



COMPENDIUM ON SOLAR POWERED IRRIGATION SYSTEMS IN INDIA

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PREFACE

Solar power has been one of the main focus areas in the clean energy trajectory with massive potential for application in the agriculture sector, particularly in the irrigation space. Underpinning technology and government programs have made accessing renewable energy such as solar power, very much within the reach of the communities. Solar powered irrigation system (SPIS) has been gaining the necessary impetus from development professionals and government, due to its ability to curtail climate change while supporting the economic growth of the country.

With an increasing focus on solar energy use in agriculture, several pilots and models of solar irrigation systems have been rolled out in the country. In spite of this, the majority of the agricultural water needs are being met by electricity or diesel operated pumps. Scaling up solar irrigation mechanism has been a challenge even though Indian government is promoting them by offering heavy subsidies. Further, recent studies have shown that while some of the existing models are limiting greenhouse gas emission, some are leading to dwindling of groundwater. This rationale the need to comprehensively synthesize existing pilot initiatives, which will in-turn lead to the identification of efficient and effective models for sustainable development. It also highlights the necessity to evaluate different business and institutional models of solar irrigation system to understand factors supporting and hindering the adoption of various solar irrigation systems. With this vision of generating comprehensive knowledge on different functional solar powered smart irrigation models in India and their scalability, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), BISA-CIMMYT with support of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, India has studied and documented different models of solar pumps in collaboration with the International Water Management Institute (IWMI).

The main objectives to bring forth this compendium are: to document qualitatively various deployment models of solar powered irrigation systems and to understand the factors impacting scalability of solar powered irrigation systems in India. Detailed information about the process of installation of SPIS, their usage and maintenance was collected. The different approaches have been documented in the form of case studies developed through primary and secondary research. Total 16 case studies describing different solar irrigation deployment models that are either highly popular and represent a significant portion of the solar pumps used today or they show innovations that have the potential to reach scale are documented. The compendium documents one case for centralised SPIS, two distributed SPIS and thirteen examples for decentralised systems. We tried to capture the key technical, social, institutional and financial attributes of the deployment approaches in the cases to enable comparative analysis and synthesis. This compendium brings together a collection of experiences from various geographies and from different stakeholders. The contributions are not intended to be state-of-the-art academic articles but thought and discussion pieces of work in progress.

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Producing this compendium has been a collective endeavour, which has been actualised by the formal and informal inputs of many. This acknowledgement is an effort to recognise the efforts and inputs given by people in putting together the case studies from across India. Our first word of thanks goes to Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, New Delhi, India for providing financial support and intellectual contributions to this work. The editors would like to sincerely thank all the contributors of various chapters of the compendium and their institutions.

The editors would like to thank Pramod Aggarwal, Asia Program Leader- CCAFS, Tushar Shah, Researcher Fellow, IWMI India and Arun Joshi, BISA- CIMMYT. The team has greatly benefited from the scintillating discussions, inputs and comments from them. Appreciation for support is also extended to Baskar Reddy (Syngenta Foundation), Sachin V Kamble and Pritam Jangam, (NABARD), Santosh Dange, Manisha Mane (Government of Maharashtra), Karan Dangayach (Shashwat Green) and Nandish Kenia (NEERMAN) who have been instrumental in providing inputs and support through many stages of development of this compendium. We thank Shivendra Srivastava and Naveen Singh, ICAR-NIAP for reviewing draft version of the compendium and providing critical comments.

The team would also like to express humble gratitude towards all the farmers who participated in the present study. They deserve a special thanks for giving their time in interacting with the researcher and actively supporting the process of data collection.

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ACRONYM

AC	Alternating Current
AKRSP	Aga Khan Rural Support Program
AVS	Agri-voltaic system
BAIF	BAIF Development Research Foundation
BESCOM	Bangalore Electricity Supply Company Ltd
CAGR	Compound annual growth rate
CAZRI	Central Arid Zone Research Institute
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CGIAR	Consultative Group for International Agricultural Research
CGWB	Central Ground Water Board
CHC	Custom Hiring Centres
CIMMYT	International Maize and Wheat Improvement Center
CST	Climate Smart Technology
CSV	Climate-smart villages
DC	Direct Current
DISCOM	Distribution Companies
DSUUSM	Dhundi Saur Urja Utpadak Sahakari Mandali
FCs	Farmer Clubs
FiT	Feed-in-tariff
GBI	Generation Based Incentive
GHG	greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GRTNfW	Grassroot Trading Network for Women
GW	Giga-watt
GWD	Groundwater Development
HP	Horse-power
HVDS	high voltage injection system
IBF	Indicator Based Framework
ICAR	Indian Council of Agricultural Research
IFC	International Finance Corporation
INR	Indian Rupees
ISMs	Irrigation Service Markets
ITP	IWMI Tata Program
IWMI	International Water Management Institute
JNNSM	Jawaharlal Nehru National Solar Mission
KUSUM	Kishan Urja Suraksha Utthaan Mahaaabhiyan
kWh	kilowatt hour
kWp	kilowatt peak
LCOE	levelized cost of energy
LPH	litres per hour
LRK	Little Rann of Kutch

MEDA	Maharashtra Energy Development Agency
MGVCL	Madhya Gujarat Viji Company Limited
MIS	Minimum Income Standard
MNRE	Ministry of New and Renewable Energy
MSEDCL	Maharashtra State Electricity Distribution Company Ltd
MSPGCL	Maharashtra State Power Generation Corp. Ltd
MW	Mega-watt
NABARD	National Bank for Agriculture and Rural Development
NGOs	non-government organizations
NRDC	Natural Resources Defense Council
PBSS	Panch Bandhu Sichai Samiti
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana (Prime Minister Agriculture Irrigation Scheme)
PPP	Public-Private Partnership
PRADAN	Professional Assistance For Development Action
PEG	Prayas Energy Group – Need to correct this as PEG in case study
PV	Photo Voltaic
RESCO	Renewable Energy Service Company
RPCAUI	Dr. Rajendra Prasad Central Agricultural University
SEIF	Schneider Electric Indian Foundation
SEWA	Self Employed Women's Association
SFI	Syngenta Foundation India
SHGs	Self Help Groups
SISMs	Solar Irrigation Service Markets
SISP	solar irrigation service providers
SKY	Suryashakti Kisan Yojana
SMTs	Solar Movable Trolleys
SPaRC	Solar Power as Remunerative Crop
SPIS	Solar powered irrigation system
SPLIS	Solar Powered Lift Irrigation System
SWP	Solar Water Pumping
TAWs	Tufanganj Anvesha Welfare Society
TPR	Ten Percent Rule
TRIF	Transform Rural India Foundation
USAID	United States Agency for International Development
VASFA	VAishali Area Small Farmers Association
VCMC	Village Climate Management Committee
WUA	Water User Association
WUG	Water Users' Group



INTRODUCTION TO SOLAR IRRIGATION SYSTEMS

India is moving ahead and committed to green development in agriculture and its allied sectors. India's Nationally Determined Contribution (NDC) targets the promotion of clean energy with its largest renewable energy capacity expansion program. As a developing country, India has not made any 'solemn vow' to Conference of the Parties to reduce its agricultural greenhouse gas (GHG) emissions, yet its agricultural policies over the last few years strive to enhance the resilience of agriculture to climate-induced uncertainties. The country is putting heavy emphasis on solar power in India and has therefore launched an ambitious Solar Mission as a major initiative of the Government. With the steep decline in the prices of photovoltaic (PV) panels, it has become one of the most viable and cleanest energy sources available and realising into several applications in the agriculture sector. The Government of India and several state governments are vigorously promoting solar irrigation pumps by offering heavy capital subsidies. Besides, the Solar Mission also aims to replace diesel/electric pumps at different stages of implementation and promotion of solar energy use in energy deficit rural areas.

