

Synthesis Report

# Solar-powered Irrigation Solutions

Seven Innovative Projects in India, Nepal and Pakistan under  
Innovation Fund Grant





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# Acronyms and Abbreviations

- AEPC:** Alternative Energy Promotion Center
- CEWRI:** Climate, Energy and Water Research Institute
- CIGS:** copper indium gallium selenide
- COP27:** 27<sup>th</sup> Conference of Parties
- DRE:** distributed renewable energy
- FDFA:** Federal Department of Foreign Affairs
- FI:** flood or furrow irrigation
- FLDG:** First Loss Default Guarantee
- GHG:** greenhouse gas
- GOI:** Government of India
- GOP:** Government of Pakistan
- GPCCE:** Global Programme Climate Change and Environment
- IMI:** individually managed irrigation
- ICIMOD:** International Centre for Integrated Mountain Development
- IF:** Innovation Fund
- IWMI:** International Water Management Institute
- KPI:** Key Performance Indicator
- MapRE:** multicriteria analysis for planning renewable energy
- MEs:** micro-enterprises
- MNRE:** Ministry of New and Renewable Energy
- NREL:** National Renewable Energy Laboratory
- NARC:** National Agricultural Research Center
- NDC:** nationally determined contribution
- OGB:** Off Grid Bazaar
- PURE:** Productive use of Renewable Energy
- PM-KUSUM:** Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
- RDI:** responsive drip irrigation
- RMUs:** remote monitoring units
- RGF:** Revolving Guarantee Fund
- SDC:** Swiss Agency for Development and Cooperation
- SDI:** standard drip irrigation
- SHGs:** self-help groups
- SIPs:** solar irrigation pumps

**SIPS:** solar irrigation pump system

**SPIS:** solar-powered irrigation system

**SKY:** Suryashakti Kisan Yojana

**SoLAR:** Solar Irrigation for Agriculture Resilience in South Asia

**SWPS:** solar water pumping systems

**UNFCCC:** United Nations Framework Convention on Climate Change

**VSBK:** Vertical Shaft Brick Kiln

**WUG:** Water Users Group

**YIIB:** Yield Improvement in a Box

# Summary

Amidst escalating concerns about climate change driven by carbon emissions, IWMI has launched the SoLAR project in South Asia, funded by the SDC in 2020.

With a focus on challenges faced by small-scale, marginal and women farmers, SoLAR launched an Innovation Fund (IF) that has supported grantees in developing and testing technological, financial and institutional innovations to address the limitations of upscaling solar irrigation. The objectives of SoLAR IF grants were to:

- *Bridge the gaps and barriers to sustainable adoption* that hamper the scaling of solar irrigation pumps by small-scale, marginal and women farmers.
- *Encourage the sustainable use of groundwater resources* when utilizing solar-based irrigation.

*Enhance climate-resilient livelihood* options for small-scale, marginal and women farmers in the region. The IF grants are a financial innovation aimed at creating livelihood opportunities for small and marginal farmers. These projects have supported solar micro-pumps for smallholder farmers, productive use of excess solar power, collateral-free loans via a revolving fund, data-driven monitoring, community-led models like women-led Water Users Groups (WUGs) and solar mini-grids, and water-saving technologies like hydroponics and responsive drip irrigation.

This synthesis report details these financial and technological innovations implemented by seven SoLAR IF grantees in three countries (see Table 1).

**Table 1.** Seven SoLAR Innovation Fund (IF) grantees, further described in the section on case studies.

IF No.	Grantee	Project	Country
1	Kalinga Renewable Energy Manufacturers Private Ltd, Bhubaneswar, Odisha	Mobile URJA—Scalable Solar Power with Innovations beyond Silicon Technology	India
2	Environment Conservation Society (SwitchON Foundation), Kolkata, West Bengal	Micro Solar Pumps for Women Farmers (MSP4WF)	India
3	Gham Power Nepal Private Limited, Kathmandu	Off Grid Bazaar—Scaling the Deployment of Solar Irrigation Systems Using a Digital Platform and Personalized Agri-advisory for the Farmers	Nepal
4	Pakistan Agricultural Research Council, Islamabad	Livelihood Improvement for Dug Well Dependent Vulnerable Communities through Energy- and Water-Efficient Responsive Drip Irrigation Systems	Pakistan
5	MinErgy Pvt Ltd, Lalitpur, Nepal	Solar Water Mini-Grid with Smart Analog Meter for Optimization of Solar Irrigation Pumps and Its Widespread Adoption among Small Landholding Farmers of Nepal	Nepal

6	Urmul Seemant Samiti, Bajju, Bikaner, India	Solar-Powered, Climate-Controlled Vertical Farming of Fodder and Mushrooms to Sustain Local Livelihood Enterprises	India
7	Collectives for Integrated Livelihood Initiatives, Jamshedpur, Jharkhand, India	Excess Energy Accumulation and Redistribution Network (EARN)	India

The successes of the seven IF grantees demonstrated the scalability of SoLAR’s work beyond irrigation, by innovating and creating social, environmental, and economic benefits across different regions of South Asia with strong potential to scale. These case studies, further discussed in Section 3, should help inform new projects by encouraging the application of best practices and key takeaways, such as the following:

- In India, Nepal, and Pakistan, solar-powered irrigation systems show significant promise. However, since irrigation is not required year-round, using solar PV solely for this purpose underutilizes its capacity. To maximize impact and productivity, surplus solar energy should be linked with other electrical applications. For example, Collectives for Integrated Livelihood Initiatives (CINI) has effectively used excess solar power to run a rice mill, flour mill, and oil expeller.
- Traditional farming often doesn’t provide sufficient earnings for farmers, but organizations such as Urmul, PARC and SwitchOn have utilized hydroponics for fodder production, RDI, vegetable growing and fish-ponds, creating opportunities to diversify from traditional farming.
- Due to limited income opportunities in villages, most men migrate to cities for better opportunities, while women remain to manage households. These case studies demonstrated the importance of women in project implementation and income generation, to advance livelihoods and gender equality across rural South Asia.
- Project packaging is important for accessing subsidies, debt financing and carbon credits.
- The involvement of the local community is essential for project success and sustainability, as they are the primary beneficiaries and custodians. Training and capacity building for all stakeholders, especially for local technicians to provide “after-sales” troubleshooting services, is essential for long-term success.

The SoLAR program has benefitted immensely from the efforts of the IF grantees, and key lessons learnt have been incorporated into phase 1 implementation (e.g. piloting of rice mill to support women farmers in Mandla, Madhya Pradesh) and phase 2 project design.

# Introduction

Agriculture is the backbone of South Asian countries, ensuring food security and creating numerous employment opportunities. Therefore, sustainable irrigation is the key adaptation strategy to improve agricultural productivity, reduce climate change vulnerability, ensure food security and generate income for farmers.

However, most irrigation systems prevalent in South Asia are energy-intensive, thus expensive, unreliable, and largely dependent on fossil fuels. Solar irrigation pumps (SIPs) offer a low-carbon, climate-resilient technological solution, especially in groundwater-abundant regions, to improve access to irrigation.

Energy, water, agriculture and livelihoods are crucial for the growth of villages, so a shift to solar energy not only provides sustainable energy access but also uplifts farming communities.

Furthermore, solar-powered irrigation supports both climate change mitigation and adaptation efforts, while also increasing agricultural productivity and reducing the cost of irrigation.

One of the major impediments to adopting SIPs for small and marginal farmers is the high upfront cost, for which they require substantial financial support. There are government financial schemes available, such as Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) in India and Alternative Energy Promotion Centre (AEPC) in Nepal. Subsidies are also available from the government for solar pumps, and banks offer debt components for the project. Proper financial packaging by linking different financial schemes will be helpful to farmers.

## Context of Energy, Water, Agriculture, and Micro-Enterprises

The interconnectedness of energy, water, agriculture and jobs is crucial for creating livelihood opportunities in rural villages. Distributed renewable energy (DRE) and energy services or micro-enterprises (MEs) are key factors in meeting these needs. DREs and MEs are interdependent, ensuring mutual profitability for both units. DRE will ensure the supply of reliable and affordable power to MEs, and MEs will purchase the promised units from DRE—this arrangement guarantees the sustainability of both units.

Solar power, a prominent form of DRE, is available only during daylight hours, but it can be used directly or stored for later use. As the water required for agriculture is seasonal, surplus solar energy generated from SIPs remains underutilized. This excess energy presents an opportunity: through the development of MEs, it can unlock livelihood opportunities in villages through clean drinking water access, clean cooking energy solutions, and food processing units.

Although the rural economy largely revolves around agriculture, it is not providing sufficient income for farmers. The development of MEs is key to enhancing the value chain of agro-products in rural areas, with appropriate storage to increase the life and value of agricultural produce. This would not only increase farmers' income but also improve food security and minimize wastage.

The creation of livelihood and enterprise activities through sustainable energy resources will, in turn, reduce pressures on agriculture and land and prevent the migration of youth from rural to urban areas.

# Present Status and Potential of Solar Irrigation in India, Nepal, and Pakistan

Landholdings in most South Asian countries are small, with farmers largely reliant on rain-fed agriculture or costly diesel-powered irrigation. However, there is significant potential for solar irrigation solutions across the region to not only reduce their carbon footprint but also improve livelihoods. The following section outlines the status and potential of solar irrigation in three countries SoLAR is implemented in: India, Nepal, and Pakistan. These countries have a wide range of political and contextual landscapes, highlighting the diverse challenges and opportunities the project navigates in scaling solar irrigation across South Asia.

## India

India submitted its long-term Low Emission Development Strategy to the United Nations Framework Convention on Climate Change (UNFCCC) during the 27th Conference of the Parties (COP27). The strategy focuses on energy efficiency, reducing carbon footprints and climate-resilient approaches toward growth. As part of India's efforts to maintain globally acceptable emission levels, the Government of India aims to generate a total of 500 GW, with 280 GW of it coming from solar energy by 2030.<sup>1</sup>

Solar holds immense potential in India, with about 5,000 trillion kWh of solar energy per year incident upon India's land area. Most areas in India even receive 4 to 7 kWh per square meter per day, making solar a highly viable renewable energy source.<sup>2</sup>

India has nearly 1.75 million square kilometers of arable land, the largest in the world, most of which is irrigated using around 30 million groundwater pumps.<sup>3</sup> With agriculture as a key sector in the Indian economy, solar-powered irrigation in India holds huge potential, as cost-effective reliable irrigation can significantly improve farmer incomes and well-being. By moving away from subsidized grid electricity, solar-powered irrigation can relieve financial pressure on utilities. According to the MNRE, the adoption of solar-powered irrigation will not only help reduce the burden of over INR 1 lakh crore in electricity subsidies for agriculture but also lower the oil import bill by decreasing diesel consumption by 1.38 billion liters per annum.<sup>4</sup>

At present, SIPs are deployed either through the PM-KUSUM scheme, launched in 2019 by the Ministry of New and Renewable Energy (MNRE), or under various state schemes. The PM-KUSUM scheme allows the inter se transfer of quantities between Component B and Component C. All three components of the scheme aim to add solar capacity of about 34.80 GW by March 2026 with a total central financial support of INR 34,422 crore. The scheme has three components: Component A—

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<sup>1</sup> PIB. 2023. *India is marching ahead in the renewable energy sector*. Mumbai, India: Press Information Bureau (PIB). <https://pib.gov.in/PressReleasePage.aspx?PRID=1944075> (accessed August 11, 2024).

<sup>2</sup> MNRE. (n.d.). "Solar overview." New Delhi, India: Ministry of New and Renewable Energy (MNRE). <https://mnre.gov.in/> (accessed August 11, 2024).

<sup>3</sup> Karmarkar, M. 2023. Solar water pumps critical to sustainable agriculture in India, *The Times of India*, February 8, 2023. Available at: <https://timesofindia.indiatimes.com/blogs/voices/solar-water-pumps-critical-to-sustainable-agriculture-in-india/> (accessed on August 10, 2024).

