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# SoLAR: Solar Irrigation for Agriculture Resilience in South Asia

## SCOPING STUDY REPORT

# SoLAR: Solar Irrigation for Agriculture Resilience in South Asia

## Review of existing solar projects and future prospects

As farmers struggle to cope with increasing climate uncertainty, they must increasingly rely on irrigation. In much of South Asia, the only reliable source of irrigation that offers on-demand water control is groundwater. The last half-century has seen a rapid expansion of groundwater irrigated area in South Asia. With an annual withdrawal of nearly 300 $km^3$, more than 60% of irrigation in South Asia is today dependent on groundwater. Some argue that this expansion has helped the region achieve food security and banish recurring famines. At the same time, over-dependence on scarce groundwater resources for irrigation has also led to unsustainable farm power subsidies and pockets of severe groundwater depletion – causing much farm distress, affecting poor and marginal farmers; and making electricity utilities financially unviable. The recent decline in unit costs and resultant popularity of solar irrigation in the region promises an opportunity to resolve some of these challenges but also poses a threat to the sustainability of groundwater irrigation. In September 2018, the Swiss Agency for Development and Cooperation (SDC) and the International Water Management Institute (IWMI) came together to form a regional partnership with the objective of addressing some of these challenges. By adopting a 'Water-Energy-Climate' Nexus approach, the partnership – Solar Irrigation for Agriculture Resilience (SoLAR) – will identify, field test and aim to mainstream climate-smart solar irrigation promotion strategies across South Asia (IWMI 2018; Verma et al. 2018).

As a first step in this collaboration, IWMI undertook a scoping study to review existing solar experiments and field projects on the ground in the four project countries – Bangladesh, India, Nepal, and Pakistan. The assessments were to be done in conjunction with regional and national stakeholder workshops in each project country. In December 2018, IWMI organized the regional consultation in India (as part of the IWMI-Tata Partners' Meet); and a national solar consultation was organized in Kathmandu, Nepal in February 2019. As we prepare for similar national consultations in Pakistan and Bangladesh – planned in the coming few weeks – this report presents a (draft) scoping study undertaken by the project team. Several on-going activities have contributed to this report:

[1] Report of the Regional Consultation on Solar Irrigation conducted as part of the IWMI-Tata Partners' Meet in December 2018;
[2] Notes from the national consultation meeting in Kathmandu on solar irrigation organized by IWMI in February 2019;
[3] Field notes from fieldwork done by IWMI-Tata team in Nepal Terai in February 2019 (Verma et al. 2019);
[4] A review of national and sub-national solar irrigation promotion policies in South Asia (Mukherji 2019);
[5] An on-going GIZ-supported CCAFS and IWMI-Tata review of solar case studies in India; and
[6] World Bank and IWMI led work in Rajasthan and Haryana on developing solar irrigation pilots.

# 1. South Asia’s Solar Irrigation Context

In less than a decade, the number of solar irrigation pumps (SIPs) in South Asia has grown from a couple of thousand to more than 250,000 – growing most rapidly in India but also showing signs of rapid acceleration in Bangladesh, Nepal and Pakistan – in that order (**Table 1**). At its current pace, the number of SIPs in the four South Asian countries is likely to exceed 1 million by the end of 2021. This is broadly in line with the target set by the Government of India’s Ministry of New and Renewable Energy (MNRE) of 1 million SIPs by 2021 (MNRE 2014), adding more than 100,000 SIPs each year.

Bangladesh set an initial target of 50,000 SIPs by 2025 (IDCOL 2015) but with new funding available (ADB 2018), it is likely that this target will be revised upwards. The Alternate Energy Promotion Centre (AEPC) and the Department of Irrigation in Nepal too have ambitious solar irrigation expansion plans. Mukherji (2019) reports a target of 35,000 SIPs by 2020-21 in addition to the donor-supported SIPs. Perennially electricity-scarce Pakistan, too, is beginning to recognize the potential for SIPs, particularly in Balochistan, Sindh and Punjab. To date, most of the installations have been done with private resources and without any government support but the Pakistan Solar Association has set a target of 30,000 SIPs and the Alternate Energy Development Board (AEDB) has estimated potential for 6,000 MW of solar irrigation pumping capacity (AEDB 2015).

**Table 1: Overview of spread of solar irrigation in South Asia**

| Country | Estimate of total units installed | Official targets for SIPs | Government recognized solar companies |
|---|---|---|---|
| **Bangladesh** | ~ 2,000 | 50,000 by 2025 | 13 |
| **India** | ~ 200,000 – 250,000 | 1,000,000 by 2021 | 19 |
| **Nepal** | < 1,000 | 35,000 by 2021 | 43 |
| **Pakistan** | < 500 | 30,000 | 139 |

Data Sources: MNRE (2014; 2016; 2018); IDCOL (2015); AEDB (2015); Mukherji (2019)

Based roughly on eight Energy-Groundwater Interaction Settings (EGIS) identified by Shah et al. (2018), the SoLAR Entry Proposal (IWMI 2018; Verma *et al*. 2018) has classified the four project countries into three broad geographies:

**Figure 1: Three distinct SoLAR geographies**


1. The ***Groundwater Depletion Zone*** in North-West and Peninsular India (except Kerala), Baluchistan, FATA (Federally Administered Tribal Areas) and NWFP (North-West Frontier Province) in Pakistan. This region faces physical water scarcity but is also characterized by groundwater over-exploitation, thanks largely to highly subsidized or free electricity for farmers. Here, promotion of solar pumps will reduce the carbon footprint of the groundwater irrigation economy but can also lead to even more groundwater abstraction. Hence, sustainable groundwater management should be a key priority for climate-smart solar promotion policies. Much of the more than 250,000 SIPs already installed in India are located in this region.

2. The ***Groundwater Abundance Zone*** covering eastern Gangetic plains in India, Nepal Terai and Bangladesh. This region sits on one of the world's largest groundwater aquifers but lack of electricity supply infrastructure and the high cost of diesel-based irrigation limits groundwater development and agrarian prosperity. Here, if promoted well, solar pumps can play an important catalytic role in delivering equitable and affordable irrigation access. Groundwater quality, particularly, the effect of arsenic pollution in affected pockets, is also a key policy concern in this region.

3. The ***Rest of South Asia*** covers a diverse geography including: [a] the mighty Himalaya – Asia's water towers where water use in agriculture is limited but solar energy can play an important role in offering affordable energy access to remote habitations; [b] Punjab and Sindh provinces in Pakistan – where conjunctive use of surface and groundwater is common and solar pumps can potentially replace millions of diesel pumps; and [c] the high-value agriculture in Kerala and Sri Lanka where farmers already pay commercial or near-commercial tariffs for farm power.

## 2. SIP Spread and Promotion Models

There is no single source of information about the spread of solar irrigation pumps in South Asia. Based on data gathered from various sources, we estimate that around 250,000 SIPs are currently operational in South Asia. Eighty percent of these are likely situated in India, where SIPs are being promoted by national and provincial governments and donor / CSR grant programs. **Table 2** summarizes the latest information on the number and spread of SIPs in South Asia as well as the major schemes / programs through which their adoption is being promoted.