The vigorous promotion of Solar Powered Irrigation Systems (SPIS) by the Indian state via offering heavy capital subsidies indicates mainstreaming of irrigation as a viable option for solarization under Jawaharlal Nehru National Solar Mission (JNNSM), which earlier considered only solar power plants and roof-tops as dominant strategies for greening the energy mix. The Government of India's Pradhan Mantri Krishi Sinchayee Yojana (PMKSY – Prime Minister Agriculture Irrigation Scheme) initiative has the vision of expanding the area under irrigation and at the same time improving the water (resources) use efficiency. The objectives set forward by PMKSY are also aligned to many activities in the National Mission for Sustainable Agriculture (NMSA) for climate change adaptation and can be achieved effectively through solarization of agriculture and irrigation. Taking the initiative of further 'greening' the agriculture sector of India, the Ministry of New and Renewable Energy formulated a scheme 'Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM)' to promote solarisation of irrigation.

About 89 percent of the total groundwater use, 221.46 BCM (CGWB 2017), is pumped annually by existing 20.5 million irrigation pumps (Rajan & Verma 2017) having a cumulative installed capacity of around 102 GW. Even without adding new irrigation pumps, this represents the current potential of solarising irrigation in agriculture. But unlike solar power plants and solar rooftops, which are the conventional ways of adding solar PV capacity, deployment of solar PV (centralized or decentralised) dedicatedly for irrigation is relatively a new and a contextualized solution for India given its agrarian economy and the associated political economy of farm power supply. Solar PV technology offers liberty to professionals to select different degrees of decentralisation of power generation and distribution as per their requirements. This enables the emergence of different technical designs of SPISs and also socio-institutional models for promoting its adoption. As the technology became more affordable and ubiquitous, multiple donors, NGOs, multilateral agencies experimented with different designs of SPIS and their promotion strategies across the country. With different contexts, objectives and intervention design, these experiments and pilots seem to be tailor-made for addressing specific localized problems.

However different these experiments may seem; common cords are connecting these experiments. Also, all these experiments and interventions are aimed towards the common goal of achieving climate-resilient and sustainable future for energy-water use for irrigation. But the approach to achieve that future is different in different experiments and pilots. This compendium is an attempt to understand and appreciate these different approaches, identify the reasons behind the differences and assess these approaches using the lens of scalability.

In order to understand the factors impacting the scalability of solar powered irrigation systems (SPIS) in India, we gathered detailed information about the process of installation of SPIS, their usage and maintenance. The different approaches have been documented in the form of case studies developed through primary and/or secondary research. Primary research entailed field visits to: a) understand the deployment model; b) interview the promoters, practitioners and beneficiaries; and c) collect data for generating evidence for claimed impacts. Secondary research entailed a detailed review of literature and data from published sources. The case studies are followed by their comparative synthesis.

SELECTION OF CASES

The 16 case studies describing different solar irrigation deployment models represent the models that are either highly popular and represent a significant portion of the solar pumps used today or they show innovations that have the potential to reach scale. Also, hydrogeology and agro-ecology of the production system have been considered while selecting the cases for documentation. Authors have tried to capture the key technical, social, institutional and financial attributes of the deployment approaches in the cases to enable comparative analysis at the end.

CLASSIFICATION OF SPISS DEPLOYMENT APPROACHES

The compendium covers 16 distinct cases describing different technical, financial and institutional attributes constituting a deployment model, which aimed at solving either a contextual problem or demonstrating a model for a larger policy change. These attributes are like the building blocks of the models and they impart features resulting in desirable or undesirable impacts and hence contribute to the significant characteristics of the interventions.

This section presents a classification of these key attributes used to discuss their significance and potential impacts.

1. TECHNICAL CLASSIFICATION

SPIS is considered primarily as a technology change in the irrigation and agriculture sector. In fact, it is only the energy system, and not a mechanical system, of the irrigation system which changes, and hence the classification is driven by the typology of energy systems.

Any energy system can be classified as a centralized or a decentralised system depending on the generation and consumption of the energy. In centralized systems, energy is generated at a central location, then is transported and thereafter distributed to different loads for consumption through the grid network. In a decentralised system, energy is generated at the load centre itself and there is no sophisticated grid network presented. Mostly centralized systems are power plants and decentralised systems are small energy generators. However, with the advent of affordable renewable energy production, a third type of energy system i.e. distributed energy systems have emerged. These systems are connected to the grid transporting electricity from centralized power plants to loads but are (usually) small scale energy generators near to loads. The main difference between distributed and decentralised system is that the latter is not connected to the grid.

The technical classification of SPISSs follows this conventional classification of energy systems broadly into three types: (i) centralized; (ii) distributed; and (iii) decentralised. Centralized systems entail MW scale power plants dedicated to the electricity supply for agriculture, distributed systems entail grid-connected solar pumps; and decentralised systems entail off-grid solar irrigation systems (figure 1).

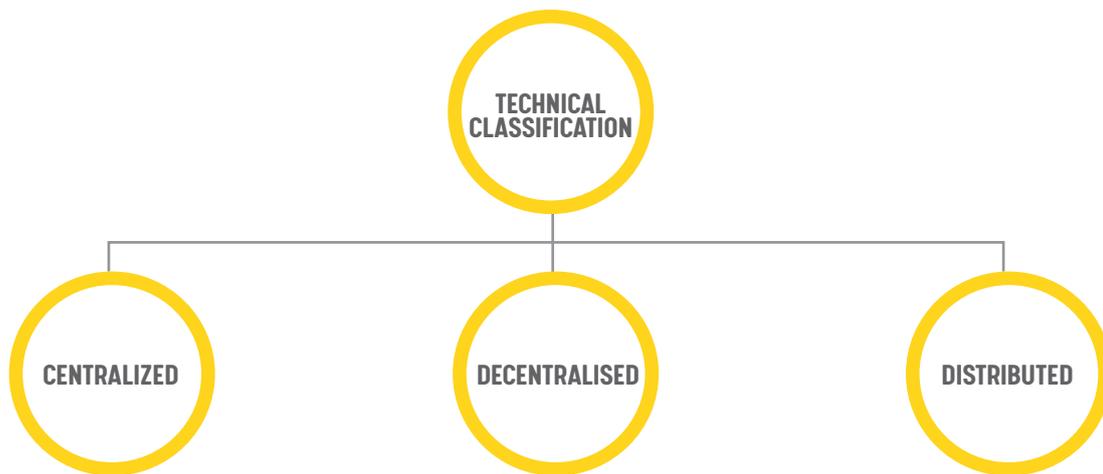


Figure 1 Solar pump technical classification

The three types of systems co-exist and have different pros and cons. In this compendium we have one case for centralised SPIS (Feeder level Solar Power Plants in Maharashtra), two for distributed (SPaRC Pilot in Dhundi, Gujarat and Surya Raitha Pilot in Karnataka) and thirteen examples for decentralised systems. Three miscellaneous cases showcasing innovation of using solar power in agriculture have also been included in the compendium. These three cases showcase three distinct innovations of solar power utilization in agriculture: (i) an innovative community led solar powered lift irrigation, (ii) an innovative solar tree structure and (iii) an agri-voltaic system for cultivating crop, harvesting solar energy and rainfall.