<sup>4</sup> Karmarkar, M. 2023. Solar water pumps critical to sustainable agriculture in India, *The Times of India*, February 8, 2023. Available at: <https://timesofindia.indiatimes.com/blogs/voices/solar-water-pumps-critical-to-sustainable-agriculture-in-india/> (accessed on August 10, 2024).

decentralized ground-mounted grid-connected pumps; Component B—stand-alone off-grid solar pumps; and Component C—grid-connected pumps.<sup>5</sup>

## Nepal

Nepal is an agrarian economy where the agriculture sector contributes to one-third of the gross domestic product. Most farmers in Nepal are smallholders who rely on traditional rain-fed agriculture; however, shifting weather patterns are exacerbating challenges to rain-fed agriculture, sustainable production, and rural livelihoods.<sup>6</sup>

Of the estimated 2.6 million hectares of arable land in Nepal, 69% is irrigable, but only 39% is currently equipped with irrigation.<sup>7</sup> Only 19% of that irrigated land receives year-round irrigation. The Productive Use of Renewable Energy (PURE) platform of the International Centre for Integrated Mountain Development (ICIMOD) indicates that the area with unmet irrigation needs in Nepal requires an additional estimated power capacity of 1,300 MW for lift irrigation.<sup>8</sup>

In response to these challenges, Nepal is committed to a clean energy transition as part of several internationally agreed goals for climate-change mitigation and adaptation. Under its second nationally determined contribution (NDC), Nepal has set a target for 15% of total energy consumption to come from renewable sources by 2030. This would replace fossil fuels and traditional fuels and expand clean energy to 15,000 MW, with 5% to 10% from bioenergy, solar, wind and mini/micro/small hydro.

Nepal has vast untapped solar potential. The 2019 multicriteria analysis for planning renewable energy (MapRE) by the World Bank estimates Nepal's solar photovoltaic (PV) market potential to be more than 50 GWp, including the utility, off-grid and rooftop subsectors.<sup>9</sup> While Nepal's estimated potential solar generation of 50,000 TWh annually is 7,000 times more electricity than the country currently uses, the country's solar energy sector is currently underdeveloped with only a fraction of its potential solar energy is captured.<sup>10</sup>

Recent data does, however, shows that Nepal has been successful in gradually transitioning from fossil fuel-based irrigation to renewable energy sources such as solar. This has been possible under the broader context of policy imperatives to decarbonize as well as strengthen rural livelihoods. Nepal's SIP expansion program is led by AEPC, a federal government agency. The primary goal of Nepal's subsidized SIP program is to raise awareness about solar irrigation and promote SIPs

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<sup>5</sup> MNRE, (n.d.) Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan (PM-KUSUM), Ministry of New and Renewable Energy (MNRE), <https://pmkusum.mnre.gov.in/landing-about.html> (accessed August 11, 2024).

<sup>6</sup> Adhikari, T.; Shrestha, N. 2023. Irrigation for rural development: Small-scale farmers can diversify their crops and improve yields through better irrigation. *The Kathmandu Post*, August 1, 2023. Available at: <https://kathmandupost.com/columns/2023/08/01/irrigation-for-rural-development> (accessed on August 10, 2024).

<sup>7</sup> Shrestha, S.; Uprety, L. 2021. *Solar irrigation in Nepal: a situation analysis report*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 43p. <https://doi.org/10.5337/2021.218>.

<sup>8</sup> International Centre for Integrated Mountain Development (ICIMOD). 2024. *Empowering agriculture with renewable energy for sustainable irrigation and inclusive policies*, Lalitpur, Nepal: International Centre for Integrated Mountain Development (ICIMOD), April 22, 2024. Available at: <https://www.icimod.org/wp-content/uploads/DAY-1-AGENDA.pdf> (accessed on August 10, 2024).

<sup>9</sup> ICIMOD. 2023. *Renewable energy in Nepal: Key findings and policy recommendations (working paper)*, Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD), [https://lib.icimod.org/record/36346/files/HimalDoc2023\\_RenewableEnergyPolicyAnalysisNepal1.pdf](https://lib.icimod.org/record/36346/files/HimalDoc2023_RenewableEnergyPolicyAnalysisNepal1.pdf).

<sup>10</sup> Koons, E. 2024. *Solar energy in Nepal: Why it's important?* Climate Impacts Tracker Asia, April 25, 2024. <https://www.climateimpactstracker.com/>.

throughout the country in an equitable manner, with a particular focus on the Tarai region. The Tarai region has traditionally been the country's breadbasket due to its flat and fertile terrain.

## Pakistan

Pakistan is the third largest user of groundwater for irrigation globally; however, as an agricultural country, it is facing several extreme challenges related to water and energy scarcity as well as inadequate irrigation.

Surface water supplies are sufficient to irrigate only 27% of the country's arable land, while the remaining 73% is directly or indirectly irrigated using groundwater. Punjab province alone accounts for over 90% of the total groundwater abstraction.<sup>11</sup> The shallow depth and better quality of groundwater have favored the extensive development of private tube wells in Punjab. Shallow tube wells are important, as the pumping cost of 1,000 m<sup>3</sup> of water from a deep tube well is three times higher than from a shallow tube well in Pakistan.

According to one estimate, there are around 1.2 million tube wells, with nearly 16% using electricity, while the remaining 84% are diesel-operated.<sup>12</sup> Farmers tend to prefer diesel tube wells due to their lower installation and operational costs compared to electric tube wells. The increasing cost of energy (both diesel and electricity) is becoming a serious issue for small landholder farmers.

Solar irrigation has the potential to address these challenges and improve agricultural productivity in Pakistan, which has significant solar energy potential due to its high solar radiation and large land area.<sup>13</sup> According to the National Renewable Energy Laboratory (NREL), Pakistan has a solar energy potential of approximately 5,500 TWh per year, which is equivalent to more than five times the country's current electricity consumption.<sup>14</sup> Solar irrigation has the estimated potential to irrigate about 1.5 million hectares of land in Pakistan.<sup>15</sup>

Pakistan is considering an alternative option to switch 1.3 million agricultural tube wells to solar energy to reduce input costs and enhance farm income, particularly for small landholders. Under the Free Solar Pump Scheme, the GOP will provide a free solar pump to low-income families and poor farmers. Statistically, the total cultivated area of Pakistan is 42.6 million acres (MA), of which 13.89 MA is conjunctively irrigated using canal and tube well water. The area irrigated by tube wells is only 6.08 MA, while the estimated coverage is 12 MA. With a rate of 0.5 kW per acre, the solar PV potential is 6,000 megawatts (MW).<sup>16</sup>

The Punjab Irrigated Agriculture Productivity Improvement Project represents the largest investment to date in groundwater pumping for agricultural purposes. This project, sponsored by the Agriculture Department of Punjab through the World Bank, aims to stimulate the use of high-efficiency irrigation

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<sup>11</sup> Qureshi, A. S. 2020. Groundwater governance in Pakistan: From colossal development to neglected management, *Water* 12, no. 11: 3017. <https://doi.org/10.3390/w12113017>.

<sup>12</sup> PBS. (n.d.). "Home." Islamabad, Pakistan: Pakistan Bureau of Statistics. <https://www.pbs.gov.pk/> (accessed August 10, 2024).

<sup>13</sup> Bukhari, M. D., Khan, H. F., Hameed, M. S., Yasir, M., Safdar, M., Ahmad, U., Khawaja, W. A. 2023. Feasibility and comparative analysis of solar power tube well with existing conventional systems and its utilization in irrigation of the agricultural lands. *PalArch's Journal of Archeology of Egypt/Egyptology*, 20 (2) <https://archives.palarch.nl/index.php/jae/article/download/11883/10481/23507>

<sup>14</sup> [www.nrel.gov/international/ra\\_pakistan.html](http://www.nrel.gov/international/ra_pakistan.html).

<sup>15</sup> Hussain, F., Maeng, S.-J. Cheema, M. J. M., Anjum, M. N., Afzal, A., Azam, M., ... Iqbal, T. 2023. Solar irrigation potential: Key issues and challenges in Pakistan, *Water* 15, no. 9: 1727. <https://doi.org/10.3390/w15091727>

<sup>16</sup> Qureshi, A. S. 2020. Groundwater governance in Pakistan: From colossal development to neglected management, *Water* 12, no. 11: 3017. <https://doi.org/10.3390/w12113017>.

systems coupled with SIPs through capital cost subsidies.<sup>17</sup> As a result of this program, there has been a district-wise spread of SIPs across Punjab, with the highest number of SIPs installed in the Rawalpindi division and the lowest in the Bahawalpur division.<sup>18</sup>

## Estimated Solar Potential for Irrigation in Three Countries

Based on the land availability for agriculture, Table 2 provides details on solar potential for agriculture in these three countries.

**Table 2.** Solar potential for agriculture in India, Nepal and Pakistan.

Description	Units	India	Nepal	Pakistan
Cultivated land area (according to available reports)	Million hectares	157.84	2.2	30.5
The average amount of water required for crops per season	Liter/hectare/season	250,000	250,000	250,000
Capacity of water pump	HP	3	3	3
Average water flow rate	Liter/hour	20,000	20,000	20,000
Hours required	Hours	12.5	12.5	12.5
The energy required to pump the water	kWh/hectare/crop	27.98	27.98	27.98
CO <sub>2</sub> savings	Tons/pump	0.07	0.07	0.07
The total kWh required to irrigate all the lands	MWh/crop	44,15,574	61,545	8,53,238
The total energy required from solar (assuming solar radiation at 3 kWh/kWp)	GWp	1,472	21	284
CO <sub>2</sub> savings	Tons/crop/season	11,480,492	160,017	2,218,418

*Note:* Table 2 presents estimate based on the national average water requirements, which will vary depending on factors such as crop type, regional location, and the depth of the water table. In this table, the consideration is based on one traditional crop, which is irrigated with solar power. CO<sub>2</sub> savings are calculated based on diesel as the replacement.

<sup>17</sup> *Pakistan–Punjab Irrigated Agriculture Productivity Improvement Program Project: Additional financing (English)*. Washington, DC: World Bank Group. <http://documents.worldbank.org/curated/en/448911512270028837/Pakistan-Punjab-Irrigated-Agriculture-Productivity-Improvement-Program-Project-additional-financing>.

<sup>18</sup> Qureshi, A. S. 2020. Groundwater governance in Pakistan: From colossal development to neglected management, *Water* 12, no. 11: 3017. <https://doi.org/10.3390/w12113017>.

# Case Studies

Through the SoLAR IF, the program has supported seven innovative solar projects in India, Nepal and Pakistan. The objectives of these projects were to address barriers to uptake and find solutions for scaling up solar energy in these regions.

## IF Grant Criteria

The SoLAR IF has helped support the development and testing of technological, financial and institutional innovations to address the constraints and challenges of scaling solar irrigation, with a special focus on the problems faced by small-scale, marginal and women farmers in South Asia. The IF also aimed to support innovations and practices that can influence policy or be expanded and integrated into public, donor and private sector programs and practices with the support of additional funding sources.

Selection of IF grantees was based on three categories: (a) technological, (b) financial and (c) institutional. A call for proposals was put out where participants were approached to apply for the IF relevant to the categories and themes/topics mentioned below:

### **i. Technological innovations**

- a. Improving energy management protocols for distributed generation
- b. Use of cost-effective sensors and the Internet of Things (IoT) for efficient water and energy usage and metering
- c. Improving data and payment compliance (e.g., payment of installments for SIPs by farmers or payment from utilities to the farmers) through the use of remote monitors
- d. Supporting sustainable groundwater use and governance, for example, through remote metering and control of pumps
- e. Recycling of old panels

### **ii. Financial innovations**

- a. Appropriate and affordable insurance products for SIPs
- b. Appropriate loan and other financial products for small, marginal and women farmers, facilitating access to SIPs
- c. Viable business models for SIP business entrepreneurs
- d. Incentives to support sustainable groundwater use and governance

### **iii. Institutional innovations**

- a. Combining solar irrigation with other livelihood options such as agricultural value chains and the creation of self-help groups (SHGs), with a focus on small, marginal and women farmers
- b. Alternative uses of excess solar energy generated from SIPs, including other energy markets for solar entrepreneurs
- c. Creating self-sustaining groups of landless and/or women SIP irrigators and service providers
- d. Incentives to support sustainable groundwater use and governance

## Selection of Grantees

The IF grants focused on supporting successful, innovative demonstration pilots to create livelihood opportunities in rural areas that have the potential for scale-up.

IF grantees were selected through an open competitive process available to all nongovernmental organizations, universities, technical institutes, research institutes, public and private sector enterprises and research laboratories, and government agencies, including local government

institutions working in any of these countries who were eligible for this grant. Applicants were required to have the necessary registrations and permits to work in the country they selected.

