanding its use in their homestead farms.”



Yashoda Devi

Member of the Kevlari Water User Association

“The rice mill has significantly reduced the time and cost involved in travelling to distant markets, as we can now process rice locally within the village. We are still at a very early stage and are actively motivating more women in the village to use the rice mill instead of depending on outside markets. The Water User Association has also collected nearly INR 14,500 (USD 150) through water sales, providing an additional source of revenue for the community. At the same time, we are exploring ways to sell rice chaff as an additional source of income. We are also encouraging other women members to operate the machine so that the work and technical knowledge do not remain dependent on just one person.”



Jamuna Devi

Member of the Chimkatola Water User Association

~8,000 kWh

of clean electricity can be generated annually by the 6.75 kWp community solar irrigation system, with productive use helping maximise the utilisation of this renewable energy.

3-5 tonnes

of carbon dioxide emissions can be avoided each year by replacing diesel-based irrigation with a solar-powered irrigation system.

INR 5,000 (USD 53)

or more in annual electricity cost savings can be achieved by WUA plus a positive NPV across various scenarios USD 992-4,592 and payback <5 years

Integrated sustainability of a community-governed solar irrigation system

Financial viability
Revenue adequacy, cost recovery and financial robustness.
(Our estimates indicate that, Reducing upfront capital costs through grant/subsidy support, complemented by sustainable community contribution)

Technical performance
System reliability, resource efficiency and operation adequacy.
(~8,457 kWh/yr per 6.75 kWp system;
~1,350 pump-hours/yr)



Gender and social inclusion
Women's participation, equity and benefit sharing.
(As they hold 100% seats)

Institutional governance
Collective decision-making, rule enforcement and accountability.

Productive use integration
Conversion of surplus energy into income and livelihood benefits.
(Rice milling used ~1% of seasonal generation; a dedicated 2.5 kWp array could unlock 825 hrs/season)

Implementation lifecycle



Recommendations for scaling

Governments

- Integrate productive-use components into solar irrigation programmes such as PM-KUSUM.
- Encourage community-owned renewable energy enterprises.
- Align solar irrigation with rural livelihood and agricultural value chain initiatives.

Financial Institutions

- Develop affordable financing for community-owned productive-use equipment.
- Support blended finance models that combine public investment with community contributions.

Development Partners

- Invest in integrated Water-Energy-Food approaches.
- Support capacity building for women-led institutions.
- Promote evidence generation on productive use and rural enterprises

Research Organizations

- Evaluate long-term financial sustainability of productive-use models.
- Assess impacts on livelihoods, gender equality, and climate resilience.
- Generate scalable evidence for different agroecological contexts.



Laxmi Tekab and members of the Bhawarda Water User Association operate a newly installed Solar Irrigation Pump in Bhawarda village, Narayanganj block, Madhya Pradesh. (photo: Tanmoy Bhaduri/IWMI)



Laxmi Tekab and fellow members of the Bhawarda Water User Association carry out routine maintenance of the solar panels powering their Solar Irrigation Pump. (photo: Tanmoy Bhaduri/IWMI)

Way forward

Solar irrigation should be viewed as more than a technology for lifting water. When combined with inclusive community institutions, women's leadership, and productive rural enterprises, it can drive resilient livelihoods and sustainable rural development. The Mandla experience shows that using surplus solar energy for productive activities can transform community irrigation systems into financially sustainable rural energy enterprises.

Scaling this approach will require integrating productive uses into solar irrigation programmes, strengthening women-led Water User Associations, improving access to finance and markets, and investing in technical support. By linking water, energy, food, and livelihoods, solar irrigation can deliver greater economic, social, and environmental benefits for rural communities.

We visited Kevlari village and saw how farmers were lifting water from the river using Solar Lift Irrigation, despite the difficult terrain and height difference. They were growing vegetables like tomato, brinjal and chilli. Seeing this, we felt that our village has relatively plain land, so we should also be able to benefit from the technology. We did not have our own diesel pump. We had to buy water from others, and the costs were high. After seeing how women in Kevlari had organised themselves, we formed a Water User Group in our village and installed solar irrigation pump with support from PRADAN and HDFC Parivartan.