2. FINANCIAL CLASSIFICATION

The instruments to finance SPISs are subsidy, debt and equity. The subsidy is a constant given the high capital cost in the distributed or decentralised system or uncoverable operational cost in the case of centralized SPISs. However, the contribution of the subsidy varies from 30 to 100 percent across the cases. The other constant is the equity contribution. However low, if the ownership is defined, then there is some equity contribution from the users/owners of the SPISs. This leaves us with the differentiating component between the models and that is access to credit (figure 2).



Figure 2 Solar pump financial classification

Centralized systems, usually developer-driven, have easier access to credit compared to the decentralised and distributed system. However, different financial models have been developed by implementers to bridge the gap but still the component of subsidy needed is much higher if access to credit is not available. It is also observed that credit may be a necessary condition but is not a sufficient condition for a

model uptake by the community/farmers and value addition/increase in income generation by the SPIS plays a significant role for successful uptake.

3. INSTITUTIONAL CLASSIFICATION

The different SPISs are owned, managed and run either by individual farmers, farmer groups (formal or informal) or government/private agencies. Hence in all the cases covered in the compendium, the institutional model to pilot or execute the experiment is one of the three. However, in some cases, some overlaps occur, especially when the government/non-government agencies are facilitating agencies for the promotion of farmer groups to own and run SPISs. Therefore, the institutional model evolves from one type to the other across the different phases of the model i.e. ideation to implementation to uptake. But for simplification, the three broad institutional models can be seen across the cases (figure 3).



Figure 3 Solar pump institutional classification

SCALABILITY OF A MODEL

From ideation to achievement of a sustainable scale, there can be many stages in the process; however, there are following five key stages (figure 4) which are core to the scaling-up process:

- 1. Ideation** Identifying the problem and generating a workable solution from a pool of existing/new solutions.
- 2. Proof of Concept/ Piloting** The solution identified in the ideation phase is developed and executed in a controlled environment with adequate support to assess its potential outcomes and limitations..
- 3. Transition to Scale** The solution, if successful in the pilot phase is developed further for the scale, using the experience and identified limitations in the piloting phase to maximize impact.
- 4. Scaling** The solution is scaled up by infusing different types of capabilities and resources. Also, given the expected results and associated externalities, a target scale to be achieved is planned.
- 5. Sustainable Scale** As the scale is achieved, multiple unexpected outcomes also accompany the expected outcomes. These unexpected outcomes help modify the estimates of the scale which can be achieved without threatening the sustainability of the system. Efficient maintenance and effective trouble-shooting are the key attributes for sustaining this stage.

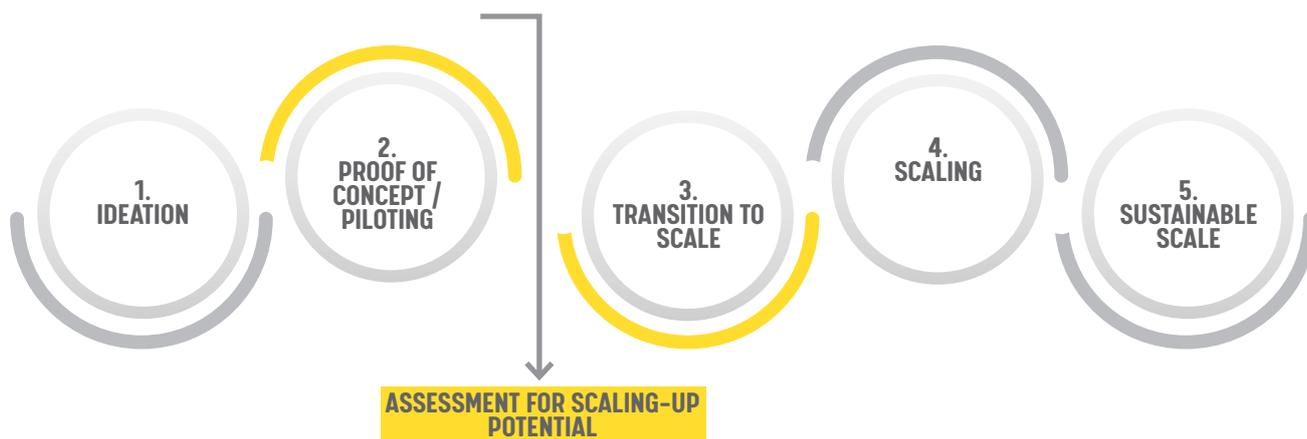


Figure 4 Stages in the scaling-up process

For making to stage 3 from stage 2, the piloted models need to be assessed in terms of potential for scale-up. While some models are designed exclusively to address a very specific problem in a particular context, others are primarily designed as a proof-of-concept for wider applicability and policy implications – with or without suitable modifications at the time of scaling. In this compendium, both types of cases, contextual and with defined policy change objectives, are included. Both types of cases are assessed for understanding their relevance and potential contribution, they can make in advancing the goal of solarising irrigation and agriculture in a sustainable yet effective way.

All the cases have different technical, financial, and institutional aspects which are complementing each other and are in line with the larger objective of the intervention. Therefore, the current classification of cases is based on the unique feature demonstrated by the model and not on any of their fundamental aspects.

Table 1 Salient features of different models of solar powered irrigation systems

Experiment	Location	Technical			Finance					
		Energy System (kWp)	Pumping Capacity (HP)	Technical Classification	Subsidy (%) Donor (D) Government (G)	Equity (%)	Credit (%)	Ownership	Management	Use
Case 1: Portable SPIs in Women Groups	Madhya Pradesh	1	1	De-centralised	80(D)	20	-	FG	FG	Self+Others
Case 2: Solar Boat	Bihar	2	2	De-centralised	100(G)	0	0	A	A	Self+Others
Case 3: Portable Solar Trolley	Bihar	2	2	De-centralised	30 (G)	70	-	A	A	Self
Case 4: Micro Solar Water Pumps	Bihar	0.1, 0.5	0.1, 0.5	De-centralised	100 (D)	-	-	A	A	Self
Case 5: Off Grid SPIs	India	2, 7.5		De-centralised	90-85 (G)	10-15	-	I	I	Self
Case 6: Off Grid SWP for Pisciculture	Bihar	2		De-centralised	90(G)	10	-	I	I	

Experiment	Location	Technical			Finance					
		Energy System (kWp)	Pumping Capacity (HP)	Technical Classification	Subsidy (%) Donor (D) Government (G)	Equity (%)	Credit (%)	Ownership	Management	Use
Case 7: Off Grid SPIs - Maximising energy use	West Bengal			De-centralised	90-95 (D)	5		I	I	Self
Case 8: Salt Pan SWPs	Gujarat	1	1	De-centralised	95 (D)	-	5	I	I	Self
Case 9: Tail-end Solar Feeder Plants	Maharashtra	2000		Centralised	-	-	-	A	A	Others
Case 10: Surya Raitha Experiment	Karnataka	7.2, 10.8	5, 7.5	Distributed	100 (G)	-	-	I+A	A	Self
Case 11: SPaRC initiative	Gujarat	8, 11.25	5,7.5	Distributed	90-75 (D)	10- 25	-	I+FG	I+FG	Self+Others
Case 12: Nalanda Experiment- Minor Irrigation Dept.	Bihar	8	5	De-centralised	100 (G)	-	-	A	I	Others
Case 13: Solar Irrigation Service Provider Model in Chakhaji	Bihar	5	5	De-centralised	50 (D)	10	40	I	I	Self+Others
Case 14: Solar Lift irrigation Scheme	Jharkhand	5	5	De-centralised	60 (D)	40				Self+Others
Case 15: Solar Tree	Bihar			De-centralised	100 (G)	-	-	A	A	Self
Case 16: Agro-Voltaic System (AVS)	Rajasthan	105	-	Centralised	100 (G)	-	-	A	A	-