Short-listed proposals were judged on the following criteria:

- Nature and scope of the innovation and its relevance to the aims of the proposal call
- Strategic and innovative value in meeting the challenges outlined in the call for proposals
- Logic and clarity of the innovation and its design
- Technological, social, institutional and financial feasibility
- Potential for replication and scaling
- Effectiveness in improving climate-change adaptation
- Financial viability of the innovation and exit strategy
- Value for money and cost-effectiveness of the project
- Expertise and qualifications of the project team
- Background and experience of the project team in handling similar projects: Innovation teams led by women or those that have at least 30% female representation, will be given priority.

Based on the above selection criteria, seven grantees were selected across India, Nepal, and Pakistan (Table 1; Figure 1).

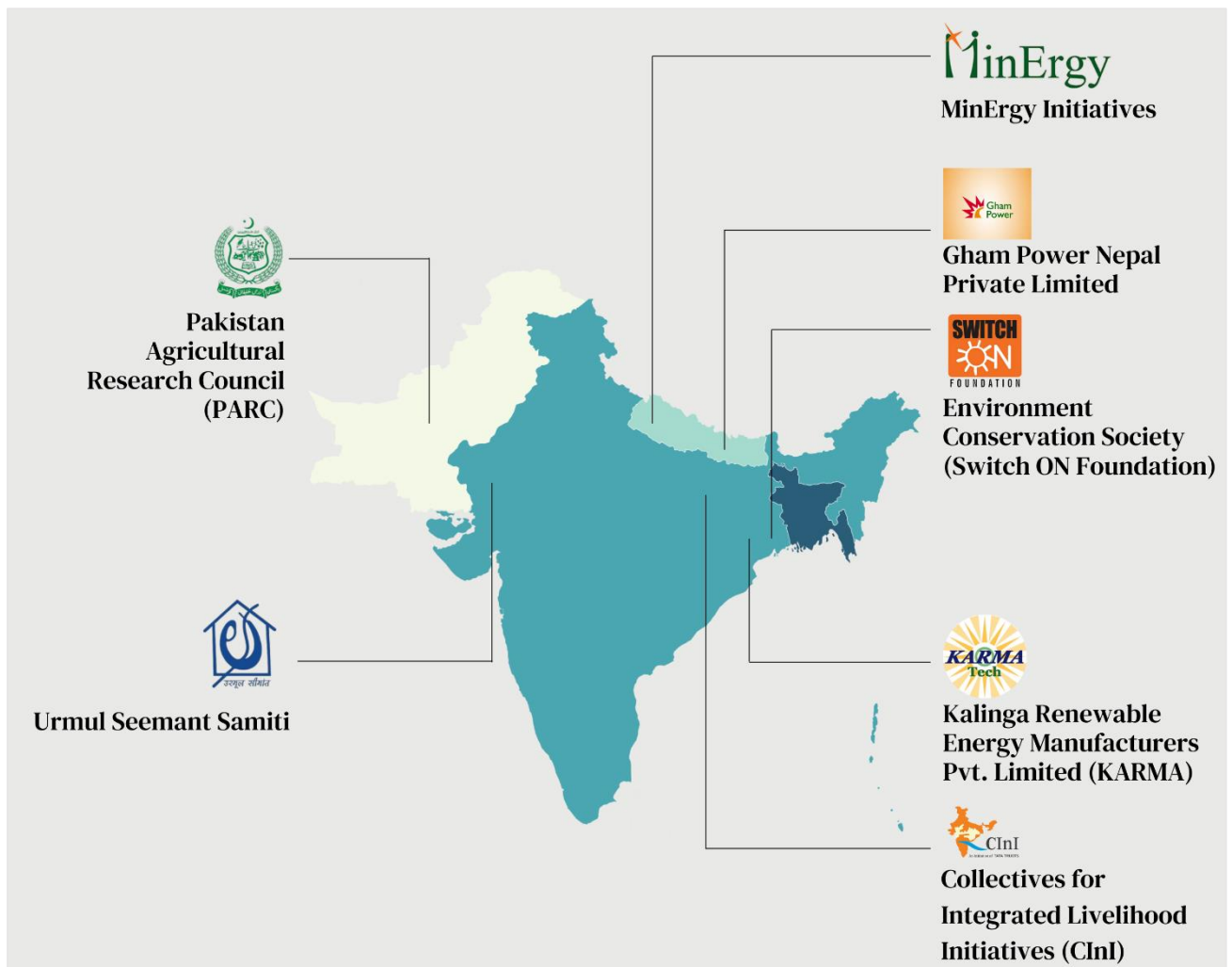


Figure 1. Location of SoLAR IF grantees (*Source:* author's creation)

# Innovation Fund Project Details: Seven Innovations

## Kalinga Renewable Energy Manufacturers Private Ltd. (KARMA), India

IIT Bhubaneswar start-up KARMA is offering state-of-the-art renewable energy technology in a cost-effective package. The mission of KARMA is to lead the way in the renewable energy sector by offering innovative, reliable and affordable solar solutions.

KARMA introduced the first solar micro-pump in India, certified by the MNRE, and its technical specifications became a benchmark for the industry. Most farmers use two or three HP water pumps, but these are often oversized. To address the optimal use of energy and water, KARMA introduced the first solar energy-efficient micro-pumps with capacities of 0.5 HP, 1 HP and 2 HP in India.

Despite hundreds of micro-pumps, like Mobile URJA, being installed and operated, many farmers still struggled to afford the technology. Initial pilots of trolley-mounted mobile pumping units by KARMA and other companies for shared use among multiple farmers, although promising, encountered usability challenges because silicon solar panels are heavy and prone to damage.

To address these challenges, KARMA tested silicon-based foldable panels through SoLAR's IF - an intervention called Mobile URJA—Scalable Solar Power with Innovations beyond Silicon Technology. These micro solar pumps are efficient and use less groundwater. Mobile URJA is the world's first mobile irrigation system based on CIGS lightweight and rollable solar panel technology. Advantages of this technology stem from being a plug-and-play system that is both easy to move and theft-proof. This would allow multiple farmers to use a single system that is easy to install and maintain.

### Project location

KARMA selected projects and local partners in two locations in two states: Bihar and Orissa. PRADAN, a leading NGO in India with a presence in almost every Indian state, is establishing projects in the Begusarai district of Bihar using polycrystalline panels And, TATA Steel, under its corporate social responsibility program, is installing flexible panels in Kalinganagar, Orissa.

During the site study, KARMA found that most farmers with 2 hectares or less of landholdings were using pumps with a maximum of 3 HP, but the majority could be served with 1 to 2 HP pumps.

### Project objectives

- To develop mobile solar power (Mobile URJA) units that will deliver affordable and sustainable energy for irrigation, with a universal charging option resulting in a simplified rental model with multiple uses.
- To conduct field testing of Mobile URJA using flexible and fixed solar panels for irrigation, along with IoT devices.
- To use Mobile URJA in other activities such as rice mills, flour mills and aerators for fish farming.

### Solution implemented

KARMA deployed two types of mobile pumping solutions: polycrystalline panels and copper indium gallium selenide (CIGS)-based lightweight and flexible solar panels.

Solar panels are mounted on a trolley, which can be carried manually from one place to another for irrigation or other electrical applications, such as charging batteries for lighting purposes. Mobile pumps are useful for farmers to irrigate fields, even in remote locations, and reposition the trolley in a sunny area, as needed, to maximize available sunlight.

Polycrystalline panels are popular due to their cost, but they are more effective in a fixed position due to their weight. The chance of these panels getting damaged is high if they are carried in a trolley, especially in rough road conditions. Additionally, it is difficult for one person to carry if five or six panels are mounted on one trolley. KARMA addressed these aspects in their trolley design to prevent damage.

CIGS technology is the latest solar technology, offering lightweight, foldable panels that are easy to transport and particularly convenient for farmers.

KARMA deployed Mobile URJA to 20 farmers; each mobile solar power unit had a pump of 1 HP capacity, using polycrystalline panels. The selection of farmers was done with the help of PRADAN, which offered financial solutions to farmers to adopt SIPs in Begusarai district of Bihar. All water pumps are surface pumps, as the water table in these villages is good.

In Kalinganagar, Orissa, KARMA deployed two flexible panel-based irrigation pumps, each with 2 HP capacity, at each site. Both pumps are submersible, as the water table in the area is deep.

After deploying the technologies, KARMA provided training to the users to ensure the longevity and success of Mobile URJA. These training courses informed users how to use the Mobile URJA units; maintenance aspects for solar panels, pumps, etc.; and, in case of any problem, informed farmers to call KARMA technicians for support.

Projects were successfully handed over to the local partners for ongoing operation.

## **Project impact**

SoLAR program funding enabled the world's first integration of lightweight and flexible solar panels with solar pumping.

In its project locations, Mobile URJA has created opportunities for farmers to irrigate remote areas where access to water and power was previously a problem. Farmers are no longer dependent on expensive diesel or unreliable grid power.

Farmers are happy to use Mobile URJA, which has helped them adopt crop diversification and share water with other farmers. Farmers using flexible panels were particularly happy due to the ease of operation.

The use of flexible panels has created a good initial demand for this technology, although the cost of the flexible panel is now the barrier to large-scale commercial deployment. As KARMA informed, the cost of the flexible panels is three to four times higher compared to polycrystalline panels, and the efficiency is about 14%. To reduce the cost of the panels, a large-scale replication plan will be needed, along with discussions with policymakers to reduce the import duty on these important panels to make them affordable.

Another important model implemented by KARMA is the ZERO PLUS model, where solar technology is used to achieve a zero-carbon footprint, and water is also harvested through dug wells as a water source. This allows farmers to use 25% to 30% less water compared to the total water they would typically harvest through rainwater.

These demonstration projects have given a significant boost to KARMA, and now they are working with other partners to develop Mobile URJA projects. The UN has even requested a proposal for implementing lightweight and rollable technology for irrigation in South Sudan.

### Beneficiaries' voices

While talking to farmers, they expressed happiness about the mobile pump, as it is helping them with year-round cultivation.

A farmer in Begusarai said, "The mobile pump is useful for my farming, but carrying it long distances is a problem due to its heavy weight."

Another farmer in Kalinganagar said, "The flexible panel is very helpful to us as it is easy to carry and use. We have received training on how to use the pump and are able to manage the project without any problems."

### Key learnings

Adoption of Mobile URJA faced several challenges, consistent with implementing solar in rural settings, related to cost, operational difficulty, and payment; therefore, KARMA's experience highlighted key learning opportunities. Through farmer feedback, flexible panels, such as those using CIGS, were found to be well-liked due to their portability, ease of use, and reduced risk of theft, but their initial cost remained a significant barrier. On the other hand, polycrystalline panels were more affordable but required greater care during transport due to their fragility making them less practical for mobile applications. Additionally, the rental model used presented difficulties related to collecting user fees under a postpaid system, which is time consuming and labor intensive. To address this, KARMA plans to introduce a digital payment system in the next phase of the project.

CGIS panels could benefit from a community-based model as it will help in sharing the initial investment cost and also in water conservation by using fewer borewells.

Given farmer feedback that mobile pumps are hard to carry for long-distances, the use of a motorized, battery-driven hand trolley (which will not be very expensive) would have benefitted. This will reduce the time and effort required to reach the field. The battery can be charged using solar panels installed on the trolley.



**Figure 2.** Mobile URJA is an innovative energy service platform developed by KARMA, a start-up from the Indian Institute of Technology (IIT), Bhubaneswar, in collaboration with Massachusetts Institute of Technology's GridEdge Solar, a research program developing next-generation solar technology for rural populations, and Flissom, an advanced solar solution provider. (*photo*: Kalinga Renewable Energy Manufacturer Private Ltd.)

## SwitchON Foundation, India

SwitchON Foundation (SwitchON), registered as the Environment Conservation Society, is promoting sustainable agriculture, clean energy, clean air advocacy and sustainable cities in 10 states of India. Their project approach includes piloting, implementing, creating ecosystems, and developing networks.

SwitchON has initiated a program called SEWA (Strengthening Energy–Water–Agriculture Nexus) and has set up over 60 solar pumps by facilitating bank financing for solar water entrepreneurs. They have strong on-ground presence and knowledge of solar pumping solutions.

SwitchON initiated the project titled Mini Solar Pumps for Women Farmers (MSP4WF) under IWMI-SDC-SoLAR, which aimed to increase the uptake of technological innovation and the use of mini solar pumps among marginal women farmers in West Bengal. This project addressed issues related to wide use of diesel pump sets, large dependence on rain-fed farming, and significant challenges faced by women farmers related to high diesel cost and transportation of heavy pumps from home to the field.