**Table 2: Spread of SIPs and key features of Solar Irrigation Promotion Programs in South Asia**

| Region (No. of SIPs) | Solar irrigation promotion program(s) | Scheme features |
|---|---|---|
| **INDIA (185,479)** | **National Solar Mission: 100 GW solar capacity by 2022** | **70-90% capital subsidy** |
| | **KUSUM: Announced in 2018; 1.75 million SIPs; 28 GWp** | **30-60% subsidy; 30-60% loan** |
| *Chhattisgarh (43,408)* | *Saur Sujala Yojana: 2-5 kWp individual SIPs* | *70-90% capital subsidy* |
| *Rajasthan (42,581)* | *2-10 kWp individual SIPs* | *70-87% capital subsidy* |
| *Andhra Pradesh (30,344)* | *2-5 kWp individual SIPs* | *70-90% capital subsidy* |
| *Uttar Pradesh (14,696)* | *2-5 kWp individual SIPs* | *70-90% capital subsidy* |
| *Gujarat (11,522)* | *3-10 kWp SIPs for farmers waiting for grid connections* | *95% capital subsidy* |
| | *SPaRC: Solar Power as Remunerative Crop (see Box 1)* | *60-90% capital subsidy* |
| | *SKY: Feeder-level solar cooperatives (see Box 2)* | *30% subsidy; 65% loan ~INR 7/kWh FiT + EBI* |
| | *Farm-top solar parks; no capital subsidy* | *Developer-led model* |
| *Orissa (8,937)* | *1-5 kWp individual SIPs* | *70-100% capital subsidy* |
| *Madhya Pradesh (6,034)* | *2-10 kWp individual SIPs* | *70-90% capital subsidy* |
| *Karnataka (5,011)* | *Capital cost subsidy for individual, off-grid SIPs* | *70-90% capital subsidy* |
| | *Surya Raitha: Grid-connected SIPs; INR 7-9/kWh* | *Subsidy + Loan model* |
| *Tamil Nadu (4,459)* | *2-10 kWp individual SIPs* | *70-90% capital subsidy* |
| *Jharkhand (3,702)* | *2-10 kWp individual SIPs* | *70-90% capital subsidy* |
| *Maharashtra (3,315)* | *Saur Krishivahini Yojana: Off-grid 3-5 kWp individual SIPs* | *80% capital subsidy* |
| | *MSKVY: Feeder tail-end 1-3 MWp solar plants* | *No capital subsidy* |
| *Bihar (1,882)* | *Solarization of NABARD Public Tubewells* | *100% capital subsidy* |
| | *Small 0.2-1.8 kWp Mobile Solar Solutions; Pay-per-use model* | *70-100% capital subsidy* |

| | | |
|---|---|---|
| | *Solar Irrigation Entrepreneurs: Pay-per-Use model (see Box 3)* | *50-60% capital subsidy* |
| | *Bihar Saur Kranti Sinchai Yojana (BSKSY): Off-grid 2-3 kWp SIPs* | *90% capital subsidy* |
| *Punjab (1,857)* | *2-10 kWp individual SIPs* | *75% capital subsidy* |
| *Haryana (1,293)* | *2-10 kWp individual SIPs* | *90% capital subsidy* |
| *Kerala (818), West Bengal (653), Telangana (424)* | *2-10 kWp individual SIPs* | *70-100% capital subsidy* |
| *Rest of India (531)* | *2-10 kWp individual SIPs* | *70-100% capital subsidy* |
| **Pakistan (<500)** | *SIPs available commercially with bank loans* | |
| | *Plan to install 300,000 SIPs with government subsidy* | *PKR 12 billion budget allocation requested* |
| **Bangladesh (~2,000)** | *Pay per use SIPs* | *50% subsidy; 30% loan* |
| | *Proposal to install 50,000 SIPs by 2025; multi-donor project* | *50% subsidy; 30% loan* |
| **Nepal (~500)** | *< 1 kWp SIPs for kitchen gardens under donor programs* | *75-100% subsidy* |
| | *1-5 kWp SIP Demonstration Pumps installed by AEPC* | *100% subsidy* |
| | *Individual / Community / Company Solar Irrigation* | *Up to 60% capital subsidy; Max. NPR 2 million* |
| ***AEPC Future Plans*** | ***Challenge Fund Type I:** Grid-connected Canal-top / Canal-bank Solar PV Systems* | *100 – 1000 kWp Grant + Soft Loan* |
| | ***Challenge Fund Type II:** Grid-connected Group Irrigation Solar PV Systems* | *10 – 100 kWp Grant + Soft Loan* |

Supported by GIZ, CCAFS and the IWMI-Tata Program are compiling case studies of different models through which solar irrigation is being promoted in India. A similar scoping was carried out in Nepal during and after the national consultation. A detailed scoping in Pakistan and Bangladesh are pending, and will be carried out along with the national SoLAR consultations planned in Islamabad and Dhaka. Table 3 classifies the solar irrigation promotion models by SIP size and ownership model.

Table 3: Matrix of Solar Irrigation Promotion Models in South Asia

| | | **SIP OWNERSHIP** | | |
|---|---|---|---|---|
| | | **Individual** | **Collective / Cooperative** | **Entrepreneur / Business** |
| **SIP SIZE** | **< 1 kWp** | Donor-SIPs: IN & NP | Donor-SIPs: IN & NP | Donor-SIPs: IN & NP<br>Mobile SIPs |
| | **1 – 5 kWp** | MNRE SIPs<br>AEPC SIPs<br>KUSUM | Donor-SIPs: IN & NP | Mobile / Portable SIPs<br>Nepal SPVs<br>IDCOL SIPs |

| | | | |
|---|---|---|---|
| **5 – 10 kWp** | MNRE SIPs<br>SKY Ag. Feeders<br>SPaRC Pilots outside Guj. | Dhundi / Mujkuva<br>SPaRC Pilot in Haryana | Nalanda SIPs<br>Chakhaji S-ISPs<br>IDCOL SIPs |
| **> 10 kWp** | SKY Ag. Feeders<br>*Surya Raitha*, Karnataka<br>SPaRC Pilots outside Guj.<br>KUSUM | Dhundi / Mujkuva | IDCOL SIPs |
| **> 0.5 MWp** | - | - | Anklav Farm-top Solar<br>MSKVY Ag. Feeders |