FG: Farmers Group, A: Agency/Agent, I: Individual

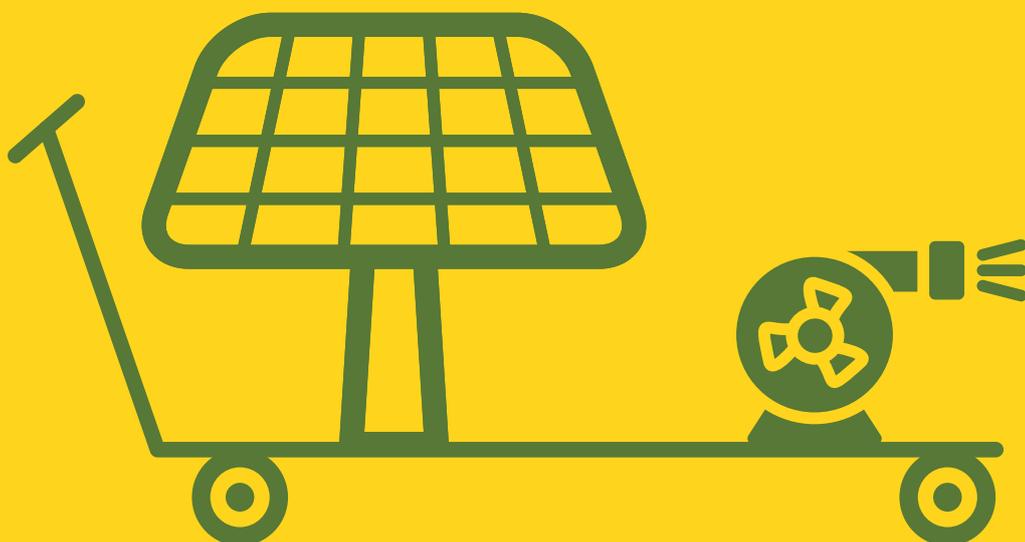
PORTABILITY IN SOLAR IRRIGATION PUMPS

Portability of assets improves its usability, accessibility and rentability. Therefore, portability has been a desirable feature in Solar Irrigation Pumps since the primary energy i.e. sunlight is universally present but the capability of converting it into a useful form, if it can be made mobile, would significantly improve the command area of the system. As the systems are becoming more efficient, more solar PV capacity is being packed in the lesser area which is good news for entrepreneurs and companies designing systems for improved portability. Improving the portability adds to the cost as solar PV is still a bulky technology, needing an area of close to 6 m² per kWp of generation capacity. Hence, important considerations while evaluating the economic viability of a portable solar irrigation pump design are: if the model is meant to provide protective irrigation, therefore making irrigation more accessible for the poor or marginal or, whether it is meant to improve the affordability of irrigation in the region, which already has access to irrigation. It is important to note that it is impossible to segregate accessibility from affordability and vice versa since both are correlated, however

for simplification of analysis, we have assumed affordability will follow accessibility. The other important consideration for analyzing portability of irrigation service is assessing if porting (or supplying) electricity, water, or asset (SPIS) from one location to the other will be more efficient and effective in improving irrigation scenarios.

Four pilot cases of portable SPIS carried out at Betul (Madhya Pradesh), Pusa (Bihar) and two at Vaishali, Bihar have been documented in this section. The four cases have not been compared with each other because of their different economic and socio-institutional design but are only described to help the reader understand the context and usability.

The focus of introducing the portability feature has been to improve rentability and hence accessibility (also affordability) of the asset. But given the voluminous nature of the technology, the portability feature is either limiting the size or making the transport cost expensive if the movement is frequent.





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WOMEN SHGS RENTING OUT PORTABLE SPIS TO IMPROVE ACCESS TO IRRIGATION IN BETUL, MADHYA PRADESH

Nitya Chanana, CCAFS¹ | Kunal Pandey, CCAFS²
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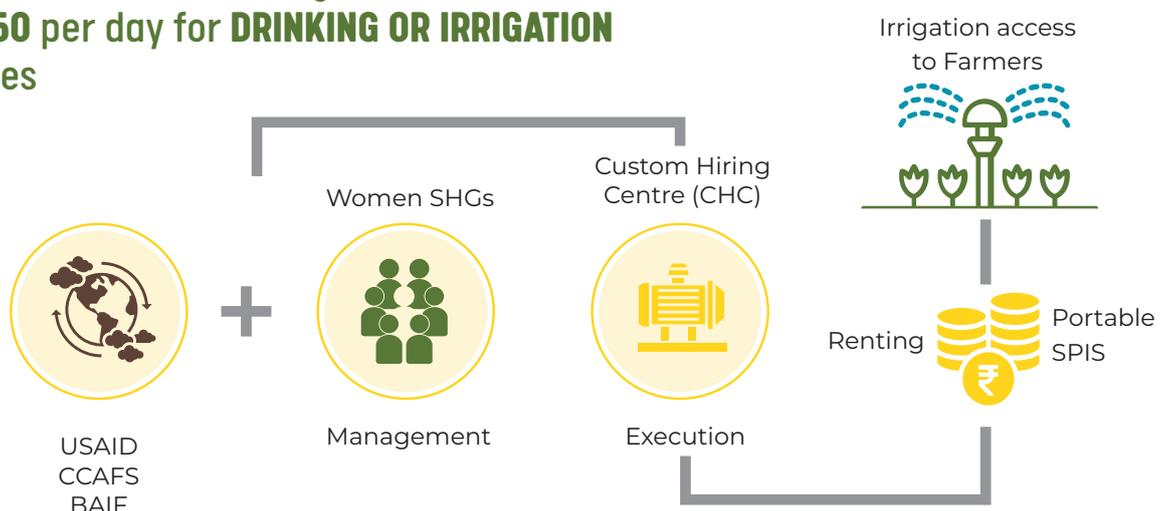
INTRODUCTION

Women Self Help Groups (SHGs) in Betul district of Madhya Pradesh are improving the access to clean, reliable and cheaper energy by renting out portable Solar Irrigation Pumps (SPIS). Largely dominated by the tribal community, the region has an abundance of groundwater resources but lacks affordable ways for accessing it because of the unavailability of grid electricity supply in undulated regions. Therefore, the model not only empowers the women groups controlling and managing the irrigation asset but also accelerates the adoption of climate-smart technology, extending cheaper, reliable and greener irrigation. The irrigation asset consists of 1 HP AC pump, ensembled into a movable system making it easily portable. These systems are owned and managed by a Custom Hiring Centre (CHC), which is managed by a women SHG with the support of the BAIF development research foundation. The group has been using portable SPIS for themselves and for renting out at the cost of INR 50 per day for drinking or irrigation purposes. The women SHG emerged as a service provider saving farmers from the vagaries of electricity supply and money guzzling diesel pumps.