Laxmi Tekab
Farmer, Bhawarda village
Narayanganj, Madhya Pradesh

Authors

Anurag Banerjee, Research Officer, International Water Management Institute (IWMI), New Delhi, India

Tripti Agarwal, Project Coordinator, IWMI, New Delhi, India

Deepak Varshney, Regional Researcher, IWMI, New Delhi, India

Saurabh Singh, Team Coordinator, PRADAN, Naryanganj, Madhya Pradesh, India

Tanmoy Bhaduri, Communications Specialist, IWMI, New Delhi, India

Darshini Ravindranath, Project Lead, SoLAR and Research Group Leader – Climate Policies, Finance and Processes, IWMI, Colombo, Sri Lanka

Gopal Kumar, Country Representative – India and Bangladesh, IWMI, New Delhi, India

Author contributions:

Conceptualization: Deepak Varshney, Darshini Ravindranath; **Methodology:** Deepak Varshney, Anurag Banerjee, Tripti Agarwal; **Validation:** Deepak Varshney, Gopal Kumar, Saurabh Singh, Darshini Ravindranath; **Formal analysis:** Anurag Banerjee, Tripti Agarwal; **Writing:** Anurag Banerjee, Tripti Agarwal, Tanmoy Bhaduri; **Visualization:** Anurag Banerjee, Tanmoy Bhaduri; **Supervision:** Deepak Varshney, Darshini Ravindranath; **Project administration:** Tripti Agarwal, Deepak Varshney, Darshini Ravindranath

Target audience

Primary audience: Government of India - Ministry of New and Renewable Energy (MNRE), Ministry of Agriculture and Farmers' Welfare (MoAFW), Deendayal Antyodaya Yojana - National Rural Livelihoods Mission (DAY-NRLM), Department of Land Resources (DoLR), Ministry of Rural Development of India (MoRD).

Secondary audience: Madhya Pradesh State Government (notably the State Department of Panchayat and Rural Development, Water Resources, Farmers' Welfare, Agricultural Development, Tribal Affairs, State Rural Livelihood Mission), and development partners financing water, livelihood, and climate resilience programs in India.

Citation

Banerjee, Anurag, Tripti Agarwal, Deepak Varshney, et al. 2026. *Gender-Responsive Solar Energy for Sustainable Rural Livelihoods: Lessons in Productive Use from Mandla District, India*. International Water Management Institute.

Acknowledgements

This research was carried out under the Solar Energy for Agricultural Resilience (SoLAR) Phase II project. The authors would like to acknowledge the Swiss Agency for Development and Cooperation (SDC) for funding this project and also acknowledge the support provided by the CGIAR Multifunctional Landscapes program, Madhya Pradesh State Rural Livelihoods Mission (MPSRLM) and the PRADAN team in Narayanganj. We acknowledge the support provided by Tanmoy Bhaduri (Communications Specialist, IWMI, New Delhi, India) in designing it.

Disclaimer

This publication has not been independently peer-reviewed. Responsibility for editing, proofreading, layout, opinions expressed, and any possible errors lies with the authors and not the institutions involved.

© 2026 International Water Management Institute. Some rights reserved. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

Contacts

Please send inquiries and comments to:

Darshini Ravindranath, Project Lead-SoLAR & Research Group Leader, Climate Policies, Finance and Processes, IWMI, Colombo, Sri Lanka
(D.Ravindranath@cgiar.org)



The International Water Management Institute (IWMI) is an international, research-for-development organization that works with governments, civil society and the private sector to solve water problems in developing countries and scale up solutions. Through partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services and products with capacity strengthening, dialogue and policy analysis to support implementation of water management solutions for agriculture, ecosystems, climate change and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center with offices in 17 countries and a global network of scientists operating in more than 55 countries.

International Water
Management Institute (IWMI)

Headquarters
127 Sunil Mawatha, Pelawatta,
Battaramulla, Sri Lanka

Mailing address:
P. O. Box 2075, Colombo, Sri Lanka
Tel: +94 11 2880000
Fax: +94 11 2786854
Email: iwmi@cgiar.org
www.iwmi.org