## 2.1 Off-Grid, Individual SIPs with High Capital Subsidy

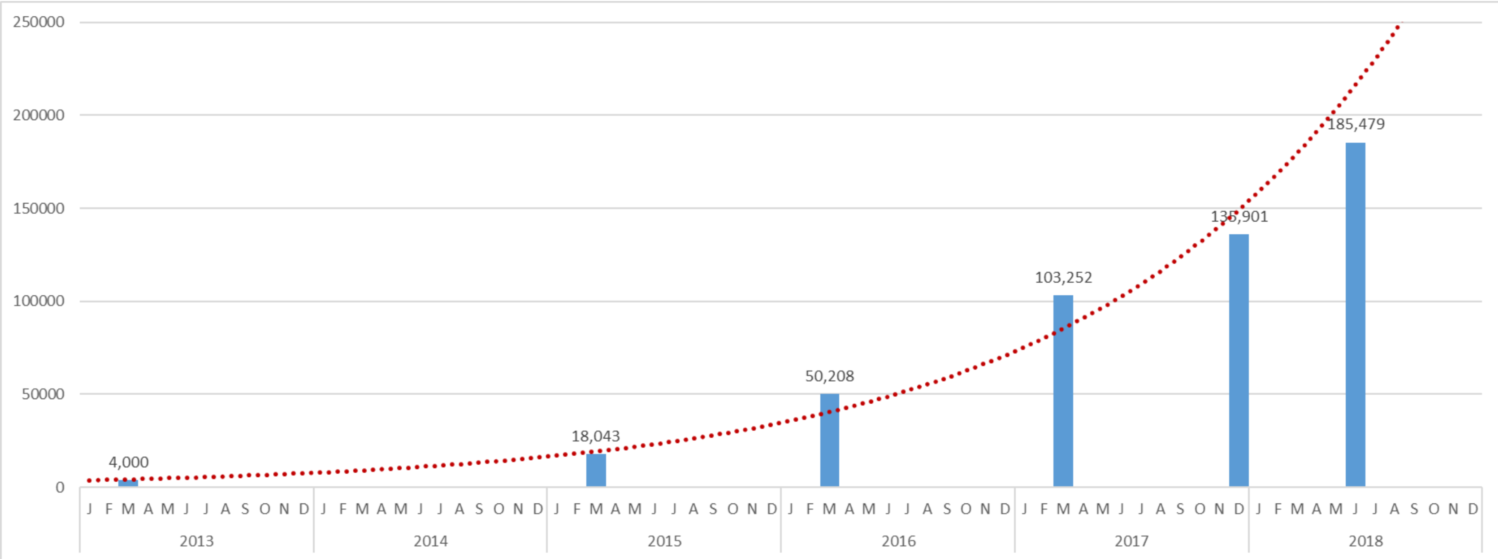
### *2.1.1 MNRE-funded SIPs in India*

India had initially set a modest target of 20 GWp solar generation capacity by 2022. In 2015, the target was revised to 100 GWp by 2022. While some reports have raised doubts about India's ability to achieve the revised target, the government insists that the target will be achieved on schedule. The Ministry of New and Renewable Energy (MNRE) in Government of India is the nodal agency for promotion of renewable energy in India. Their work includes promotion SIPs. At present, MNRE provides 30% capital subsidy on solar irrigation systems up to 10 kWp capacity. All state governments have built their solar promotion schemes on top of the MNRE subsidy by offering additional capital subsidy from their side.

As the number of SIPs in India has expanded, the unit cost per '*watt-peak*' has rapidly declined. In 2012-13, the unit cost was around INR 120-150 per watt-peak (1 USD ~INR 70), while today it is less than INR 50 per watt-peak. Yet, solar irrigation pumps are too expensive for small farmers to purchase on their own. In this context, it is a reasonable estimate to say that more than 80% of the 200,000-odd SIPs in India have been installed with some MNRE subsidy. As of 30 June 2018, 185,479 SIPs have been installed with government support (MNRE 2018; **Figure 2**). This number also includes 4,012 SIPs installed under a NABARD (National Bank for Agriculture and Rural Development) '*grant-cum-loan*' scheme. The MNRE subsidy is available only up to a maximum capacity of 10 kWp.

- **Rajasthan** took an early lead in utilizing the MNRE subsidy through an innovative convergence with the state Horticulture department. The Government of Rajasthan initially offered 87% capital subsidy, limited to 2 and 3 kWp, but responding to farmers' demand, they later allowed higher capacity SIPs in the scheme while gradually reducing the subsidy to 70% (Tewari 2012; Kishore *et al.* 2014). So far, nearly 45,000 SIPs are operational in Rajasthan.
- In **Chhattisgarh**, the state government announced the *Saur Sujala* scheme under which approximately 45,000 off-grid SIPs have been installed with an 80-95% capital subsidy. An IWMI-Tata study (Sharma and Singh 2018) found that the bulk of the demand for SIPs came from the more prosperous central Chhattisgarh region where well density was already high and farmers also enjoyed free farm power. The resultant groundwater pumping was so high that the state government had to temporarily ban paddy cultivation!

**Figure 2: Official number of SIPs installed under government subsidy schemes in**




**India**
Source: MNRE (2018)

**Figure 3: A SIP in Rajasthan, supported by the state government**

- State governments in **Andhra Pradesh** and **Uttar Pradesh** also offer attractive capital subsidies for SIPs and have installed 30,000 and 15,000 SIPs, respectively, to date.
- **Gujarat**'s first solar irrigation policy offered SIPs at 95% capital subsidy (farmers were asked to pay ₹5,000 per HP of connected load) to those farmers who had applied for electric pump connections but were waiting in queue. The state also offered off-grid SIPs to farmers whose farms were located at remote locations. The SIPs were installed in farmers' fields but their ownership remained with the local electricity utility. Despite huge backlog in farm power connections, the Gujarat scheme had few takers. Farmers preferred to wait for electric connections rather than getting SIPs. The scheme worked better in Saurashtra, where a large number of farmers are using SIPs as secondary pumps. They use their grid connections to pump water into their farm ponds while the SIPs are used to irrigate from water stored in farm ponds (Thakur and Aanchal 2016). In all, approximately 11,500 SIPs are reported to be operational in Gujarat.
- MNRE subsidies in conjunction with state subsidies have also been offered to farmers in **Orissa** (~9,000), **Madhya Pradesh** (~6,000), **Karnataka** (~5,000),

**Tamil Nadu** (~4,500) and **Jharkhand** (~3,700) with a few thousand SIPs installed in each of these states.

- The Chief Minister of **Maharashtra** announced his intent to solarize all 4 million irrigation pumps in the state but the response from farmers was tepid and only a little over 3,000 SIPs have been installed so far.
- Under its *Saur Kranti Sinchai Yojana*, the government of **Bihar** offers small, off-grid SIPs to farmers with 90% capital cost subsidy; about 2,000 of these have been distributed so far. ITP field studies found that the SIPs were poorly targeted; not serviced properly and severely under-utilized (Durga *et al*. 2016).
- Both **Punjab** and **Haryana** offered high capital subsidies on SIPs (75% and 90%, respectively) but found few takers (~1,800 in Punjab and ~1,300 SIPs in Haryana). One reason for this low interest could be poor experiences with SIPs in the past.
- **Telangana** is another state where the state government has ambitious plans to expand SIP numbers through high capital subsidies. The state has set itself a target of 2 million SIPs, although the number of SIPs on ground, so far, is reported to be less than 500.

The state government schemes mentioned above cover the bulk of the SIPs operational in India. In addition to these pumps, various donors, foundations, research institutions and CSRs are experimenting with innovative technical, economic, and institutional models for solarizing agriculture. Though their numbers are small, we will see that such experiments have the potential to influence large SIP investments. Since 2017, some state governments also seem to be moving away from offering high capital subsidies on off-grid, individual SIPs and are developing schemes and pilots to solarize complete feeders. Karnataka was the first to announce *Surya Raitha* scheme which proposed to solarize entire feeders and offer farmers the option of selling surplus power back to the grid. However, the scheme failed to take off for various reasons. Gujarat recently announced the *Suryashakti Kisan Yojana* (SKY) under which the state has already solarized more than 40 agricultural feeders. We discuss SKY in greater detail in section 2.2.2 (below).

### *2.1.2 AEPC-promoted SIPs in Nepal*

In Nepal, the Alternative Energy Promotion Center (AEPC), and the Ministry of Energy, Water Resources and Irrigation are the focal institutions for promoting and implementing renewable energy-based technologies in Nepal. They provide policy, planning and technical support for RE projects, and develop standards and design guidelines for photovoltaic pumping systems (PVPS) for irrigation, drinking and multiuse water systems. In the Terai (along Nepal's southern border with India), AEPC has installed a few SIPs (1 – 5 kWp capacity) as technology demonstrations with a 100% capital subsidy for farmers (**Figure 4**). During our field visit, we found three such pumps[1]. In all, AEPC has implemented 200+ drinking water PV systems and 400+ irrigation systems in different parts of Nepal covering 47 districts. Under its current policy provisions, AEPC offers up to 60% capital subsidy (subject to a maximum of NPR 2 million per system) for irrigation systems managed by individual farmers, farm communities, or private companies. The subsidy was introduced in 2016-17, specifically targeting farmers growing cash crops through a 'demand-driven approach' (Chaudhary 2019). At the national consultation in Kathmandu, Chaudhary (2019) explained a new approach for SIP promotion. AEPC is currently developing modalities for a nation-wide

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[1] Two of the AEPC demonstration SIPs we visited had dusty panels and poor discharge rates. When beneficiary farmers were asked why the panels were not clean, they reported that they were not told about the need to clean panels or its impact on water discharge. A third farmer seemed to be making better use of the SIP and was keen to become a solar irrigation entrepreneur provided AEPC offered bigger pumps with a network of buried pipelines.