Figure 1.1: Location of Betul district in Madhya Pradesh

The **GROUP** has been using portable SIP for themselves and for renting out at the cost of **INR 50 per day for DRINKING OR IRRIGATION purposes**



DESIGN OF THE INTERVENTION

BAIF development research foundation (a non-government organization) has been working in Betul region since 2006. They have been working on the thematic areas of enhancing capacities of women, promoting clean technology, supporting livelihood development by increasing food production, etc. BAIF along with CCAFS, with the financial support of USAID has been working on an initiative to promote a sustainable and comprehensive framework of technology transfer. CGIAR-CCAFS provides technical leadership and overall guidance to BAIF for implementing the project on the ground.

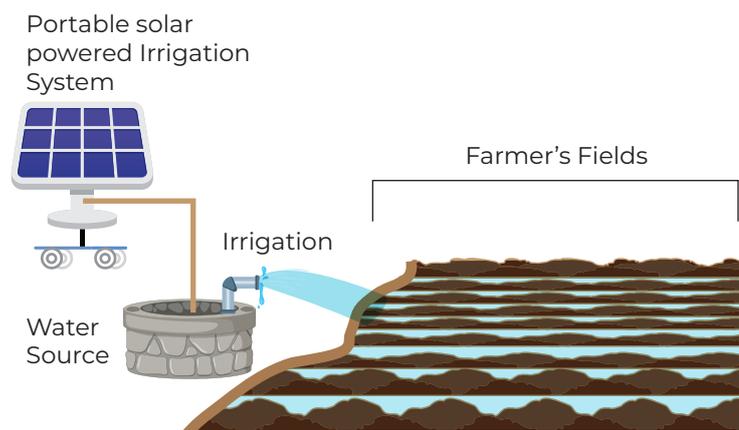


Figure 1.2: Design of the intervention at Betul, MP

As part of this initiative, they have established Custom Hiring Centres (CHC) managed by women self-help groups (SHGs) from the respective region. These CHCs house different farm equipment pertaining to various climate-smart technologies such as harvesting machines, solar pumps, tractors, etc. The initiative has been conceptualized with the vision of providing access to the latest climate-smart technologies to smallholder farmers with low investment capacity by renting out at affordable rates. In this project, five CHCs have been established in five villages i.e. Baretha, Kundi, Rampurmal, Chunagosavi and Silpati in the Betul district of Madhya Pradesh. The project team approached the community members to form a CHC in the year 2017 and the community came together to form a Village Climate Management Committee (VCMC). From this committee, 66 women came together to form five CHCs, responsible for renting out equipment, operation and management of the equipment, maintaining accounts and purchasing new equipment, etc.

The women members of VCMC are often members of a local self-help group, and thus are more aware and exposed to different government programs supporting the socio-economic development of farmers. Besides, being a part of the VCMC they are also exposed to climate-smart technologies. These women spread awareness amongst other community members and are catalysts of change in the adoption of new technologies by farmers. Currently, around 80 farmers benefit from four portable SPIS, available for rent in four CHCs. Given the smaller capacity of SPIS (1 HP), farmers are unable to tap the deep groundwater and can access only surface water from water bodies or groundwater from shallow wells for both drinking and irrigation purposes. This reduces the risk of groundwater exploitation.

In the absence of government subsidy for portable SPIS, the current intervention is fully funded by USAID to improve access to clean technology for small scale farmers in Betul. However, SHGs have contributed 20 percent to the capital cost of portable SPIS while the rest has been financed by the project. The portable SPIS were procured in 2018 and have been rented out at INR 50/day to farmers approaching CHCs. Based on the availability, portable SPIS are issued, upon payment of the rent in advance. Renting is being done on a trust basis and so far, no cases of theft, damage, or loss have been experienced due to comradery in the community. The average income for all the five groups during the Rabi season 2018-19 has been INR 2,000 for irrigation, and INR 1,800 for drinking purpose. The sum is adding to the corpus being built at CHCs saving account for acquiring new equipment. The SHG group had decided to save the amount for reinvestment instead of withdrawal/distribution for two to three years.

ECONOMICS OF THE MODEL

MODEL-SPECIFIC MERITS AND DEMERITS

MERITS

For Government

- Supports government in achieving the targets for the production of renewable energy;
- Augmenting government efforts to deliver cheaper and affordable electricity for irrigation for all, especially in regions, where grid expansion is challenging.

For Farmers

- Shared ownership and lower cost of the solar pump,
- An economically feasible option for providing irrigation to smallholders.

DEMERITS:

For Farmers

- Chances of damage to equipment are higher during transportation
- The smaller size of 1 HP ensures portability but limits the pumping capacity of the system resulting in lower water discharge per hour. This increases the time taken to irrigate farms and limits the usability.
- The irrigation rate of INR 50 translates into INR 10/kWh or more, which is comparable to diesel pumping but is way higher than grid electricity. Hence, some tribal farmers still prefer rainfed irrigation.

The present model showcased an interesting deployment approach which could increase the accessibility and affordability of irrigation to small scale farmers if promoted through lucrative incentive structure. However, in the absence of government support, the financial cost of the model is high, requiring an external agency to support the initiative. Despite significant support, the cost of irrigation is still not competitive with grid electricity-powered irrigation (considering a non-subsidized tariff of INR 5/kWh). The higher cost of irrigation is also not contributing to irrigation-market creation as some farmers still find rainfed farming to be economically more rational than irrigated farming. External financial dependency and the absence of any alternate financing mechanism impede scaling out this model until systematic government support is available. Thus, making the proposition less lucrative for farmers if the equipment is not rented regularly.

SCALABILITY OF THE MODEL

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BOATING BEYOND SAILING: SOLAR PUMP FITTED BOATS IN SAMASTIPUR, BIHAR

R C Srivastava, RPCAU¹ | S K Jain, RPCAU² | Ravish Chandra, RPCAU³

INTRODUCTION

Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Samastipur in Bihar, designed and piloted a boat-based solar pumping system comprising of a wooden boat fitted with a 2 hp pump (either AC or DC) powered by an 1800 watt solar photovoltaic array. The solar system powers the boat as well as the pump which can withdraw water at the rate of 5.75 lps (liters per second) or 20 m³/hr. Solar Pump mounted boat is designed to provide irrigation to small and marginal farmers using the riverbed land for farming. Since the land in riverbed farming is available for a few months in a year, the pumps and other equipment mounted on land, get flooded and are difficult to use. Therefore, the boat-mounted solar pump is providing a floating alternative to the conventional land-based pump apart from making it movable from one point to the other in the river/water body. The pump has been carefully caged to reduce the chances of theft as well as damage from the algal growth in the river. RPCAU, Pusa has developed eight such systems until now. Six of them are being used at the campus around the Burhi Gandak river, whereas two have been given to farmers for piloting in the Sitab diara region of Chapra town in the Saran district of Bihar. The current case is a contextual solution targeted at the niche segment of riverbed farming.