This project has addressed factors leading to financial, environmental, social and sustainability-related solutions, especially for women farmers. In addition, the empowerment of small and marginal women farmers was a focused area, aiming to create solar assets in their name while enhancing income generation through crop and livelihood diversification.

### Project location

The areas of operation under the project are the districts of Nadia, North 24 Parganas, Purba Medinipur, Paschim Medinipur, and Paschim Bardhaman in West Bengal.

Under this project, SwitchON installed 20 small solar pumps (2 and 3 HP) for women farmers. These progressive women farmers were identified as experts in using mini solar pumps to inspire others in their neighborhoods to adopt solar pumps for better income, increased agricultural productivity and a sustainable environment.

### Project objectives

- To replace diesel- or grid-powered irrigation pumps with solar-powered irrigation solutions for small and marginal women farmers through the provision of clean and cost-effective water solutions to ensure sustainability.
- To create awareness and demonstrate a successful operating model consisting of technological and financial innovations.
- To establish a Revolving Guarantee Fund (RGF) for lending micro solar pumps to women farmers.
- To develop replication potential by engaging stakeholders, including financial institutions, policymakers and end users.

### Solutions implemented

Team members of SwitchON conducted a detailed baseline survey in 11 districts across five identified agroclimatic zones and identified 20 interested women farmers. The five agroclimatic zones were strategically selected for the study because they differed significantly from one another and, therefore, catered to different types of crops.

A total of 47 surveys were conducted across 11 districts. The study captured information on asset ownership, landholding patterns, crops grown, irrigation patterns, etc. During the survey, it was found that 5 HP capacity pumps are the most commonly used water pumps.

Based on the results of the baseline survey, the project design was developed to install 2 and 3 HP solar pumps to meet the irrigation needs of the farmers. A technology partner was identified, and solar pump installation was completed at all 20 locations.

Financial packaging was done by SwitchON, taking into consideration the equity, debt ratio and available subsidies from state and central governments.

SwitchON tied up with the banks to organize project loans for the identified farmers. As per the bank norms, banks require a collateral guarantee in addition to solar assets for the debt component, and farmers should also be creditworthy to avail themselves of the loan. It is obvious that poor farmers will find it difficult to meet the bank conditions. To overcome this, SwitchON created a revolving fund facility with the bank to arrange collateral-free debt.

The First Loss Default Guarantee (Fund or FLDG) model is undoubtedly the most successful achievement of this project. An arrangement was made with the bank for the loan component, and a revolving fund facility was created with the bank to offer collateral-free loans to farmers. The creation of the financing solution model, i.e., the FLDG, was a great instrument for farmers who couldn't offer additional collateral to the bank.

SwitchON also created a WUG to introduce a water-sharing model among farmers living in close proximity. The WUG can help other farmers as well as create an additional revenue source for the pump owners, while simultaneously aiding in water conservation. In this way, the utilization of solar pumps can be maximized.

Training and capacity building for farmers were conducted on the aspects of operation and maintenance (O&M) of solar pumps and crop diversification.

Several awareness camps were organized to generate interest among other farmers in adopting solar irrigation solutions, and a successful operational project will build confidence among farmers.

## Project impact

The project has created a number of direct and indirect positive impacts, and farmers are benefiting from the use of solar pumps. SwitchON has reported that the income of women farmers has increased by 50% due to the availability of affordable and timely water for farming and asset creation.

Twenty operational solar pumps save ~26.28 tons of CO<sub>2</sub> emissions per year by replacing diesel and electric pump sets.

The success of these operational pumps has opened doors for the development of a financial ecosystem support mechanism to scale up solar-powered irrigation. Many public and private sector banks, as well as cooperative banks like Punjab National Bank, RBL Bank, Axis Bank and Hooghly Central Cooperative Bank, have partnered in this novel initiative, benefiting small and marginal farmers in eight districts of West Bengal.

### Beneficiaries' voices

Farmers reported that they are able to cultivate year-round and engage in diversified farming, such as developing nurseries and fish ponds and raising ducks, as well as growing fruits and vegetables in addition to traditional crops.

Farmer Sutapa Mandal said, "SwitchON Foundation has provided us with the necessary support to build linkages with government departments, understand the schemes and experience a smooth process for applying for a subsidy to install a solar pump."

Another farmer, Nirma Jana, said, "We are poor farmers. Without the provision of a collateral-free loan, it would have been impossible for us to afford a solar pump and eventually manage our cashew nuts business."

## Key learnings

This project clearly demonstrates that solar pumps and collaboration within the community can bring positive changes to the lives of farmers, helping them enhance their income. With proper training, both women and men farmers can efficiently manage solar projects. The formation of WUGs also helped solar pump users sell surplus water to nearby community members at a rate of 10% to 15% lower than the existing water rate from diesel, providing an additional source of revenue. WUG members also benefit from knowledge sharing. Overall, key recommendations include:

- **Financial Innovation and Collateral Flexibility:** The FLDG model has been successful in this project and should be replicated at other sites to support financial inclusion and risk mitigation. The project should explore with the bank the possibility of accepting solar assets as collateral only. This would be a great help for farmers, encouraging more of them to engage in solar irrigation.
- **Productive Use Integration:** In addition to solar pumping, other productive use applications linked to agriculture, such as food processing units, mini cold storage and dryers, can also be integrated with existing solar systems. Utilizing surplus power will optimize system use and create additional livelihood opportunities.
- **Knowledge Transfer:** Learnings from the Collectives for Integrated Livelihood Initiatives (CINI) project should be applied to guide effective use of surplus solar energy for diverse electrical needs.
- **Entrepreneurship Development:** Installing more solar pumps in a cluster can create opportunities to develop new local entrepreneurs by setting up a regular training center for the skill development of new users and refresher courses and creating a maintenance team for the annual maintenance contract services of the solar plant.



**Figure 3.** A woman farmer stands beside the solar irrigation pump installed on her farm through a grant supported by the International Water Management Institute (IWMI), in Paschim Medinipur, West Bengal. (photo: SwitchON Foundation)

## Gham Power Nepal Private Limited, Nepal

Gham Power Nepal Private Limited (Gham Power) is a solar power company based in Kathmandu, Nepal. For the first few years, they focused on solar residential projects in the cities. Later, in 2014, they ventured into rural markets and installed Nepal's first micro-grid in Khotang.

Today, they have completed over 4,000 solar-powered projects throughout Nepal. With over a decade of service in the energy sector, they are dedicated to reducing the carbon footprints of businesses and empowering rural communities and smallholder farmers through cleaner solar solutions and transformative digital tools.

Gham Power has worked on various innovations to bridge the gap between agriculture and energy using smart technologies such as the following:

- **GRIPS Project:** An integration of solar power and a smart battery with the grid that offers seamless power switching and grid resilience, resulting in more robust electricity.
- **Gham Power Krishi Meter:** A smart agriculture device that provides precise farm data analysis, assists in informed decision-making and supports the adoption of sustainable farming practices.
- **Off Grid Bazaar:** A project development platform that designs tailored irrigation services through proprietary algorithms to make solar pumps more accessible and affordable.
- **Super Krishak App:** A digital agri-advisory app that equips farmers with digital tools and provides access to valuable agriculture information to optimize their farm efficiency.

Gham Power combines technology and modern practices in the agricultural sector by developing a system of data collection to conceptualize impact monitoring and assess the challenges and needs of farmers more comprehensively. They provide eco-friendly, innovative solutions, such as Yield Improvement in a Box (YIIB), which combines reliable irrigation, affordable and easy financing, a digital platform for data-driven project development, and customized agri-advisory for each farmer. This holistic approach has helped increase farming efficiency, productivity and income. Additionally, partnerships with microfinance institutions and agents with last-mile distribution presence have helped reach more farmers and track impacts better.

Under SoLAR, Gham Power implemented a project called Off Grid Bazaar (OGB)—Scaling the Deployment of Solar Irrigation Systems Using Digital Platform and Personalized Agri-advisory for the Farmers.

The goal of the project was to understand and improve the impact of the integrated irrigation and advisory solution on smallholder farmers and the operational processes of relevant stakeholders, such as the government, aid agencies and the private sector. The project would help identify key performance indicators (KPIs) for adopting Gham Power's digital platform, OGB.

### Project objectives

- To create an inclusive package that allows poor and marginal farmers to access affordable and reliable solar water pumps, which will help them increase their efficiency, productivity, and, consequently, income.
- To demonstrate a digital platform and data-driven, customized agri-advisory solution on site.

### Project location

Using the farmer list procured by AEPC, the project implementation area was meticulously selected, and a detailed site survey was conducted to determine the technical viability of the Gham Power

Krishi Meter installation. The monitoring system was installed in the districts of Chitwan, Nawalparasi, Dang, Kailali, Banke, Bardiya and Kanchanpur.

Under the aegis of the SoLAR IF projects, the installation of the Gham Power Krishi Meter was carried out across more than 14 districts, along with the conduction of awareness and agent training programs for the promotion of solar water pumping systems (SWPS).

## **Solution implemented**

OGB supported smallholder farmers through data-driven, personalized services. The platform enables data-driven farming by offering customized solar pump solutions based on individual farm data, crop selection guidance aimed at maximizing profitability, and real-time data tracking to help increase yields. It also promotes financial inclusion by streamlining access to financing through quick loan decisions, reduced paperwork, and flexible, affordable payment options tailored to farmers' needs. Additionally, OGB provides personalized agri-advisory, delivering farm-specific crop recommendations and data-backed insights to improve farming efficiency and decision-making.

OGB is a big leap forward compared to conventional solutions because of its overall effectiveness and unique algorithms that track real-time agricultural data and impact figures, allowing it to provide agri-advisory tailored to each farmer's needs.

The project carried out a range of targeted activities to support its objectives. Field activities for social mobilization included training sessions for local agents and farmers, as well as the development of marketing and awareness materials to increase community engagement. To enhance personalized agro-advisory services, the team conducted testing and calibration of agricultural sensors, built a crop advisory database, and integrated new sensors into the OGB platform. For impact measurement and validation, the project tested field improvement solutions with AEPC farmers, developed key performance indicators (KPIs) in collaboration with partners, and incorporated mechanisms for continuous impact assessment. In support of market activation and development, activities included technology demonstrations, user testing, ongoing monitoring, evaluation, and learning (MEL), comprehensive reporting, and active knowledge sharing and stakeholder engagement.

The project also implemented a multifaceted solution to address agricultural water management challenges through the deployment of 10 SWPS enhanced with remote monitoring units (RMUs), plus an additional 10 RMUs integrated with water level and soil quality sensors. To raise awareness about SWPS, concrete efforts were made in collaboration with the microfinance partners to organize various awareness and demonstration programs across six provinces: Province 1, Madhesh Province, Bagmati Province, Gandaki Province, Lumbini Province and Sudurpaschim Province. Agricultural training was also conducted in these regions.

Gham Power worked closely with other partners to provide solar water pumping solutions to small farmers, making irrigation accessible and affordable.

## **Project impact**

Gham Power reported that the project has created a number of positive impacts, and they could measure them using the solution they have implemented. Regular monitoring, evaluation and knowledge sharing have helped farmers adopt best practices, which have enhanced their income, culminating in an overall 80% improvement reported in farmers' income. The use of smart meters and sensors allowed for consistent tracking of solar plant performance and crop cultivation data, enabling timely interventions to enhance efficiency. These sensors also provided critical insights into soil conditions and precise water and fertilizer needs, which led to a 20%-30% reduction in water and fertilizer consumption. Additionally, the project successfully promoted digital engagement and awareness, reaching over 20,000 farmers through various social media platforms. Environmental

benefits were also achieved, with a measurable reduction in CO<sub>2</sub> emissions through the installation of 10 SIP (solar irrigation pump) sets, replacing traditional diesel and electric pump systems.<sup>19</sup>

### Beneficiaries' voices

Mr. Harka Bahadur Karki, a retired police officer now engaged in commercial farming, said installing a solar water pumping system has been a game-changer for him. For the last four years, he has been using the system without any issues. He also received a subsidy from AEPC Nepal to install the system, and it has made his life so much easier.

Ms. Tara Ghimire is running a hostel and needs to buy vegetables daily. Using Super Krishak ChatBot helps her know the daily prices of vegetables, and accordingly, she makes decisions. This app helps her save both money and time.