*"Challenge Fund" that* will target rain-dependent and diesel-genset operating farmers through two modes:

- **Type I: Grid-connected solar PV Irrigation system on canal-top / canal banks**
    - *Private companies will install and operate 100 – 1,000 kWp solar PV systems on canal top or canal bank in collaboration with local governments that will meet irrigation requirements and evacuate surplus solar energy into the national grid through a Power Purchase Agreement (PPA) with the Nepal Electricity Authority (NEA).*
- **Type II: Grid-connected solar PV irrigation for groups of farmers**
    - *Private companies will identify and organize farmers into groups and in collaboration with local governments. They will also identify land (preferably unsuitable for agriculture) for solar installation. The 10 – 100 kWp solar PV irrigation systems will also have the option to evacuate surplus power to the national grid under a PPA with NEA.*

In both cases, AEPC will provide a capital subsidy and facilitate soft bank loans for the private company, which will collect a water tariff from farmers. After an agreed period for recovering investment, the company will hand over the system to the local government.

**Figure 4: AEPC-funded 'technology demonstration' of SIPs in the Terai**

**Image source: IWMI-Tata Program (2019)**

## 2.2 Donor-led SIP Promotion

In India and Nepal, usually among small and marginal farmers, several donors, foundations and CSRs have helped communities acquire SIPs, as the following examples illustrate:

### *2.2.1 Donor-supported SIPs in Nepal*

- **IWMI** and **iDE Nepal** partnered to distribute 80 wp **SunFlower** pumps (Figure 5) to a group of eight women farmers who cultivate 20 *katha* (0.66 Ha) individually, and 8 *katha* (0.26 Ha) collectively. The SunFlower SIP can irrigate only 0.5 *katha* in a day and women have to wait a week for their turn to irrigate again. The major problem in the area is rocky sub-surface and bore failure. The women we met demanded bigger pumps and to lease-in more land and expand their irrigated and cultivated areas. The group we met has also taken two electric connections to fill farm ponds for fish cultivation and to sell irrigation services at NPR 10/kWh for group members and NPR 15/kWh for others (Verma et al. 2019).

Overall, iDE Nepal has implemented 28 SIPs across 11 districts with the help of implementing NGOs. These SIPs benefit roughly 1200 households and irrigate ~62 Ha. The community has contributed about 32% of the capital cost, while the government has contributed 54% and donor grants have accounted for the remaining 14% (Pariyar and Karki 2019).

**Figure 5: IWMI and iDE Nepal supported sub-HP SIPs for women's groups in the**


**Terai**
Image source: IWMI-Tata Program (2019)

- In partnership with **Sabal** and **SunFarmer**, **ICIMOD** installed 56 SIPs across four districts of Nepal. Twenty-three of these were installed in Saptari district where ICIMOD ran a randomized control trial to understand: [a] which financial model works best for farmers; and [b] whether offering additional subsidies to women farmers would lead to better ownership by women. The financial models offered included: [a] a '*grant*' model, where 60% of the capital cost was offered as grant and the rest was borne by the farmers; [b] a '*grant cum loan*' model, where in addition to the 60% grant, 20% of the capital cost was provided as loan at a 5% interest rate, and the remainder was to be borne by the farmer; and [c] a '*pay-as-you-go*' model where farmers paid a monthly or seasonal rent for using the SIP and owned the pump over a period of three years.

  ICIMOD offered an additional 10% capital subsidy (or 10% discount on rent under '*pay-as-you-go*') to women farmers if they also owned the land. ICIMOD researchers hoped this arrangement would incentivize the transfer of land to women farmers. The 1.2 kWp solar panels were used to operate 1.5 HP pumps, offering a capacity to extract 60 $m^3$ of groundwater per day (Figure 6). Of the three financing models offered, the '*grant cum loan*' model was the most popular (46%), followed by '*pay-as-you-go*' (34%) and '*grant*' (20%) models. All but one of the 65 applications received by ICIMOD in Saptari district were from individual farmers, indicating a strong preference for individual ownership of SIPs. ICIMOD also noted that farmers who applied for SIPs had, on average, larger land holdings (1.85 Ha) vis-à-vis those who attended meetings but did not apply (0.90 Ha). Eighty-four percent of the applicants had either an electric or a diesel pump (Mukherji et al. 2017). ICIMOD reports a reduction of more than 59 tons of $CO_2$ emissions as a result of their solar installations (ICIMOD 2019).

We were able to meet only a handful of beneficiaries during our fieldwork. Incidentally, all of the beneficiaries we met had recently acquired electric pumps to supplement their SIPs. The combination of electric and SIPs managed to crowd out diesel pumps completely and provided a boost to vegetable and summer paddy cultivation by virtue of cost savings. However, farmers reported limited or no expansion in irrigated areas due to migration-related labour scarcity, open grazing, and working capital scarcity (Verma et al. 2019). The rapidly improving availability of farm power and government policies that encourage new farm power connections pose a threat to future prospects of SIPs in Nepal and other parts of the eastern Gangetic basin.

**Figure 6: ICIMOD, Sabal and SunFarmer promoted SIPs in Saptari district**


Image source: IWMI-Tata Program (2019)

- **LI-BIRD** (Local Initiatives for Bio-diversity Research and Development) has installed 22 community owned and managed SIPs benefitting ~400 farmers spread across six districts. In Mahottari district, LI-BIRD collaborated with **CDFAN** to install **CCAFS**-supported SIPs (Figure 7) that lift water into small, lined farm ponds which are then used to irrigate small parcels of land. Here, too, we found electric pumps supplementing SIPs. Given the small, kitchen-garden-type parcels on which farmers were growing vegetables, SIPs seemed like a huge investment for small returns. Our impression was that given the availability of water in the source, much more irrigation could be done, possibly with a larger pump and bigger on-farm storages or delivery through buried pipelines (Verma et al. 2019). However, LI-BIRD reported "tremendous impact on crop production and diversification" as a result of their interventions. In Bardiya district, they report a 150% increase in area under vegetable cultivation and a 73% decline in overall expenses after adoption of SIPs. The cost of irrigation has declined from NPR 400 per hour with diesel pumps to NPR 50 per hour with SIPs (LI-BIRD 2019; 1 USD = 100 NR).

- **SunFarmer**, a leading solar player in Nepal, has installed approximately 85 (0.3 – 9.5 kWp) SIPs benefitting more than 1,850 farmers spread across nine districts. SunFarmer reports that with their installations, net irrigated area has increased by 30%, farmer incomes have increased two-fold, and $CO_2$ emissions have been reduced by 1,114 tons (SunFarmer 2019).