Figure 2.1: Location of Samastipur district in Bihar

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DESIGN OF THE INTERVENTION

RPCAU designed and assembled eight pumpfitted boats, out of which two are currently given to two farmer groups for piloting

Farmer groups paid INR 50,000 as refundable security deposit to RPCAU for the solar pump fitted boat

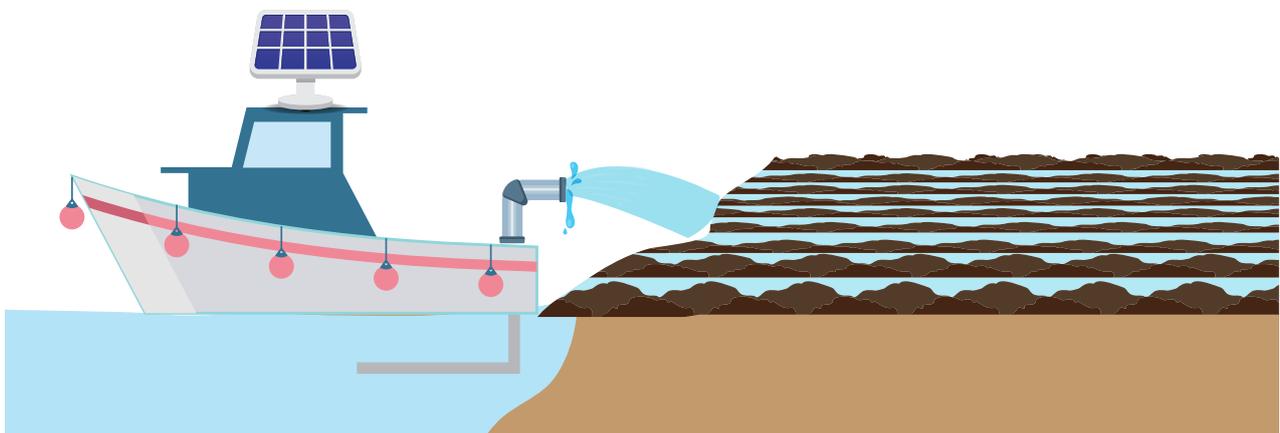


Figure 2.2: Design of the intervention

The irrigated command area can increase up to **10 ACRES** if this system is coupled with a sprinkler irrigation system.

This model was developed under a research initiative of Dr. Rajendra Prasad Central Agricultural University and was funded by the institution. The system was designed and assembled in 2017, sourcing different components such as the boat (INR 200,000), pump, solar panels (INR 300,000), and other components. Six out of eight systems are currently being used by the institution to irrigate diara land within the campus, in which seed and fodder production is done. The other two systems after being tested for about 1.5 years, were given to two groups of farmers in Chapra, with five farmers each, in lieu of INR 50,000 deposit given by each farmer group as security charges. The extension department of Dr. Rajendra Prasad Central Agricultural University organized an exposure visit of farmers to the Dr. Rajendra Prasad Central Agricultural University campus to display the system and its utility in the riverbed region of the campus. They further convinced the farmers to participate in the pilot and pay the security deposit which was to be fully reimbursed upon return of the boat-mounted solar pump. The farmer agreed to participate considering that they would be able to increase their area under cultivation using this system. The system can irrigate a length of 100 meters along the river with a maximum command area of 6 acres considering the present cropping pattern. The irrigated command area can increase up to 10 acres if this system is coupled with a sprinkler irrigation system..

ECONOMICS OF THE MODEL

Dr. Rajendra Prasad Central Agricultural University with the mandate of researching for improving agricultural practices funded the ideation and installation of eight boat-based solar pumps with a total outlay of around forty lakhs. The boat has costed the institution around 2 lakhs while the 2HP solar pump along with the panels has costed around 2.5 lakhs in the year 2017. This translates into INR 2,50,000 per HP of the pump and considering 20-year life of the entire system and negligible maintenance cost, the cost of energy would be about INR 10/kWh, which is quite high compared to the conventional grid electricity. But since the system is meant to serve the areas inaccessible to the grid, the closest valid comparison could be a diesel pump. The lower capital cost and easy portability of diesel pumps make it look attractive in comparison to the expensive and bulky solar pump if the financial viability for an individual farmer (or even a group of farmers) is considered. The piloted option can only become interesting if the government provides subsidies to these portable pumps to farmers who practice farming on the riverbed where no grid expansion is possible. The government of India is planning to offer a 90 % subsidy for the installation of 30 million solar pumps under KUSUM Project by the year 2022. If this solar boat pumping system is considered under such a type of subsidy scheme by the government, it will be of great help to the underprivileged farmers of Diara area.

The group of five farmers is using the system to irrigate around 1.25 acre of their land and is also selling irrigation to other farmers at Rs 100/irrigation. Farmers acknowledge the increase in their income due to the increased area of cultivation and additional income by selling irrigation water. Despite the benefits, they were not keen on contributing even 25% of the total cost of installation of the system, which is around INR 100,000 for the system. The cost of the entire system substantially increases owing to the presence of a boat. As the current subsidy does not include such arrangement and is only extended to pumps fixed to land, the concept fails to attract farmers.

CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- Ease of portability of the system along the river or any water body
- Protects panels in case of overflow or flooding
- Environment Friendly: No pollution compared to diesel-operated pumps

DEMERITS:

- Portability is possible only in case there is a minimum depth of the water body/river
- Higher cost as compared to the regular solar pump, due to the additional cost of the boat

The concept of a renewable source of energy on a boat is promising but given its contextual underpinning, it is relevant with limited scalability due to its high costs only in specific areas, where riverbed farming is a common practice and is done at a substantial scale.

Given the current policy design of SIP promotion, where the SIPs-attached to land are only subsidized, these arrangements will find it difficult to occupy a space in the national agenda. Its scalability may get a boost if this gets subsidized under KUSUM. It is also important to mention that it has recently been selected to 3rd Cohort of Startup Agribusiness Incubation Program (SAIP) under RKVY-RAFTAAR by MANAGE-CIA. But the concept of the floating source of energy is promising and can be explored further. This may be possible given the increasing popularity of floating solar panels, which may give rise to floating SIPs.

SCALABILITY OF THE CONCEPT

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PORTABLE SOLAR IRRIGATION PUMPS

Sakshi Saini, CCAFS¹ | Sonal Adlakha, Claro Agro Solution Private Limited²

INTRODUCTION

With the vision of providing affordable solar powered irrigation, to farmers dwelling in the rural area, Claro Energy Private Limited has designed Solar Movable Trolleys (SMTs) comprising of solar panels mounted on the top of an e-rickshaw, connected to a 2 HP -DC surface pump having a discharge of up to 30,000 litres per hour (LPH)* at a rate of Rs 3 per 1000 litres (or Rs 120/hr). SMTs come with a provision of approximately 50 m of cable length for service provision. This length enables farmlands within 50 m radius from the movable system to be irrigated. Farmers can pay for energy as a service for pumping water from their water source instead of investing in individual SIPs using a map-based mobile app or by calling a toll-free number. Once the service is scheduled, an authorized person comes to the selected location and connects the system to the water source. Farmers need to pay the amount using the 'pay as you go' card before the service is extended, hence it is a prepaid system. This card can be charged by mobile money, cash deposit or directly through micro-finance institutions. The organization has also devised alternative payment mechanisms owing to the local needs as at times the farmers are more comfortable in paying on a per acre basis.

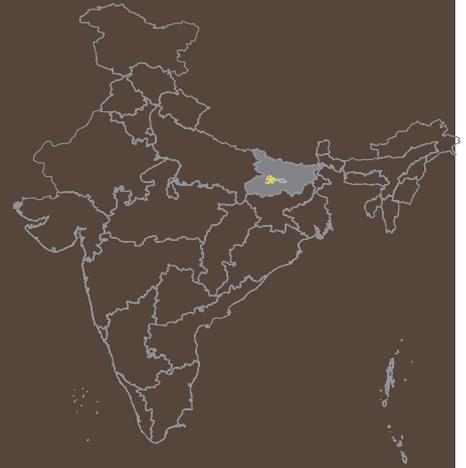


Figure 3.1: Location of Vaishali in Bihar

*The output of the solar pump is dependent on various factors including solar irradiation, water level in the bore/source of water, ambient temperature etc.