### Key learnings

The project provided valuable insights into the target market and consumer perceptions of Gham Power's products and services. Social media platforms proved to be effective communication tools, enabling Gham Power to engage directly with farmers and share relevant information in a timely and accessible manner. A key takeaway from the project was the importance of adaptability and strong partnerships. By aligning more closely with the needs of its partners, Gham Power was able to develop marketing materials and outreach strategies tailored to end users, improving communication and engagement with farmers. The introduction of the OGB Connect Mobile App and its integrated back-end reporting platform further enhanced operations by streamlining the lead generation process and enabling real-time monitoring and strategic adjustments.

The program showed that smart agriculture can be helpful in improving overall farm productivity and the income of farmers. Presently, many individual farmers can't afford to buy the solution upfront, and Gham Power has come up with a financial solution for farmers through a monthly EMI plan to support but partnerships with the government and financial institutions are needed to further scale affordability. The support from the IF grant played a crucial role in the successful demonstration of 10 pilot projects, significantly accelerating Gham Power's ability to scale up the deployment of solar irrigation systems and personalized agri-advisory services across Nepal.



**Figure 4.** Gham Power has developed an integrated solution called –Yield Improvement in a Box– that provides farmers with reliable irrigation through solar water pumps, easy and affordable financing, and knowledge of modern agricultural practices through personalized agri-advisory. (photo: Gham Power Nepal Private Limited)

<sup>19</sup> Typically, a 3 HP solar pump can save about 2 tons of CO<sub>2</sub> per year compared to the grid and 5.5 tons per year compared to diesel.

## Pakistan Agriculture Research Council, Government of Pakistan

The Climate, Energy, and Water Research Institute (CEWRI), an executing arm of the Pakistan Agricultural Research Council (PARC), was established in 1991–92 following a reorganization of water-related research programs at the National Agricultural Research Center (NARC), Islamabad. Presently, the CEWRI is involved in problem-oriented, strategic, operational and interdisciplinary research in areas of national importance. CEWRI has a trained, multidisciplinary team of qualified scientists and engineers supported by skilled staff, with well-equipped laboratories and weather stations.

CEWRI aims to optimize the productivity of water use in both rain-fed and irrigated environments; to develop a sustainable balance between resource utilization and its replenishment; to explore alternative energy resource production, harvesting, and management; and to assess the impact of climate change on water resources and agriculture, including adaptation and mitigation strategies.

With SoLAR IF, CEWRI worked on the project entitled Livelihood Improvement of Dug Well Dependent Vulnerable Communities through Energy and Water Efficient Responsive Drip Irrigation (RDI) Systems.

The RDI system is a novel irrigation method that allows plants to self-regulate their water delivery. When crops and plants need water and nutrients, they emit root exudates that enable them to take up what they need from the surrounding soil. The RDI system responds to and interacts with these root exudates, allowing water and nutrients to be released from the billions of “smart micropores” in the polymer tubing. It provides a slow-release delivery of water flow that matches the absorption capacity of the roots.

The soil water matric potential alone drives the flow in the absence of system pressure, but both factors drive the flow if the water head is available. This irrigation system is highly efficient, operating at low pressure, consuming less power, offering low maintenance costs, and ensuring long, steady, and plant-responsive irrigation. RDI is claimed to be highly water- and energy-efficient; it saves 30% to 50% water compared to conventional or standard drip irrigation (SDI), uses low pressure (2 to 3 psi), and requires minimal to zero energy for operation. By coupling this innovative technology with a solar pumping system, a sustainable and efficient irrigation system has been developed and demonstrated under this project.

In this project, a completely new but low-cost solution, i.e., water pumping using solar power and application of the most efficient water-saving RDI system to vegetables and fruits, has been tested and piloted in various water-scarce areas, including research and demonstration sites, as well as female farmers’ sites for women’s empowerment.

### Project location

The experimental sites were selected to carry out experimentation of the proposed micro solar pumping system coupled with RDI, whereas, at some locations, SWPS have already been installed, and only overhead water tanks of appropriate capacity were provided to facilitate gravity flow RDI systems.

A total of 11 sites have been developed for research studies and trials in different ecologies of the country, including seven research and demonstration sites (NARC-Islamabad, Federal; Lasbella, Balochistan; AZRC, Sindh; Jand-Attock, Punjab; SARC-Karachi, Sindh; Mankera-Bhakkar, Punjab; and Renala Farm-Okara, Punjab) and four female farmers’ sites ( Umerkot, Chor, Madhu Arnrrio and Dukkarcha villages of Sindh province) from a “gender equality and social inclusive” perspective. All these sites were selected based on criteria defined by PARC for research and demonstration purposes.

The project addressed a range of region-specific challenges across different ecologies. In the Pothowar region, limited water availability and inefficient utilization methods restrict agricultural productivity. Farming in this area primarily depends on dug wells, with minimal cultivated land due to inadequate irrigation infrastructure and a prevailing monocropping system. In Sindh and Baluchistan, severe water scarcity and persistent drought-like conditions are compounded by low awareness of efficient irrigation practices. Agricultural activities are further hindered by unreliable electricity access and the high cost of diesel for water pumping. A lack of knowledge about renewable energy options poses a significant barrier to adoption. In Punjab, particularly the Thai (Bhakkar) area, desert-like conditions and sand dune-dominated topography impede traditional flood irrigation. This region also faces a substantial knowledge gap regarding efficient water management and continues to underutilize available clean energy solutions.

## Project objectives

- To adopt high-value production systems (horticulture and vegetables) using scarce water resources (dug wells, boreholes, ponds etc.) through a micro solar pumping system (energy-efficient and irrigation with a responsive drip system).
- To pilot and demonstrate integrated innovation across different ecologies.

## Solution implemented

Different experiments regarding RDI have been conducted on mixed vegetables and fruit orchards to assess three distinct irrigation methods: RDI, SDI, and flood or furrow irrigation (FI). The primary objective of the study was to quantify the water consumption and yield outcomes associated with each irrigation method. The results reveal a substantial reduction in water consumption with RDI when compared to SDI and other conventional FI methods. Impressively, SDI and RDI exhibited average water savings of 58.4% and 67.69%, respectively, in comparison with flood irrigation; whereas RDI showed average water savings of 24.69% in comparison with SDI, highlighting their effectiveness in optimizing water resources.

Recognizing the efficiency of RDI, CEWRI used a system in which a micro solar pumping system coupled with RDI was installed and compared with a conventional farmer's flood irrigation system for fruit and vegetable production using dug-well water. The basic purpose of the experiment was to evaluate both irrigation technologies in terms of the livelihood improvement of the farming community.

A series of structured tasks were carried out as part of the project's implementation. The initial start-up activities focused on assembling the project team and laying the groundwork for field operations. This was followed by the design of the system, which involved detailed engineering of a solar irrigation setup, initially piloted on a one-acre plot of vegetables for experimental purposes. A suitable experimental site was selected, where a technology demonstration was initiated to test the system's feasibility in real-world conditions. Upon completion of the trial period, a comprehensive data collection process began, gathering information on irrigation application, operating power, hourly solar radiation, crop yield, water consumption, labor input, and other relevant variables throughout the crop cycle. Finally, a structured approach to results compilation and data analysis was established, with a focus on evaluating water savings, productivity improvements, and conducting a cost-benefit analysis to assess the system's overall effectiveness.

The technology was demonstrated across different ecologies to support future upscaling and assess performance in varied agro-ecological conditions. Capacity-building activities included a two-day workshop, hands-on training, sessions on the RDI irrigation regime, a seminar on RDI, and a research publication.

The RDI system was also targeted, tested and fabricated at a female farm to engage women, especially those involved in kitchen gardening. Women are an integral part of small landholders, especially in rain-fed areas with limited water sources for growing vegetables. Few women not only manage all agricultural operations but also handle the financial outlays. However, they rely on male

family members for the irrigation system, which is primarily considered a male job. With the introduction of the automated RDI irrigation system, the women farmers were able to manage irrigation themselves with a one-button push system.

## Project impact

The one-acre area under RDI for vegetables and fruits saved 5,207.58 kWh of energy. If 1 kWh of energy saved due to the reduction in water consumption through RDI avoids 0.699 kg of CO<sub>2</sub> emissions, then the cumulative energy savings across these research and demonstration sites, with an area of 5,738.47 m<sup>2</sup> under vegetables and fruits, amount to 7,384.06 kWh. Thus, an estimated 5.2 metric tons of CO<sub>2</sub> emissions were avoided.

The concept of the RDI system is helpful in improving the climate-change resilience and food security of vulnerable communities in water-scarce areas prone to climate change. Measured impacts include water, energy, and fertilizer savings of up to 40% compared to SDI. Both SDI and RDI showed average water savings of 58.4% and 67.69%, respectively, over flood irrigation, with RDI alone achieving 24.69% more water savings than SDI. The system reduces evaporation and percolation losses, ensures continuous 24/7 watering for increased plant productivity, and eliminates the need for constant pumping by operating under gravity, requiring only a small-capacity pump to fill an overhead tank. It also leads to significant reductions in maintenance time and costs, decreases pest attacks and disease incidence, and is particularly well-suited for remote desert areas. The RDI system is simple in design, easy to install by a trained plumber, and features minimal blockage, straightforward troubleshooting, and high flexibility for use across different land sizes without the need for a pumping system or its associated costs.

### Beneficiaries' voices

Farmers associated with the project were very happy about the outcome of the project, especially women farmers who were able to generate better income.

## Key learnings

The significant energy savings achieved through the RDI system highlight its strong potential for generating carbon credits, reinforcing its position as one of the most efficient and environmentally friendly irrigation methods. Integrating RDI with optimized solar pumping systems offers an innovative and sustainable solution for water-stressed regions. Although initial costs may be high, broader adoption by farmers and stakeholders is expected to reduce unit costs over time. Government support through subsidies and targeted interventions will be critical in accelerating this transition by offsetting initial investment costs and encouraging the shift to sustainable irrigation practices. Moreover, promoting one-time sustainable solutions like RDI for kitchen gardening can offer more meaningful and lasting livelihood improvements for poor and vulnerable farming communities than traditional cash disbursements or incentive programs such as the Benazir Income Support Programme. The pilot sites established under this project are now evolving into educational hubs, offering hands-on training and learning opportunities for professionals, students, farmers, and other stakeholders. These help demonstrate that RDI, along with the hydroponic and/or poly/net house concepts, will be effective for sustainable farming and the use of a poly/net house will increase both agricultural productivity and income. A water storage solution offers better water and energy management practices, but at the same time, storage for irrigation is expensive. If this is linked with the government's clean drinking water program, it will serve both purposes: water for drinking and irrigation at any given time.

## MinErgy Pvt. Ltd., Nepal

MinErgy Pvt. Ltd. (MinErgy) is an organization dedicated to developing and promoting energy-efficient, environmentally sound, cost-effective and socially responsible technologies and approaches that generate livelihoods.

A team with an entrepreneurial spirit initiated the company and inherited the competencies, know-how and expertise of the Vertical Shaft Brick Kiln (VSBK) project in Nepal, funded by the Swiss Agency for Development and Cooperation (SDC). A team of enthusiastic, highly motivated and qualified professionals in technical and social dimensions, most with over a decade of experience, drives MinErgy toward its goal of achieving a clean, green and energy-efficient Nepal. They currently work in energy planning, climate change and renewable energy areas.

MinErgy is committed to empowering communities to address their needs and issues and to adopt solutions for a secure livelihood.

With SoLAR IF support, they implemented a project titled Solar Water Mini Grid (SWMG) with Smart Analog Meter for Optimization of Solar Irrigation Pumps and Its Widespread Adoption among Small Landholding Farmers of Nepal. It is an innovative project designed to improve access to SIP services for poor farmers with small farm sizes and to promote the efficient and equitable distribution of groundwater resources extracted through a community-based irrigation facility.

Although the cooperative model has allowed a group of smallholder farmers to collectively own the SIP systems, not all farmers in the group have had an equal chance to benefit from the SIP services. Water-selling charges for the current solar-powered irrigation systems are based on an hourly rate, which is a common practice among farmer groups using community-owned irrigation systems. This approach is straightforward and relatively easy to implement but falls short in addressing equitable distribution concerns.

Furthermore, water loss through seepage and poor irrigation distribution systems leads to irregular water distribution and requires more energy.

A metered tariff would benefit farmers and discourage excessive groundwater discharge.