Figure 7: LI-BIRD-CDFAN-CCAFS SIP in Mahottari district, Nepal

**Image source: IWMI-Tata Program (2019)**

### *2.2.2 Donor-supported SIPs in India*

- One of the early experiments in solarization of tubewells was undertaken in Nalanda district of Bihar where Claro Energy installed 30-35 NABARD-funded, solar powered public tubewells that had been formerly diesel-based. The public tubewells has been mostly lying defunct due to their very high operating costs, and their network of buried pipelines also needed significant repairs. After solarization, the tubewells were handed over to 'operators', usually the owner of the land where the tubewell was situated, and these operators were expected to offer irrigation services to farmers at hourly prices fixed by the government. IWMI-Tata studies (Tiwary 2012; Shah and Kishore 2012; Durga et al. 2019) found that despite shortcomings on the institutional side, some of the tubewells were performing exceptionally well, thanks to the enterprise of the operators (Figure 8).

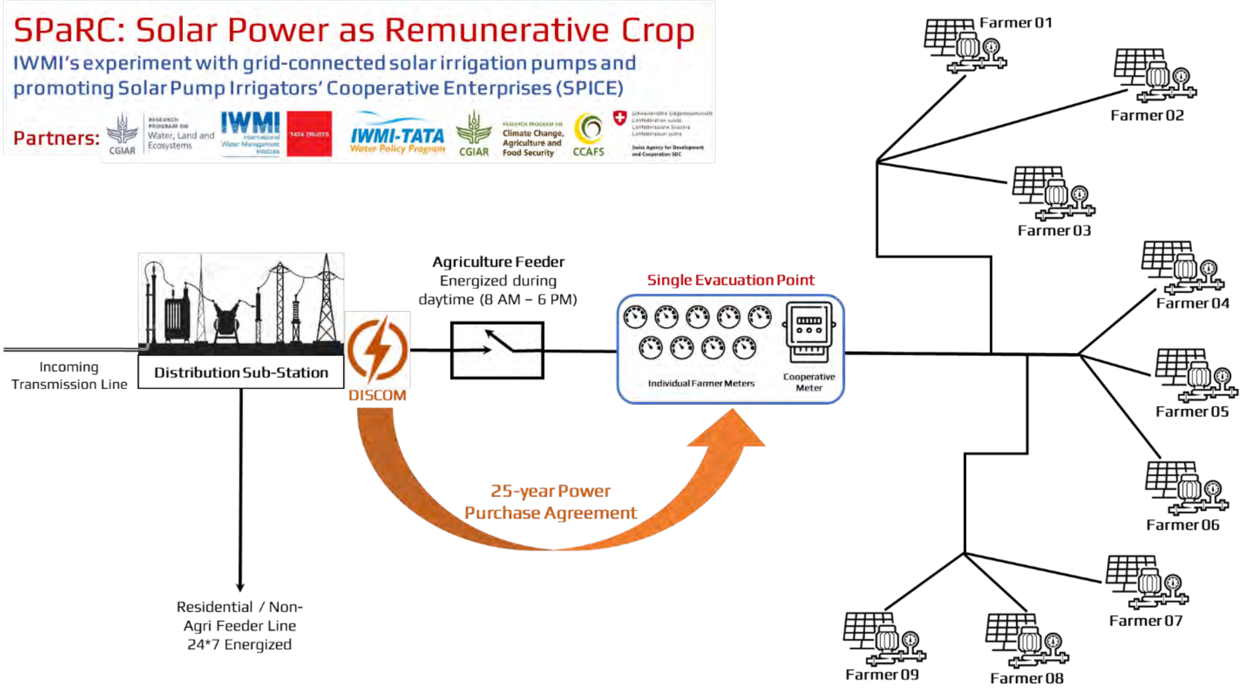
- IWMI, CCAFS and the Aga Khan Rural Support Program, India (AKRSP-I) collaborated to pilot a model for catalysing equitable, competitive, and buyer-friendly irrigation service markets through solar irrigation entrepreneurs with buried pipelines. IWMI argues that such a model of promoting solar entrepreneurs is significantly more efficient in delivering reliable and affordable irrigation to the largest number of farmers as opposed to its current model of offering 90% capital subsidy on small 1-3 kWp stand-alone SIPs (Durga et al. 2016; see Box 2).

**Figure 8: Solarization of defunct NABARD-funded public tubewells in Nalanda,**

**Bihar**
**Image source: Tiwary (2012)**

- In Gujarat, **IWMI** and **WLE** came together in 2014-15 to field test the idea of grid-connected solar farmers. In Thamna village in central Gujarat, IWMI gave an 8.5 kWp solar irrigation system to Ramanbhai Parmar and convinced the local power utility – Madhya Gujarat Vij Company Ltd. (MGVCL) – to allow him to evacuate his surplus power to the grid. IWMI paid the farmer INR 5 per kWh of energy evacuated and Ramanbhai became the world's first solar farmer. The tiny experiment gained a lot of media attention and, within a few months, the Energy and Petrochemicals Department of Government of Gujarat invited IWMI to scale up the experiment and share its results. Through a grant under 'Climate Smart Agriculture' from **CCAFS**, IWMI helped create the world's first solar irrigators' cooperative: **Dhundi Saur Urja Utapadak Sahkari Mandali** (DSUUSM). The National Dairy Development Board (NDDB) and REIL later joined hands to replicate the solar cooperative in Mujkuva village. The model is described in Box 1 and shown in Figure 9.

**Figure 9: IWMI's SPaRC (Solar Power as Remunerative Crop) model of solar**




**irrigation promotion**

- In **West Bengal** – perhaps the only Indian state where farmers pay near-commercial tariffs with time-of-day metering – several farmers Water User Associations (WUAs) were offered SIPs at 100% capital subsidy under a World Bank-funded program. An ITP study (Sabharwal and Sharadindu 2017) found significant increase in winter crop area and reduction in the cost of irrigation. The study estimated that even without the 100% capital subsidy, SIPs would be preferred over grid pumps, especially by small farmers.

- In addition to these examples, there are numerous other small-scale pilots and experiments with SIPs underway in India. As part of its energy access program, GIZ has supported a community-based 'Water-as-a-Service' model for solar irrigation pumps in Bihar. Claro Energyand the SELCO Foundation have also experimented with mobile / portable solar irrigation pumps. These pumps largely cater to small-holder farmers in regions where land fragmentation is high and water tables are shallow. Claro's 'Movable Solar Trolley' includes 1.8 kWp solar panels mounted on an e-rickshaw and connected to an AC pump. These trolleys are operated in a "pay-as-you-go" model (**Error! Reference source not found.**; PfA 2018; CCAFS 2019). Dr. Rajendra Prasad Central Agricultural University (RPCAU) has developed a "Solar Tree" to maximize solar energy generation with minimal land footprint (Figure 10).

Figure 10: 'Solar Tree' developed by Dr. Rajendra Prasad Central Agricultural University (Pusa, Bihar)

Image Source: https://www.rpcau.ac.in/wp-content/uploads/2017/11/Solar-Tree-web.jpg

## 2.3 Large Government Initiatives for SIP Promotion

In the 2018 union budget, India's Finance Minister proposed an ambitious new scheme for solar pump promotion: Kisan Urja Suraksha evam Uthaan Mahabhiyan (KUSUM). With a projected outlay of $20 billion (of which, the union government would invest roughly $5 billion over 10 years), the scheme proposes installation of 10,000 MWp of feeder tail-end solar plants (of the kind proposed under MSKVY); 1.75 million off-grid SIPs; and 1 million grid-connected SIPs (as proposed in SPaRC). Inspired by IWMI's solar irrigation experiment in Dhundi, the Government of Gujarat announced the Suryashakti Kisan Yojana (SKY) in June 2018. The scheme is explained in detail in Box 2.