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DESIGN OF THE INTERVENTION

Claro Energy is employing three business models for promoting the pay-as-you-go model i) leasing out SMTs to community- organization or a custom hiring centre ii) hiring operators for SMTs, and iii) a commission-based model. In the first model, the SMTs are leased at annual rent of INR 45,000- 60,000. In the second model Claro Energy hires operators who transport the portable pumps from one place to another. The monthly salary of the operator is around INR 8,000 per month. In the third model, a community/individual works like an operator for Claro energy and charges a commission of Rs 0.5/m³ of water sold. In case the transaction model is based on payment per acre then the commission is decided accordingly.

In Bihar, the Custom Hiring Centre (CHC) managed by the civil society- Vaishali Area Small Farmers Association (VASFA) has rented the solar irrigation system at the cost of INR 45,000- 60,000 per annum. They further rent out this system to farmers on a pay per usage basis. While, in another deployment approach being implemented with the support of another civil society- Jan Nirman Kendra the system is being managed by the operators hired by Claro. Jan Nirman Kendra is playing the role of a facilitator under the memorandum of understanding (MOU) between farmers and Claro energy. Their responsibility is to transport the system from one place to another and set it up, to provide irrigation to the farm.

Although, at site it was observed that the requirement was further deep inside farmlands (beyond the 50 m radius of SMT) and movement of a trolley inside farms is not practically possible. Farmer's lands are small

parcels adjacent to each other without any access roads in between. A typical google imagery of farmlands is shown below. This resulted in further engineering a solution so that farmers whose land fall in the highlighted areas (away from the accessible region) can be served.

After taking a cognizance of the above requirement and the potential of access to nearly five to six times additional farmlands the company has improvised and come up with an altogether different solution using flexible panels which are mounted on a lightweight waterproof PVC material. This arrangement brings the following benefits:

- Makes assembly light weight
- Can be easily carried manually or kept on a hand held trolley or on a bicycle
- SMT be used to store two to three new systems in the storage space till the access road and the system can be manually taken to internal farmlands manually
- Nearness to access road no longer remains a constraint
- The total cost of the system gets reduced due to removal of the e-vehicle

The initiative is led by Claro Energy, with no subsidy support being used (to date, the government is not providing subsidy for portable pumps). Claro energy has been piloting this system, with the support of grass root level organisations or locals (who are hired as a operators of the portable solar irrigation system, by the organization).

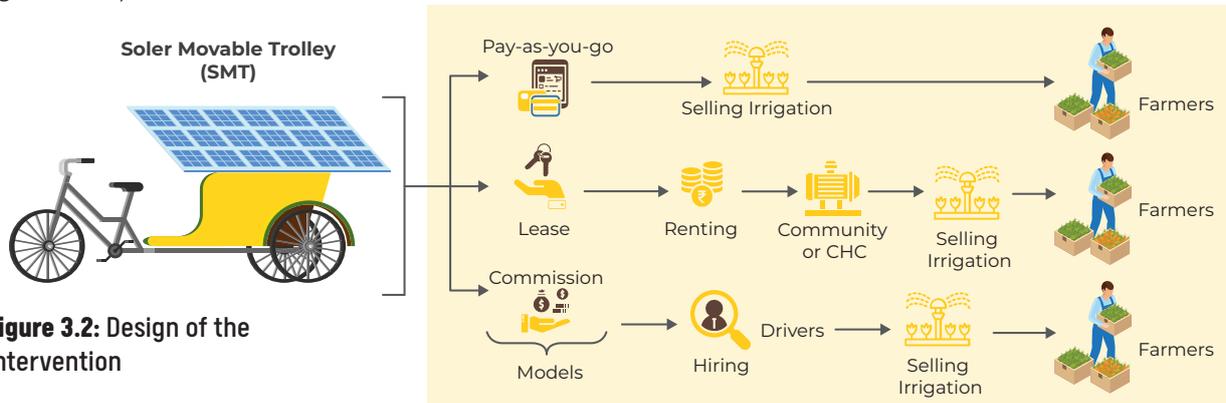


Figure 3.2: Design of the intervention

ECONOMICS OF THE MODEL

The three models adopted by Claro Energy to promote the pay-as-you-go model differ in their operation. The economics of the system will be attractive only if the system is utilized close to their full potential. Also, portability is expected to increase the utilization of the asset by allowing the system to be used by several farmers thereby increasing the command area. Though, the additional transportation cost and effort involved in accessing the system defers the economic viability of the system, further limiting the command area of the SPIs. Essentially, the parameter which will make the business model in all the three models is the number of hours of irrigation sold. To pay an annual rent of Rs 45,000 and considering a cost of Rs 20/hr as fuel cost for moving trolley, a farmer (or CHC) will have to sell 450 hrs of irrigation every year, though using an e-vehicle would significantly reduce the operation cost of the SMT, further reducing the irrigation cost for farmers. This translates to 4.5 hr every day, considering 100 days of operation, and under improvised marketing and awareness conditions the usage can even go upto 190-205 days.. This is the minimum operation needed to breakeven. But the average no. of hours irrigation is sold is only about 120 hr and hence not economically viable to pay the annual rent. In the other two models, Claro Energy owns and operates the system but either hires operators for direct operation or keeps agents on the commission basis

CONCEPT SPECIFIC MERITS AND DEMERITS

As reported by the CHC, a very small fraction of farmers is renting this system for irrigation services. Reasons reported for the same are cheaper electricity available, problematic transportation of SMT, the inability to reach a water source away from the main road etc. Thus, the revenue generated is much lesser than the rental cost of the system. This is a major impediment in keeping CHCs interested in renting the system from Claro energy. Drivers also shared their concerns regarding high wear and tear of the system and delayed repair response. This renders the system dysfunctional for many days further impacting their income.

Also, if the groundwater depth changes drastically from one location to the other, it might limit the usability as it may take more time to draw the same amount of water. But with the groundwater remaining comparable in North Bihar, this problem does not arise.

MERITS

- Paying per usage reduces the financial burden of owning a solar irrigation system.
- Portability of the system allows usage of one system by many farmers
- As the system is not installed on the farmers' field, it saves on space usage.

DEMERITS:

- Panels cannot be expanded on roads or pathways, as it blocks the passage for passersby. It needs to be placed in the field to be able to have enough space for the expansion of panels.
- Transportation of the system especially on kutchra roads or farms has been a challenge for the drivers. Cases of the toppling of carts were also reported.
- Portability makes the system extremely vulnerable to wear and tear, thus significantly increasing the maintenance cost of the system.
- Varied Water Discharge in case of changing groundwater depths

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SCALABILITY OF THE MODEL

The present model showcased three different ways of promoting the pay-as-you go model, which essentially targets at improving the affordability of irrigation by allowing the resource-poor farmer to rent irrigation services. The portability feature improves the accessibility of the system. But the low usage indicates the lack of enthusiasm from the irrigation buyers. This can be because of the higher cost of irrigation service because the model is non-subsidized. Given that Claro Energy has done the cost-plus pricing of irrigation to recover the capital investment made by them, the cost of irrigation service is significantly higher (Rs 60/kWh!!). This is not competitive even with diesel pump sets, which have a low upfront cost but high running cost (and very high portability).