### Project location

Chitwan and Nawalpur (Nawalparasi-East) were the selected districts for integrating the solar water mini-grid (SWMG) intervention. The sites include three stand-alone or individually managed irrigation (IMI) systems and one community-owned SIP in Chitwan district, as well as two community-led SIPs in Nawalpur district. Kuleni Mishirit Krishak Samuha (KMKS), located in Devchuli municipality, is the main focus of the study.

### Project objective

- To introduce a SWMG, coupled with a digital payment system based on analog metering with monthly tariff readings, a manual database and a mix of manual and digital wallet-based payment systems.
- To generate evidence of good practices of an institutional mechanism that will aggregate individual farmers as shareholders in a cooperative model with a common SWMG SIP system, aiming to influence subsidy policy.

### Solution implemented

In order to address the concerns regarding the lack of access for poor and smallholder farmers to SIP systems and uncertainty around the financial viability and sustainable operation of community-based SIP system, as well as encourage the efficient use of groundwater extracted through SIP systems, the concept of a SWMG with an overhead tank was developed. A community-based 9.45 kWp (kilowatt-

peak) SIP system is being managed by KMKS, based in Devchuli municipality of Nawalpur district, Nepal.

The major objective of the project was to maximize the use of the irrigation system and increase smallholder farmers' access to irrigation services by enabling more farmers to connect to the operating irrigation system.

A total of 61 farmers were surveyed during the baseline study, which shows that the average land area owned and currently being used for farming by a family in KMKS is 0.27 hectares per household, with the smallest land area being 0.08 hectares per household and the largest being 0.84 hectares per household. Fourteen percent of households have more than 0.4 hectares of land, whereas 31% of the farmers have less than 0.2 hectares of land, and 34% of the farmers have land sizes between 0.2 ha and 0.29 ha, which shows that most of the farms in Kuleni are small. Twenty percent of the farms have land ownership between 0.2 hectares and 0.4 hectares in Kuleni.

The average landholding of farmers with stand-alone SIP was 1.1 hectares per household, with a minimum landholding of 0.5 hectares and a maximum of 1.5 hectares of land ownership.

The operational premise of this project posited that a SWMG integrated with an analog meter system would prove both technically and financially feasible for SIP overseen by a cooperative model led by small landholding farmer groups.

Solar irrigation pumps have been considered a game changer for decentralized irrigation. The gap between the supply and demand for SIPs has been phenomenal, as evidenced by the number of requests (around 15,000) received by the AEPC compared to the subsidies availed for only 400 to 500 SIPs annually. The subsidy, on the other hand, structurally excludes small landholding farmers, as the eligibility for the subsidy requires a minimum landholding size of 0.334 ha, while the average landholding of small farms in Nepal is only about 0.2 ha.

In this model, the group of farmers (irrespective of landholding size) owned and operated a single large SIP in a cooperative model. Water pumped out of the system was stored and distributed to all group members through a high-density polyethylene piping network.

At each farm, analog flow meters were installed to monitor the volume of water discharged. The readings were taken by trained staff, similar to how electricity or water supply readings are taken for monthly billing. The same process was used for three community stand-alone SIPs for comparative analysis. The data will also be maintained in a database for comparative analysis.

A tariff system was set up, and farmers were charged on the basis of the volume of water used. The reading of the flow meter was synchronized with the remote monitoring system, and a system was developed for mobile payment. In addition, to ensure the best and most efficient use of water, farmers were encouraged to irrigate their lands through drip irrigation and sprinklers rather than the current practice of flood irrigation.

Conserving the request of the user committee, an overhead tank of 15,000 liters was provided instead of the planned 10,000 liters, further increasing the irrigation potential of the system. It takes only 15 minutes to fill up.

## **Project Impact**

This project's impact was encouraging as the number of beneficiary households increased from 36 to 53. After the implementation of the project, the number of beneficiaries further increased to 58 households.

The SWMG system allows for the parallel irrigation of three land plots at once, so small landholders now have a shorter waiting period to use solar PV for irrigation. The extension of the pipeline for irrigation increased the efficiency of the system as well as the command area from 7.3 to 11.4 hectares, which helped increase revenue associated with water sales.

The new land coverage under SWMG has helped farmers cultivate rice during the spring season as well. The SWMG has covered more small landholders within the reach of irrigation (31% farm less than 0.3 hectare and 34% farm between 0.31 and 3.0 hectares) in comparison to the other SIPs.

### Beneficiaries' voices

Bishnu Dutta Subedi, a farmer, shares, “The irrigation operator (IO) provides me with the scheduled turn. During peak demands, we inform the IO about our water turn. If no one else has the turn, the water is provided instantly; however, sometimes our irrigation turn may be 1 to 2 days late. The overhead tank has helped in the quicker distribution of water and shorter waiting periods. The flow meter also gives us an idea of the amount of water we have been using.”

Laxmi Subedi and Bhagwati Sen said that the SWMG has resulted in a higher discharge rate and, hence, quicker irrigation of the plots. Their turns for irrigation have decreased to a maximum of 2 to 3 days, which is twice as fast as the previous system, and they are highly satisfied with it.

### Key learnings

Key learnings from the project highlight the importance of aligning agricultural interventions with farmers' needs, particularly around harvest periods and implementation timelines. The availability of a stable electricity source, which is also used for irrigation during non-solar hours through a storage tank, presents opportunities to explore grid integration and net metering. Of note, once the water storage is filled, the solar PV is unutilized, and hence other electrical applications must be added to improve efficiencies. The design should consider the operation of the pump and other electrical loads in an efficient manner to ensure that both run profitably. To maximize the utility of solar irrigation pumps (SIP), productive end uses such as cold storage and grinding mills are essential. Additionally, while digital literacy and willingness exist, changes in payment modalities are limited by generational dynamics, as older family members typically manage finances. A longer engagement period is therefore needed to encourage youth participation in digital payment systems and related processes.

While the project has demonstrated a successful mini-grid model for irrigation, there remains scope to also include other services within the premises of the mini-grid such as supplying lighting and drinking water for the member farmers and/or other agro-based units. However, before adding any new requirements, a careful assessment of demand must be conducted. SIPs with a storage system offer a good solution for small-scale and marginal farmers, as water can also be stored and used during nighttime hours.



**Figure 6.** A farmer stands beside a solar irrigation pump (SIP) installed on his farm in Nepal. (*photo*: MinEnergy Pvt. Ltd., Nepal)

## Urmul Seemant Samiti, India

Urmul Seemant Samiti (Urmul) is part of the Urmul family, originating Bajju, a village just under a hundred kilometers west of Bikaner. The Urmul family has been working in the dairy sector since 1972.

Bikaner is one of the largest, driest and most sparsely populated districts in the westernmost part of the Rajasthan desert. Bikaner has vast stretches of open sandy spaces with little vegetation. Due to scanty and erratic rainfall, the land is better suited for use as rangeland for livestock rather than cultivation. Hence, habitations are few and far between, and frequent migrations occur.

Animal husbandry, along with the agrarian economy in western Rajasthan, has remained a traditional source of livelihood. Given the low probability of successful agriculture in the region, many families rely on various nonfarm activities. For decades, the people of the Thar Desert have depended on traditional livestock farming, primarily centered around animal husbandry and localized production. Livestock, especially cattle, play a vital role in the lives of these communities, providing essential resources such as milk. Small ruminants and livestock contribute significantly to rural income, accounting for approximately 20% to 50% in these regions.

Herding communities used to move or send animals from one place to another in search of grazing or fodder. This practice has been severely challenged by several changes in the pastoral landscape.

Rapidly changing climate conditions and scarcity of water have made it increasingly difficult for pastoral communities to secure a consistent source of high-quality fodder for their livestock. This eventually affects the quality of milk and results in an extremely variable range of milk availability—both qualitatively and quantitatively.

Shortages of green fodder, consecutive droughts, depleting groundwater tables, and shifting crop choices have reduced the volume of crop residue from paddy and increased the prices of procuring green fodder. As a result of rising input costs, farmers' income and dairy productivity are severely impacted, with reductions of 20% to 30% or a decrease in the number of livestock units held.

In this context, DRE innovations to promote better availability of green fodder throughout the year in the desert landscape are of paramount importance. Urmul has been working on developing the entire ecosystem for pastoralists and agro-pastoralists. One of the interventions in this ecosystem development approach is to deploy low-cost hydroponic-based fodder stations, enabling green fodder for nutrition and year-round feed. This is part of the green value chain for dairy that Urmul is working on. The key mandate is to demonstrate a functional net-zero dairy model.

With the IF grant, Urmul implemented a project titled Solar-Powered Hydroponic Fodder Station model and the transformative impact it has on addressing the critical issue of fodder scarcity by harnessing the power of hydroponic technology. By cultivating high-quality green fodder without the need for traditional agricultural methods, this project aimed to improve the livelihoods of livestock farmers, enhance the health and productivity of cattle, and contribute to the sustainable development of the Thar Desert region.

### Project location

The project is located in Ghantiyali and Bajju villages in the Phalodi and Bikaner districts of Rajasthan. A total of 523 household surveys were conducted across 13 villages to assess the livestock population, the availability and accessibility of fodder and water for the livestock, and various other challenges faced by livestock rearers and farmers.

The survey was held across Khindasar, Nandra, Neniya, Cheemana, Hanuman Nagar, Bheloo, Saranpura, Santok Nagar, Imam Nagar, Khikhniya Patta, Khara Lohana and Siyana villages.

## Project objectives

- To provide a consistent and nutritious source of green fodder for livestock.
- To reduce the environmental impact of fodder production through the use of water-efficient hydroponic systems.
- To enhance livestock health, productivity and overall farm profitability.

## Solution implemented

Due to harsh weather conditions and water scarcity, soil-based agriculture is becoming difficult in Rajasthan's desert region. To address the resulting crisis of critical fodder shortages, especially during the extreme summer months, Urmul and its promoted social enterprise, Bahula Naturals, are developing replicable and scalable models of "innovations in the fodder value chain." These pilot projects demonstrate the scope and potential of the technology and assess the application of clean energy across the value chain.

The solar-powered, low-cost hydroponic fodder station project, located in Ghantiyali and Bajju in the Phalodi and Bikaner districts of Rajasthan, harnesses solar-powered hydroponic technology to grow high-quality green fodder year-round, addressing the challenges of traditional fodder production in arid climates.

This solar-powered dairy input innovation qualitatively enhances livestock farming through sustainable and efficient soilless fodder production. Low-cost, customized hydroponics-based fodder solutions save water, ensure year-round green fodder, and use 100% renewable energy sources.

Two fodder stations are successfully operating, catering to cow farmers in the remotest locations of Bikaner and Jodhpur. These stations are managed by two micro-entrepreneurs who earn their livelihood from them. Farmers benefit from the availability of year-round fodder at an affordable cost. The value chain is designed to utilize surplus produce from the flush season, which can also be used in its dried powdered form.

With 70% of farmers actively engaged in the dairy enterprise being women, Urmul endeavors to create opportunities and support systems for their active participation.

By cultivating high-quality green fodder without the need for traditional agricultural methods, the project improved the livelihoods of livestock farmers, enhanced the health and productivity of cattle, and contributed to the sustainable development of the Thar Desert region.

## Project impact<sup>20</sup>

The fodder solution significantly reduces emissions, cutting 25% of the 40% carbon footprint attributed to feed in milk production, where 1 kg of milk generates 2.5 kg CO<sub>2</sub>e. Powered entirely by clean energy, the project eliminates additional emissions from processing and milk handling. It produces 100 to 170 tons per year of carbon-negative, high-protein fodder and sprout varieties, even in harsh climates. The system is highly efficient, using up to 95% less water, requiring minimal physical space, and operating without any reliance on grid or diesel energy. By extending the availability of green fodder from 4 to 10 months a year, it improves feed consistency, leading to an increase in milk yield of up to 1.5 liters per cow and a rise in fat content by 0.5 to 0.8 per liter. Overall, the project not only promotes sustainable practices but also strengthens community livelihoods and enhances farmers' incomes.