### *2.3.1 SPaRC Initiatives / Experiments outside Gujarat*

- In 2014, even before IWMI's Dhundi pilot was set-up, Karnataka announced its Surya Raitha policy offering grid-connected SIPs to farmers and a feed-in-tariff of INR 7-9 per kWh for evacuating surplus solar power (Shah et al. 2014). Even though much of this attractive FiT was to be used to re-pay the massive loan on capital, Surya Raitha was attractive for farmers – almost too good to be true. The scheme ran into trouble on multiple fronts. For one, the location of its pilot became politically contested. Two, the technical partner – SunEdison – ran into financial trouble and sold-off its Indian assets. And three, several farmers who did not have grid-connections earlier also had to be accommodated in the scheme. An ITP-ISEC study (Durga and Verma 2019) in the pilot feeder found significant subsidy savings for the local utility (BESCOM) but little positive impact on groundwater abstraction as farmers never received even the small portion of the FiT they were promised. Eventually, the pilot was not scaled up as neither the farmers, BESCOM nor any political leader took ownership of the scheme.
- In one feeder near Vizag, Andhra Pradesh has implemented grid-connected SIPs in a pilot feeder albeit with a slight modification of the model. Unlike SKY, where farmers have the option of drawing power from the grid and are net-metered, Andhra Pradesh has installed DC-pumps on the farmers and farmers do not have the option of drawing any power from the grid. Further, while Gujarat has offered a

feed-in-tariff of INR 3.5 per kWh, Andhra Pradesh has set the tariff at INR 2 per kWh. It remains to be seen how this will impact pumping behaviour and farmer incomes.

- In Rajasthan, under the World Bank-supported Rajasthan Agricultural Competitiveness Project (RACP), the Government of Rajasthan has sought technical assistance from the World Bank to help them design pilots on two feeders for grid-connected SIPs. The IWMI-Tata Program is working closely with the World Bank to help the Government of Rajasthan design these SPaRC pilots.
- Likewise, in Haryana, the state government sought technical assistance from the World Bank to design appropriate business models for pilots on two feeders for solarizing agriculture. Here too, IWMI-Tata Program helped World Bank design the pilots, which are now awaiting final approval.
- Seeing the early success of Gujarat's SKY scheme, the Government of Maharashtra has invited the National Dairy Development Board (NDDB) to help them pilot SPaRC in Maharashtra.

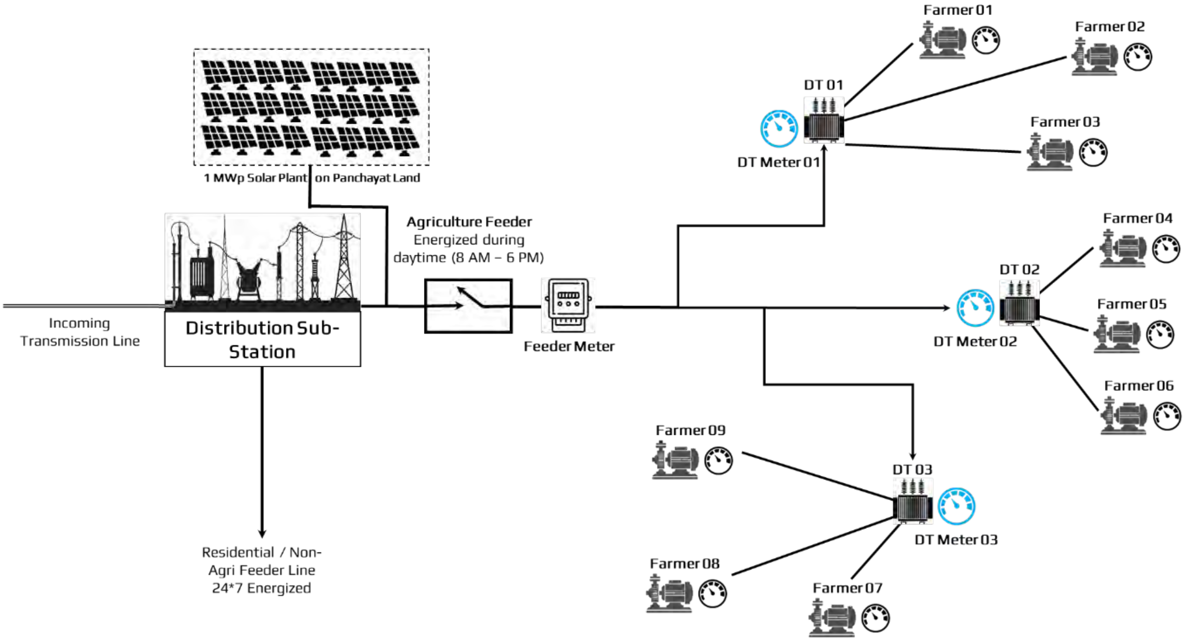
### *2.3.2 Maharashtra's MSKVY*

Besides offered individual off-grid SIPs to farmers, Maharashtra is also trying a different model of solarizing agriculture under the Mukhyamantri Saur Krishi Vahini Yojana (MSKVY). Under this scheme, the state government is inviting bids from private developers to commission 1-3 MWp distributed solar plants at the tail-end of agricultural feeders (Figure 11). The government will help the developers lease-in common land from the local panchayat and pay the developer a feed-in-tariff for all energy units generated at the plant through a process of open bidding (at current costs, the FiT is expected to be ~INR 3.10 per kWh).

The developers will commission, operate, and maintain the tail-end plants. The farmers will continue to get free / subsidized farm power but now during daytime. And the DISCOM will save a part of their farm power subsidy bill since generating solar energy at the tail-end will cost less than their current cost-to-serve for farmers (~INR 4.5 per kWh). Proponents of this model claim it will attract a lot of private investment and will start delivering savings for DISCOMs from day one.

Whether private investors will participate enthusiastically remains to be seen. The MSKVY pilots are being implemented through EESL (Energy Efficiency Services Limited), an energy services company of the Government of India. One concern about implementing this model in a groundwater-scarce region like Maharashtra is that it might lead to increased groundwater pumping (since farmers will now get better daytime power) and increase farm power use over time. However, this is an empirical question that can be easily tested once the model is implemented in a few locations.

**Figure 11: Maharashtra's model of solarizing agriculture under MSKVY**



**Box 1: Growing 'Solar Power' as a Remunerative Crop**

*In Gujarat's Dhundi village, under a grant to implement "Climate Smart Agriculture", IWMI and CCAFS (CGIAR's research program on Climate Change, Agriculture and Food Security) have supported the creation of the world's first solar irrigation cooperative. Started in early 2016 with six small farmers, the experiment has received a lot of media and policy attention (see Annexes 5 and 6) due to its unique model of promoting solar power as a 'remunerative crop'. Under the pilot, farmers have installed 5-10.8 kWp SIPs that are connected to each other through a micro-grid. The SIPs are installed at an elevation such that even land beneath the panels can be utilized for cultivation. The panels generate roughly 1,500 kWh per kWp of capacity in a year and this energy can be used by the farmers to lift groundwater for irrigation. Also, registered as a cooperative society, the farmers can pool any surplus power they generate at a central point and, under a 25-year power purchase agreement, sell it to the local electricity utility to earn cash income. In order to incentivise generation of green energy and efficient groundwater use in agriculture, IWMI offers a top-up on the feed-in-tariff the cooperative gets from the utility. Over a little more than two years of full-scale operations, the cooperative has avoided 136 tons of* $CO_2$ *emission and earned more than INR 850,000 (~US$ 12,500) from selling surplus solar power. This added revenue is considerable in a context where the mean household income is approximately USD 2,000 per year.*

*Beyond greening the groundwater irrigation economy and helping member farmers pool and sell their surplus solar power, as the cooperative matures, the group can also undertake additional activities to help maximize member returns. Solar cooperatives can provide technical services to ensure that the pumps operate smoothly; can encourage adoption of water and energy efficient irrigation technologies; stimulate discussion on shifting cropping patterns to high value, less water and energy intensive crops etc. A mature and financially healthy cooperative can also help members make investments in new technologies and expand solar capacity by acting as an intermediary with local financial institutions.*

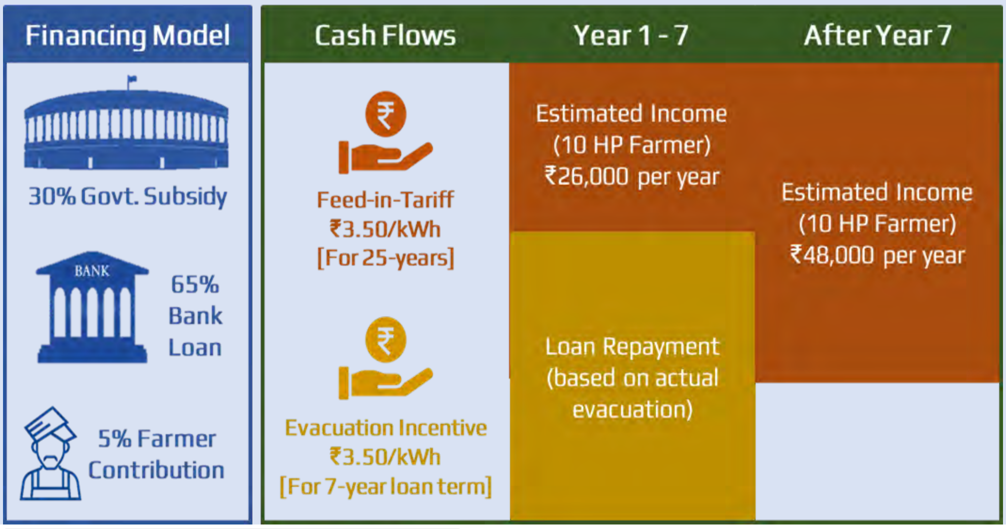
*Dubbed as SPICE 1.0 (Solar Pump Irrigators' Cooperative Enterprise), IWMI argues that mainstreaming of such SPICE cooperatives constitutes 'smart solar promotion'. The central premise of the experiment is that when farmers have the option of selling their surplus solar power for non-trivial returns, this will incentivise them to use energy (and therefore groundwater) efficiently. With support from the National Dairy Development Board (NDDB) – which has experience promoting thousands of dairy cooperatives in India – IWMI is now working on SPICE 2.0 in another Gujarat village. While in Dhundi, farmers had shifted from diesel pumps to SIPs, under SPICE 2.0 in Mujkuva, the pilot will solarize grid-connected farmers who will give up access to highly subsidized farm power. Another model of solar cooperatives that IWMI and SDC have explored is one where the solar cooperative can sell its surplus power to a commercial user – a local factory, for instance – rather than evacuating it to the electricity grid.*

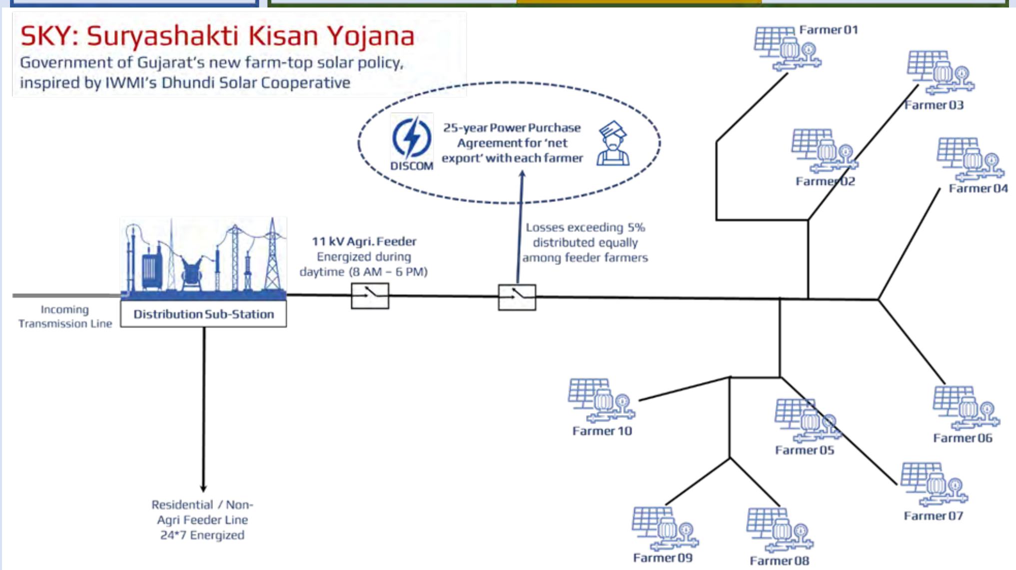
*In groundwater-scarce western and peninsular India, every grid-connected farmer that shifts to solar under this model will relieve some grid capacity for the local utility. The program will also reduce the government's farm power subsidy bill. But importantly, it will offer farmers an additional and reliable source of climate-proof income. While there are technical, financial, and institutional challenges to upscaling this experiment, the idea is starting to appeal to farmers as well as policy makers. Inspired by the experiment, the Government of Gujarat has drafted a new solar irrigation scheme called SKY (Suryashakti Kisan Yojana) to promote feeder-level solarization across the state.*

**Box 2: Gujarat aims for the SKY – *Suryashakti Kisan Yojana***

*In June 2018, under the overall framework of KUSUM and inspired by the Dhundi Saur Urja Utpadak Sahkari Mandali (DSUUSM), the Government of Gujarat announced a new farm-solar policy: Suryashakti Kisan Yojana (SKY). In its first phase, SKY will solarize 100+ agricultural feeders across all 33 districts of Gujarat by replacing farm power connections with grid-connected SIPs. With a Phase I outlay of INR 870 crore (~US$ 126 million), the scheme will solarize more than 12,400 agricultural pumps. As of March 2019, about 1,200 farmers in 40 agricultural feeders have already transitioned from grid power to solar power under SKY. The technical design, financial model, and projected cash flows for farmers are shown below.*

*In the scheme, farmers must contribute 5% of the capital cost at the beginning. Thirty percent of the capital cost will be covered by an MNRE subsidy while the remaining 65% will be financed through a loan that the Government of Gujarat will take on behalf of farmers. SKY farmers will receive a feed-in-tariff of INR 3.50 / kWh of solar energy evacuated to the grid. In addition, they will also get an* INR *3.50 / kWh 'Evacuation Based Incentive' (EBI) that will go towards repaying the 65% loan in the first seven years of the scheme. During the first seven years, a farmer using a 10 HP SIP will make an estimated INR 26,000 per year. Once the loan is repaid fully, farmers are expected to* *earn INR 48,000 per year. Of course, the actual earnings of each farmer will vary depending on the size of their pump and actual consumption and evacuation.*