## Key learnings

The hydroponics project in the arid Thar Desert of Rajasthan has yielded significant insights into sustainable fodder production. Fodder grown hydroponically shows significantly faster growth compared to traditional soil-based methods. These systems are highly water-efficient, making them well-suited for water-scarce regions, and they produce nutrient-rich fodder that supports better

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<sup>20</sup> Urmul Trust. (n.d.). "Home." Urmul Reports. <https://urmul.org/reports> (accessed August 11, 2024).

livestock health and productivity. However, maintaining quality control is essential to achieve consistent rapid growth. Active community engagement has been critical, with farmers' participation and understanding playing a key role in the project's success. Project accomplishments include precise crop growth, water efficiency, nutrient optimization, uniformity and the production of nutrient-rich fodder. The IF grant served as a crucial enabling instrument, helping to demonstrate a viable model that can now be replicated in other regions. Some key recommendations include:

- Cultivating green fodder hydroponically, even in an environment where traditional farming faces significant hurdles, can be successful in providing fodder. This is important in desert areas where fodder is not only expensive but also largely unavailable.
- DRE-powered hydroponic-based fodder solutions appear to be a great opportunity for livestock farming across different dry zones. They can be easily replicated.
- Developing entrepreneurs who can manage nontraditional, profitable business units is crucial. Existing pilot projects are a testimony to the development of new projects.
- Development of a local nursery for in-house seed requirements is necessary to avoid dependency on outside sources. This will help reduce production costs and improve sustainability.
- Training and capacity building for local communities involved in hydroponic fodder production are necessary. This includes educating farmers on crop management, system/process management and maintenance, and pest control.
- Setting up awareness camps to facilitate knowledge sharing and adopt best practices is important.

#### Beneficiaries' voices

Farmers associated with the project have expressed satisfaction with the fodder station. In the Thar Desert, the probability of obtaining green fodder for around 8 months is very low or nonexistent due to insufficient water and arable land, but the solar-powered hydroponics system can operate throughout the year.

"My livestock are enjoying eating it, and the input cost has decreased by 20%, while the output cost has increased by INR 2,000 per month," says Kayamdeen, a sheepherder from Narayanpura.

"At first, livestock is reluctant to eat maize grass, but after 2 to 3 days, it becomes their daily diet. Eventually, after a week, the yield of milk has increased to 2 liters per cow, and the fat content has increased to 4.5."—Palu Dev, Ghantiyali

In deserts and water-scarce areas, efficient groundwater use is essential for sustainable resource management. Technological solutions have been demonstrated by the grantees, such as the use of hydroponics, responsive drip irrigation (RDI) and micro mobile pumps. Innovations supported by IWMI have shown results that MEs can be developed alongside solar irrigation by using available surplus solar energy. All these innovations have the potential for large-scale replication to support the social and economic development of villages in South Asia.

## Collectives for Integrated Livelihood Initiatives, India

Since 2007, CInI has been committed to improving the well-being of rural and tribal communities across the Central Indian belt. The goal of CInI is to empower communities, especially tribal households, by increasing their income sustainably and enhancing their overall quality of life.

Over the past 16 years, CInI has continuously refined its approach to holistic development, pioneering scalable programs in agriculture-based livelihoods, education, drinking water and sanitation, and primary healthcare systems. These programs are anchored by community-led institutions, ensuring sustainability and effectiveness on the ground.

Their flagship initiative, “Lakhpati Kisan,” has successfully enabled over 100,000 small and marginal tribal families to move out of poverty in an irreversible manner. CInI believes that success lies in the ability to understand the aspirations of the community, along with understanding their needs and leveraging existing ecosystems to provide long-term solutions. CInI is working on three core areas: economic security/prosperity, social security, and environmental security.

CInI is working in remote tribal locations across central India to install 2,000 solar pumps. Most pumps in a village are within a radius of 500 meters, and these locations have a huge demand for flour mills, chaff cutters, paddy threshers etc., the absence of which has led to drudgery among female community members.

As a replacement for diesel pumps, off grid solar pumps have resulted not only in a reduction of drudgery but also in an increase in the area under efficient irrigation by almost 20-30%. Despite these benefits, solar pumps, mostly in the tribal hinterlands, remain underutilized. As a result, the potential of energy generated by solar PVs is unused.

A typical solar panel of 5 kWp can generate 7,000 kWh of energy annually, of which only 50% to 60% is utilized for irrigation. Thus, the potential to tap into this resource becomes paramount, and it can be used for agro-based applications. With the IF grant, CInI implemented a project titled Excess Energy Accumulation and Redistribution Network.

The project aimed to use the available excess energy from the existing solar panels installed for irrigation pumps in other electrical applications.

### Project Location

Saridkel village in the Tirla Gram Panchayat, Khunti District, Jharkhand, has been chosen as the project site.

Saridkel village is located in the Khunti district of Jharkhand. It is situated 9 km away from Khunti, which is both the district and subdistrict headquarters for Saridkel village. Tirla is the gram panchayat of Saridkel village. The total geographical area of the village is 439 hectares. Saridkel has a total population of 896 people, with 443 males and 453 females. There are about 171 houses in Saridkel village. Khunti is the nearest town to Saridkel village for all major economic activities.

The local partner in this project is an NGO called PRADAN, which has an active presence in the project implementation area.

### Project Objectives

- To set up a distribution network that will allow for the aggregation and transfer of excess energy from the three solar pumps installed at a selected location in the Khunti district.
- To use excess energy generated from three units of 5 HP solar irrigation systems in the Khunti district to run productive equipment such as flour mills, chaff cutters and paddy threshers.
- To connect solar systems and monetize excess solar energy in real time.

## Solution Implemented

There were three solar pumps installed in Saridkel village in 2015. Out of a total of 28 households in that habitation of Saridkel, 24 families are connected to the solar pumps. Moreover, 20 families have electricity connectivity, while the remaining 8 families do not have a connection.

Given the main occupation in Saridkel village is farming and driving autos and tractors, the farmers use the solar pumps for 8 hours a day and 200 days (January to June) in a year. After using the solar pumps for agricultural purposes, the income of farmers has increased to INR 30,000 from INR 20,000 due to improvements in agricultural productivity.

The solar pump is used for 8 hours per day from January to June. The maximum solar radiation received in a day is between 9 a.m. and 3 p.m., thus solar energy production is then at its peak. After 4 p.m., both solar radiation and resulting energy production decreases. Therefore, farmers still use diesel pumps for 3 to 4 hours to lift water to meet their needs. Furthermore, in the rainy season, the use of solar pumps is reduced.

CInI estimated that the excess energy from three 5 HP solar pumps is 42 kWh (including a 5% radiation loss), and planning for the installation of a rice mill, flour mill and oil expeller was made accordingly.

Several key activities were undertaken to implement the project. Multiple meetings were held between the Gramsabha, CInI, and PRADAN teams to finalize the operator, location, and productive loads. A facility center was established in the village, and productive loads, including a 3 HP flour mill, a 3 HP rice huller, and a 5 HP oil expeller, were finalized and installed. The system design and its operations were shared by the technical consultant, Gramoorja, with CInI, IWMI, PRADAN, and the community during field visits. Installation was completed according to the proposed design, which involved tapping three irrigation pumps at different locations and connecting them via a single cable to power the facility center using solar energy. Entrepreneur identification and training were completed, and a business plan was prepared and discussed with PRADAN and the local partner for implementation.

## Project Impact

An integrated, innovative approach to using excess energy for other livelihood opportunities was created. The development of MEs created new jobs in the village. Villagers are now able to get facilities within the village, saving them time and money. Previously, for the same facilities, they had to travel to a nearby city, which cost them time and money. CO<sub>2</sub> savings from the use of DRE solutions for irrigation pumps and MEs from the project are estimated to be about 30 tons of CO<sub>2</sub> annually.

### Beneficiaries' voices

Farmers are happy with both the facilities (solar pump and enterprises), as they are helping them directly. Some of the farmers have expressed the following:

Premani Bodra, a farmer, says, "We had to travel 12 km to process rice and ragi for our daily consumption. My husband helped me whenever he was free, but mostly, I had to carry the grains and bring back the flour. This took a lot of time, and the bags were generally heavy. With the establishment of the processing center, I don't have to travel to the market, and my time and energy are saved. Plus, I get the work done at a much cheaper rate."

Nagita Hassa: "We mainly consume mustard oil for our daily use. However, mustard is not grown extensively in our village, so we had to buy the oil from the market. The main problem was the purity of the oil. This processing center has greatly helped in minimizing that problem, as we are now growing mustard in our fields and can obtain pure oil without the risk of foreign elements being mixed in."

Neha Dhanvar: "The cost of processing 1 kg rice in the market is INR 30, and for oil processing, it is INR 10 per liter. We also had to spend INR 50 on one-way transportation. After this processing unit was established, we don't have to travel anywhere, and since the prices are nearly half the market rate, it greatly helps in saving."

Now efforts are being made toward proving the “commercial success” of the innovation and working on replicating it.

## Key Learnings

Onboarding the Gramsabha and local institutions has been critical to the project's success. However, aligning all stakeholders, especially when changes in design are proposed, remains a challenge. Identifying a suitable technical consultant for rural areas also proved difficult. Establishing strong market linkages for the end products is essential, as is the identification and capacity-building of local entrepreneurs to ensure long-term sustainability. For scaling up, partnerships with government bodies and funding organizations will be necessary. The IF grant played a vital role in demonstrating the concept on the ground, creating a strong foundation for large-scale replication.

## Broad Recommendations

The result of the project should act as a demonstration for over 150,000 solar PV installations that are installed under various programs and schemes across Jharkhand. It should also help increase the use of excess energy in 2,000 pump installations CiNI is undertaking across the four states of central India.<sup>21</sup>

- Grid-tied solar pumping solutions are practiced in many states in India, but not all remote areas have good grid connectivity; hence, off-grid solar for irrigation and enterprises appears to be a good solution.
- The micro-grid<sup>22</sup> approach will also be very useful for managing irrigation and other enterprise loads within the village in a much more effective manner.
- Solar PV alone can't meet the year-round energy needs of the villages; hence, a hybrid renewable energy solution should be explored based on geographic conditions.



**Figure 7.** Off-grid, small-scale and decentralised renewable energy solutions are enabling rural communities to enhance their earnings and living standards in Jharkhand. (*photo:* Collectives for Integrated Livelihood Initiatives, India)

<sup>21</sup> CiNI. 2023. Annual report (2022–23). West Bengal, India: Child in Need Institute (CiNI), <https://cini-india.org/wp-content/uploads/2024/04/Annual-Report-22-23-2.pdf>.

<sup>22</sup> A micro-grid is a local electrical grid with defined electrical boundaries, acting as a single, controllable entity to meet local demands reliably.

# Need for Innovative an Approach

All seven projects the IF grants supported are different in nature but share the same objective: to use solar to improve livelihood opportunities for farmers, water conservation, and CO<sub>2</sub> savings. For adequate scaling of innovations, there is a need to better unpack experience and learnings from these projects:

- i. **Data Driven Monitoring:** Data to monitor and understand use of technology becomes critical to analyze progress of these projects, enabling timely course-corrective actions, and suitability for scaling. Affordable automation, such as remote monitoring and sensors, can be very helpful in the project for collecting real-time data.
- ii. **Integrated Approach:** The projects have established the fact that SIPs should be promoted together with MEs in the villages. That means an integrated approach should be adopted in future projects to maximized impact.
- iii. **Data Integrated Project Design:** Data collection and its analysis are very important for the design of new projects, especially with respect to integrated rural projects addressing the energy-water-agriculture nexus to create sustainable income avenues in villages. Such projects require multidimensional data regarding not only energy requirements but also water, agriculture, and local resources. A data-driven dynamic modeling tool, which can handle complex data, could help in identifying gaps and proposing optimized design solutions for new projects.
- iv. **Hybrid Technology:** A hybrid micro-grid along with solar power will be a more efficient option, as mono technology has limitations in meeting year-round energy requirements.
- v. **Women's Involvement:** The formation of women SHGs to operate micro-grids as businesses and promotion of community-based water (for irrigation and drinking) and clean cooking as services, and creation of livelihood opportunities are essential for inclusive development.
- vi. **Policy Alignment:** Linkages with existing government policies, such as PM-KUSUM and Suryashakti Kisan Yojana (SKY) schemes in India, is crucial. These programs support grid-connected and off-grid solar irrigation and enable farmers to sell surplus power at attractive rates. A dedicated and enabling platform is needed for farmers to enroll and benefit from these schemes.
- vii. **Financial Access:** Banks should consider using solar assets as collateral, as poor farmers will not be able to offer additional collateral.

## Monitoring, Evaluation and Learning (MEL)

The IWMI team periodically visited the seven IF grantees to monitor project progress, provide feedback and document the learnings.