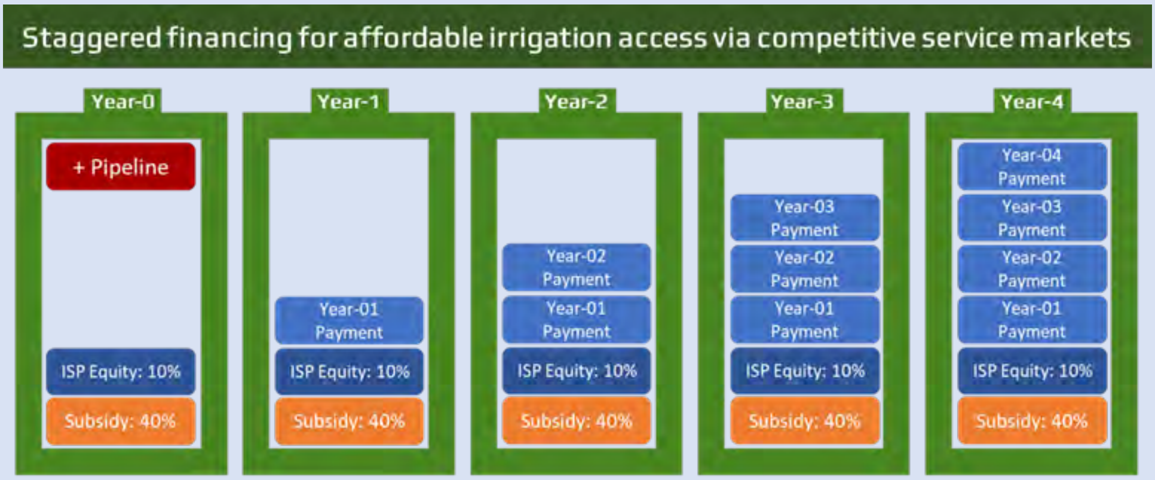


## Box 3: Catalyzing 'Buyer-Friendly' Solar Irrigation Service Markets

*In eastern India's fertile Gangetic plains that stretch across India, Nepal and Bangladesh, many farmers have limited or no access to farm electricity. This is largely due to poor rural electricity infrastructure and, as a result, farmers are forced to use expensive diesel to run their irrigation pumps. Despite being situated on top of one of the world's best aquifer systems and having shallow groundwater table, farmers tend to economize on irrigation and practice deficit irrigation. This situation, to a large extent, explains the low productivity of agriculture in the region and the resultant rural poverty and massive scale of distress migration from the region. If promoted smartly in this region, solar irrigation can catalyse rapid agrarian growth and lift millions of smallholder farmers out of poverty by turning monopolistic diesel-pump based irrigation service markets into highly competitive and equitable solar irrigation service markets that are friendly to water-buyers.*

*In Chakhaji village of Samastipur district in Bihar, IWMI, CCAFS and AKRSP-I (Aga Khan Rural Support Program, India) have supported seven solar irrigation entrepreneurs to install 5 kWp SIPs along with a network of buried water distribution pipes. The financial model requires entrepreneurs to pay a fixed lease amount each year to take full ownership of the asset over a period of five years. This arrangement exerts pressure on the entrepreneurs to maximize returns from the asset by operating it throughout the year to sell irrigation services to farmers in the village. As it is, a shift from expensive diesel to SIPs significantly reduces the cost of irrigation. Furthermore, as the solar irrigation service market matures, the entrepreneurs compete for greater market share in the village irrigation economy by offering better irrigation services at the lowest possible cost. In Chakhaji's solar irrigation experiment, the average cost of irrigation has declined from INR 120 per bigha (1 bigha = 2,528 m$^2$ or roughly 0.25 ha) to INR 45 per bigha. After more than a year of full-scale operation, the village is*




*experiencing significant changes in cropping patterns. Area under summer cultivation – is expanding rapidly and the agricultural income has more than doubled.*

*The SIPs are financed through an innovative model (shown here) where the ISPs must make a small upfront contribution. This arrangement allows even small farmers to participate as S-ISPs. Each year, the S-ISPs must pay an annual lease amount, which also incentivises them to maximize their earnings from irrigation service sales. IWMI's hypothesis is that this will act as a catalyst for creating and sustaining a buyer-friendly competitive irrigation service market in the village, as opposed to a sellers' market that dominates under diesel irrigation.*

# 3. Next Steps

Following the regional consultation in Anand (Dec 2018) and the national consultation in Nepal (Feb 2019), IWMI is now gearing up for organizing similar consultations in Bangladesh and Pakistan. In Pakistan, the national consultation is planned for 29 April at the Marriot Hotel, Islamabad. The Minster of the Ministry of National Food Security and Research (MNFSR) has been invited as the Chief Guest. Participation is expected from:

- the Pakistan Council of Research in Water Resources (PCRWR)
- the Federal Water Management Cell (FWMC)
- Pakistan Agricultural Research Council (PARC)
- On Farm Water Management (OFWM), Punjab
- SDC
- World Bank
- Asian Development Bank (ADB)
- Alternative Energy Development Board (AEDB).

In Bangladesh, IWMI has firmed up a partnership with IDCOL (Infrastructure Development Company Limited) – the key stakeholder in solar irrigation promotion in the country. In early May 2019, a team of IWMI researchers will visit Bangladesh to meet IDCOL, learn about SIP schemes in Bangladesh, discuss with farmers their experience of using SIPs, and finalize the agenda for the national consultation, planned for June 2019. IWMI is also planning another consultation on solar irrigation in India, in partnership with the Indian Council for Agricultural Research (ICAR) and the International Solar Alliance (ISA). Besides discussing the SoLAR project, the consultation is also expected to help IWMI and SDC build a network of potential partners among ISA member countries.

The detailed proposal development is well underway, including discussions on the nature of and implementation protocol for, the 'Solar Irrigation Innovation Fund' portion of the SoLAR project. Early discussions among the SoLAR team have identified the following objectives and potential areas of innovation it can support.

**Solar Irrigation Innovation Fund – Objectives**

- Innovations in the adoption, use and upscaling of solar-powered irrigation in South Asia;
- The identified innovations will target a well-identified obstacle that prevents proper adoption, use and upscaling of solar irrigation in the region;
- Innovations targeted at reducing barriers for adoption by small, marginal and women farmers will be encouraged;
- All innovations must be cost effective and possible to scale up.

**Technical Innovations**

- Preventing theft and farmer malfeasance in SIP implementation
- Developing low-cost panels and frames with improved mobility and modularity
- Remote monitoring of SIP performance through cost-effective sensors and IoT
- Exploring alternate energy uses – both on-farm and off-farm
- Improving payment compliance by users
- Innovations in panel placement and installation geometry for peak performance and plant growth underneath solar panels

**Financial Innovations**

- Developing innovative financing models (including crowd funding) to facilitate adoption by small and marginal farmers and women farmers

- Developing SIP insurance and buy-back products
- Maximizing SIP operating factor and minimizing user cost
- Optimizing the trade-off between panel efficiency, durability and cost

**Institutional Innovations**

- Catalyzing self-sustaining groups of landless / marginal solar farmers
- Training a grassroots cadre of (women?) technicians for locally fabricating and servicing SIPs
- Testing alternate institutional models – cooperatives, FPOs, JLGs – for solar feeders
- Promoting SIPs to catalyse pro-poor irrigation service markets
- Testing centralized hardware-distributed ownership model for SIPs

At IWMI's Annual Research Meet in Colombo in May 2019, IWMI will organize side meetings and brainstorming sessions to discuss the SoLAR proposal and solicit input from several IWMI colleagues.

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