Further, a team of eminent experts conducted an independent review of a subset of grantees as part of the mid-term review of the SoLAR project. Impressed by the outcomes of the IF component, they provided several key observations and recommendations. They noted that IF projects expanded the impact of SoLAR interventions by engaging diverse partners and exploring new, relevant approaches. To ensure sustainability and wider adoption, future SoLAR interventions, including those supported by the IF, should work closely with governments for scale-up. Sharing insights from these innovations with stakeholders across the relevant countries and with a global audience was emphasized as essential.

Additionally, producing policy and research briefs can help highlight scaling opportunities and document how these processes have supported women, smallholders, and landless laborers. Overall, the IF projects were seen as a valuable part of SoLAR, despite some issues with payment modalities. Looking ahead, there is a need for collaborative innovation to develop and test solutions for SIP O&M under future IF initiatives. Additionally, future IF projects should prioritize financial support for solutions that explicitly benefit women.

## Conclusions and Way Forward

While implementing solar-powered irrigation system (SPIS), two major, mutually exclusive objectives of the government and the individual farmers must be addressed:

- The government aims to reduce subsidies and the natural resource footprint of operations.
- The farmers' objectives are to improve farm productivity and increase income to achieve economic sustainability and prosperity.

With the careful implementation of the technology and complementary government policies, SPIS provides an excellent alternative to diesel- or electric-run pumps for irrigation. Dedicated programs are essential to develop necessary last-mile skills with the local entities for post-pilot success.

Sustainable successes and widespread adoption of the approach require such interventions on a commercial scale. To enhance knowledge on the subject and tap into the abundant solar potential, global platforms should organize conferences and regional seminars/workshops for knowledge exchange and technology transfer. For example, IWMI has organized numerous events involving SoLAR stakeholders from different regions.

Energy availability for irrigation would also be useful in other agro-related applications, and this will create a sense of energy security in the villages. Many projects have successfully demonstrated the use of solar power for irrigation and other applications together; learning from past projects should inform new ones.

SPIS is not just a technology-driven activity; to ensure future success and scaling, SPIS requires an enabling policy environment, locally adaptable business models, and adequate capacity building for farmers, entrepreneurs, and developers.

# Recommendations

SoLAR's IF grantee projects underscore the transformative potential of solar solutions in agriculture. They offer replicable models for sustainable agricultural practices and community empowerment by addressing region-specific challenges and fostering inclusive development. These initiatives enhance productivity and livelihoods and contribute to global efforts toward mitigating climate change. The overall understanding of the IF experience suggests that to promote sustainable agriculture and improve energy access for farmers, the government and other organizations must work together to provide subsidies, financial assistance and technical support to farmers for installing solar irrigation systems. Policymakers must develop and implement effective management plans and policies to replace existing diesel-powered pumps with solar pumps and prevent excessive groundwater abstraction. Adopting efficient, reliable and low-cost technology and an easy-to-maintain system suitable for small landholder farmers is necessary.

Recommendations for SPIS Deployment across locations are as follows:

- **Regional scaling:** SPIS holds immense potential in India, Nepal and Pakistan. The seven successful IF projects should be used as replicable models for larger scale adoption regionally.
- **Increasing institutional support:** To promote sustainable agriculture and improve energy access for farmers, the government and other organizations need to work together to provide subsidies, financial assistance and technical support to farmers for installing solar irrigation systems.
- **Expanding solar policy:** Policymakers must develop and implement effective management plans and policies to replace existing diesel-powered pumps with solar pumps and to prevent excessive groundwater abstraction.
- **Adopting low-cost technology:** It is necessary to expand access to and the use of efficient, reliable and low-cost technology and an easy-to-maintain system that is suitable for small landholder farmers.
- **Shifting farming practices:** Adaptation of modern farming practices and diverse crop patterns is necessary to use less water and for better income generation.
- **Developing innovative financing models:** It is crucial to develop innovative financing mechanisms such as PM-KUSUM, AEPC and SKY schemes, microfinance support, leasing models etc. Business models for solar irrigation and other energy-based services are needed to operate them as businesses.
- **Including and prioritizing women:** Due to fewer income opportunities in the villages, most of the men migrate to cities for better opportunities, while the women remain to manage their families. These innovative projects have demonstrated the importance of including and prioritizing women during the entire project to enhance their income and promote gender equality.
- **Building capacity:** It is important to create knowledge and fill information gaps through awareness campaigns, technology demonstrations, training and capacity-building exercises to enable farmers and other stakeholders to make informed decisions. Training local technicians to provide "after-sales" troubleshooting services is essential for long-term success.
- **Collaborating across sectors:** Fostering partnerships and collaborations between the public and private sectors to promote research and development, knowledge sharing and technology transfer in the field of solar irrigation is necessary.
- **Involving the community:** The involvement of the local community in the project is essential for its success and sustainability, as they are the key stakeholders in the entire process. Aligning project goals with community-specific needs, such as drinking water or alternate livelihoods, could create win-win scenarios.

# Annexures

## Annexure A.

### *Solar-Powered Irrigation System (SPIS)—Planning, Design, Suitability and Business Models*

Needless to say, before planning to set up an SPIS, the following steps are essential:

- Site assessment and data analysis
- Preparation of a feasibility report
- Access to finance
- Optimum project design
- Community engagement and capacity building
- Monitoring and evaluation of the project

All the grantees have taken proper planning into consideration and implemented their projects successfully. Based on the experience from existing projects, a brief overview of the process is described below:

#### *Planning*

Site selection through a proper site survey to ensure:

- Site is suitable for solar, i.e., the site has adequate sunny days in a year, and land and water availability.
- Crop patterns and water needs must suit the system design.
- Installation, maintenance and O&M support for the project.
- After-sales service mechanism.

#### *Design*

System design has taken the following into consideration:

- Solar radiation at a particular site (it determines the size of the panels at that location)
- Water depth and irrigation water requirement (to determine the type and capacity of the water pump)
- Any other energy needs
- Agro-climatic conditions of the area

PV panels constitute a major share of the total cost for SPIS. Therefore, solar insolation has a strong effect on the costs of SPIS and is a factor influencing economic rather than technical feasibility, as sufficiently large PV panels can provide electricity even at low levels of irradiation.

The essential components of SPIS are solar PV field, i.e., a PV panel or array of panels used to produce electricity, mounting structure for PV panels, either fixed or equipped with a solar tracking system to maximize solar energy yield, pump controller, surface or submersible water pump, and distribution system and/or storage tank for irrigation water.

In addition, automation has helped improve the overall efficiency of the plant and schedule irrigation water based on the types of crops.

The solar PV is also connected to the inverter and battery storage to supply surplus energy for other electrical applications such as household lighting or a rice mill, flour mill and oil expeller.

A micro-grid approach has also helped serve both water and other energy services together in the villages.

Developers can decide on the use of hybrid renewable energy technology options together with solar PV to ensure a year-round power supply for domestic, irrigation and business purposes.

### *Innovation*

Some of the grantees have demonstrated the use of automated control systems to optimize plant efficiency and have also helped in water conservation through the use of remote monitoring systems and sensors. The problem is that these solutions are expensive to deploy on a smaller scale.

Other innovations such as the micro-grid approach and community water-sharing models are quite unique and can also be adopted in other locations.

### *Suitability*

The SPIS project is suitable for almost all regions of the globe where decent sunshine is available, farming requirements exist and a water source is present. Additionally, the project needs adequate access to institutional and financial support mechanisms, as well as sufficient training and awareness. Moreover, the promotion of more surface pumps is required to ensure groundwater sustainability.

### *Business models*

It is essential to develop business models for the SPIS project; the business model will vary from location to location.

Seven grantees have adopted business models in their projects, which are successfully working in their areas of operation. Some of the adopted business models are water sold as a service on a sharing basis, individual farmers seeing benefits compared to diesel, ease of operation etc.

## **Annexure B.**

### *Solar-Powered Irrigation System: Benefits, Risks, Challenges, Opportunities and Ability to Scale Up, as well as Lessons Learned*

This section captures an overview of SPIS in terms of its scaling-up potential across the country. Based on the learnings from the seven innovations, the benefits and opportunities for scaling up SPIS in South Asian countries have been captured, highlighting some important aspects of SPIS as follows:

#### *Benefits of SPIS*

In rural areas, agriculture is the main source of livelihood for farmers. Many parts of these areas face a power crisis, and diesel-powered irrigation is very expensive; hence, it affects agricultural activity.

With SPIS in place, the farmers have a dependable source of electricity for irrigation, and if coupled with a sustainable source of water supply, it offers a sustained source of livelihood.

Women play a fundamental role in agriculture, and thus, the impact of SPIS on women is of great importance. SPIS operation is simple compared to conventional irrigation methods. SPIS also opens the door to additional revenue-generation possibilities through backyard vegetable farming for women and other local businesses.

### *Bottlenecks*

Access to easy finance is a constraint for smallholder farmers with small landholdings, and farmers find it difficult to get bank loans or subsidies due to eligibility criteria.

Although the initial investment costs are high for solar energy systems, in the long run, the cost of solar energy is cheaper than that of diesel-run pumps over their lifetime. Project packaging becomes important for large-scale adoption, and farmer groups or project developers can play an essential role in this. Once project finance is packaged properly, farmers will be happy to use it and repay the debt from their savings.

*Table 3: An example of a 3 HP SPIS from India.*

Description		Solar pump	Diesel
Solar running potential (average)	Hours/year	1,825	
Average Irrigation pump running hours	Hours/year	1,000	1,000
Current cost of diesel	INR/liter	0	96
Solar pump capacity	HP	3	
Diesel pump capacity	HP		3
Diesel consumption	Liter/hour	0	1
Typical cost of the system	INR lakhs	2.50	0.50
Life of the system	Years	25	20
Operating hours	Hours/lifetime	25000	20000
<b>Cost of water</b>	<b>INR/Hour</b>	<b>10</b>	<b>96</b>
CO <sub>2</sub> savings (over lifetime of the project)	Tons	123.75	
<b>Overall savings (over lifetime)</b>	<b>INR lakhs</b>	<b>21.5</b>	

*Note:* There are still 825 hours per year available from solar for other applications, and using surplus power will generate additional revenue.

### *Key Risks and Challenges*

Solar-powered irrigation systems also come with some risks and challenges that should be considered while planning the project. Some of the main risks are given below:

- Arrangement of the initial investment for smallholder farmers
- The maintenance and repair of the systems in remote locations
- Solar systems relying on the availability of sunlight, which can be affected by weather conditions such as clouds and storms.

### *The Problem of Policy-Related Issues*

Schemes to provide free electricity to farmers for the purpose of irrigation make an adverse impact on power companies. Farmers outside the reach of the current grid, as well as those who fall within the grid but do not have connections, are lured by the promise of free power.

On the other hand, the incentives for people to install their own solar-powered irrigation equipment are weak. This makes farmers aspire to grid power for irrigation and reluctant to get their own solar systems.

The main factors that adversely affect the implementation of solar schemes are farmers seeing free, unlimited power from the grid as an easier option, a lack of awareness and knowledge about solar systems, and the absence of proper local agencies for the repair and maintenance of the system, among others.

There are opportunities to link SPIS with government policies for both off-grid and grid-connected projects. Policies such as PM-KUSUM, SKY schemes and subsidies from state governments on solar in India offer benefits to farmers. SwitchON, one of the grantees, was able to secure available subsidies from state governments, allowing farmers to benefit from them.

### *Scaling Up potential*

In recent years, solar energy has emerged as one of the cleanest, most environmentally friendly and most reliable sources of energy. Results from seven pilot projects built under the SoLAR program show how SPIS is a boon for sustainable agricultural and rural development.

The SPIS not only provides the opportunity for irrigation but also offers additional income in the case of surplus power generation, where the excess electricity can be either sold to the national electric grid or used in off-grid mode for other electrical applications. There are examples from innovation projects under SoLAR.

However, despite the policy push, the government needs to offer creative subsidies and special financing to help marginal farmers transition to solar water pumps effectively and immediately. Additionally, a single-window clearance approach, such as linkages between different financial schemes available for solar irrigation, will attract farmers.

### *Capacity Building*

The capacity development programs are needed to support farmers, local agribusinesses and others. Scientific communication is of utmost importance. All seven grantees have included training, capacity building and awareness programs as part of the project, and this has helped users tremendously.

To further develop the technical capacity at the farm and community levels, sustained interventions from the government and the private sector are required. The main agenda of these programs should be to generate awareness among farmers to use water judiciously with the objective of improving productivity and reducing input costs.

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International Water  
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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.

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