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Acknowledgement: **Claro Agro Solution Private Limited**

MICRO SOLAR WATER PUMPS FOR AGRICULTURE USE: A CASE STUDY OF VAISHALI, BIHAR

Nikhil Goveas, KOAN Advisory Group¹ | Diego Senoner GIZ GmbH²

INTRODUCTION

Bihar's agrarian population is dominated by small and marginal farmers. Only 7.5% of Bihar's farmers operate land above two hectares, while over 92.5% of farmers can be characterised as small and marginal. A key challenge facing farmers in the region is assured energy access for pumping solution. To test sustainable alternatives, a pilot exercise was conducted to test the potential application of micro solar water pumps in Bihar's Vaishali district with a group of 12 small/ marginal farmers. All farmers in the study have diversified their agricultural production activities to include dairy, goat rearing and other small businesses. Before the pilot, all farmers were reliant on diesel/kerosene-based water pumps or on water markets for the irrigation. Farmers were given two types of portable micro solar water pumps (0.1 hp and 0.5 hp) to be used for irrigation on a rotational basis over the course of the pilot. During the experiments, information was collected through physical verification of micro solar water pumps in operation and through a perception study of farmers to map out the experiences of operating and comparative functioning of the two types of micro solar water pumps. Through the data collection exercise, several key data points were captured, including – user experience, water discharge of the pumps, satisfaction levels, and cost sensitivity and probability of farmers to adopt micro SWP solutions through loans, subsidies and external financing. Additionally, information on ground level challenges faced during usage of micro SWPs, capability gaps of the technology and users, local ecosystem for repairs and spare parts, portability of machinery, safety, user friendliness, etc. was also collected through the surveys.



Figure 4.1: Location of Samastipur district in Bihar

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DESIGN OF THE INTERVENTION

A group of 12 marginal farmers were selected to administer the pilot. The identification of the farmers was based on the following criteria: a) marginal and small farmers who own/ operate less than one hectare of land, b) farmers who have access to borewells and surface water and are currently reliant on diesel/kerosene-based water pumps and c) farmers who do not currently own diesel/kerosene-based water pumps and who lease pumps for irrigation. A baseline survey of the group was undertaken to assess existing cropping patterns and irrigation demands and practices. Six portable micro solar water pumps were used for the pilot with farmers using both capacity pumps for a period of one week each. Farmers were assisted in setting up the solar photovoltaic panels and the micro pumps and provided with on-ground training on operating and maintaining the pumps by the team at Koan Advisory.

ECONOMICS OF THE MODEL

All farmers in the group owned a diesel/ kerosene pump and shared it with other farmers of their household as per their needs. Price of kerosene averaged INR 60 per litre and expenses incurred by farmers on repair and maintenance of kerosene pumps averaged INR 880 per year. Farmers reported that expenditure on kerosene for irrigation of rice crop was 1.4 times the cost of other inputs taken as a whole, and for wheat, tobacco and maize, kerosene costs constitute almost 50 percent of total production costs.

In comparison to the high costs of fossil fuel powered irrigation, farmers who have switched to solar pumping solutions, particularly the 0.5 Hp pumps, are experiencing significant energy savings. Of the twelve farmers in the group, six farmers have completely switched over to solar pumping and are saving 100% of their erstwhile energy costs. Two farmers in the group practice energy stacking, using both the solar pumps and kerosene pumps, and are saving approximately 60% of their energy costs compared to the previous year. Four farmers in the group, have discontinued using the solar pumps since they found the discharge levels to be low and would prefer using a higher capacity solar pump. With the support and guidance of the team at Koan Advisory, farmers in the group want to diversify their crop selection from food crops towards horticulture products, medicinal herbs and spices.

With the increased energy savings, farmers have been able to purchase better quality seeds, inputs and even pay back outstanding debts. However, farmers have expressed two concerns with regards to adopting solar solutions for irrigation. First, farmers would prefer fixed solar PV panels to avoid transportation hurdles and to prevent theft. However, farmers also require mobile pumps that can help them irrigate multiple plots. Second, farmers reported not being able to understand the internal dynamics of the pump and felt unsure as to how to fix the pumps. Currently, there are no local local repair and maintenance shops that can fix solar pumps in case of any damage or repairs.

Water discharge from the 0.1 Hp pump averaged 225 litres per hour (LPH) and when used for the entire day (average of eight hours) pumped approximately 1800 litres. All farmers felt that despite its ease of use, the poor discharge levels of the 0.1 Hp submersible SWP and the extent of time taken to irrigate even small plots with lower water requirement rendered the pumps ill-suited for their irrigation needs.

The 0.5 hp system was difficult to manoeuvre, especially the SPV panels, and required a minimum of two people to transport and install the pumps. Water discharge from the 0.5 Hp pumps averaged 1800 litres per hour and when used for the entire day (average of eight hours during the test period in February 2019), pumped approximately 14,400 litres per day. Farmers reported that it took them more than three days to irrigate a plot measuring one bigha (2500 m²) for their wheat, tobacco, mustard, and potato crops, whereas the green peas crop could be irrigated in a single day. In comparison, farmers could irrigate a full bigha of wheat, mustard, tobacco or potato using a kerosene powered pump in 8-10 hours. In 2020 tests began on an innovative and affordable 0.3 hp pump with a tested discharge of over 25,000 litres per day at a 10m water head. The increased affordability and performance over the tested 0.5 hp pump combined with a higher portability shows high potential but further tests need to be conducted for a final verdict.

CONCEPT SPECIFIC OPPORTUNITIES AND CHALLENGES

MERITS

- The pumps are portable, comparatively affordable and showed potential to meet irrigation requirements for vegetable and less water intensive crop cultivation.
- Pumps were easy to assemble, set-up and operate.
- SWP systems could be used in combination with kerosene powered pumps to reduce expenditure on kerosene.
- Once operational, solar pumps could operate for a longer time and required little supervision from farmers. This freed up their time to adjust the water pipes and dig channels to direct the flow of water.

DEMERITS:

- Expensive for small and marginal farmers because of high initial cost.
- Pumps did not provide good discharge for irrigating water intensive crops using flood irrigation methods.
- Irrigation operations took significantly more time to complete.
- If labour resources were hired by farmers for the longer period to complete irrigation, then labour expenses would increase.
- Solar panels would be easier to install and operate if they were permanently fixed on a stand. However, this increased the chance of theft and would require some type of anti-theft measures.

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SCALABILITY

Micro SWPs have the potential to provide sustainable irrigation solutions for only marginal and small farmers in regions with a relatively higher water table, poor grid connectivity and no irrigation or absolute reliance on diesel/kerosene powered irrigation. SWPs with a capacity below 14,000 litres per day will not be able to meet irrigation requirements of marginal and small farmers who need to grow at least one food crop (water intensive crops). For farmers who cultivate only vegetables (non-water intensive crops), pumps with a capacity below 14,000 litres per day could have utility if operated with a gravity drip system attached to a water tank. Micro SWPs with a capacity of over 14,000 litres per day display great promise even for marginal and small farmers who grow water-intensive crops. However, farmers' crop selection, depth to water level, and time constraints of farmers need to be factored in before identifying the capacity of the pump best suited to irrigation needs. Micro SWPs have lower water discharge and this is the most limiting factor to its scalability, hence, micro SWPs need to be deployed with efficient irrigation solutions to achieve optimum utilization and performance.

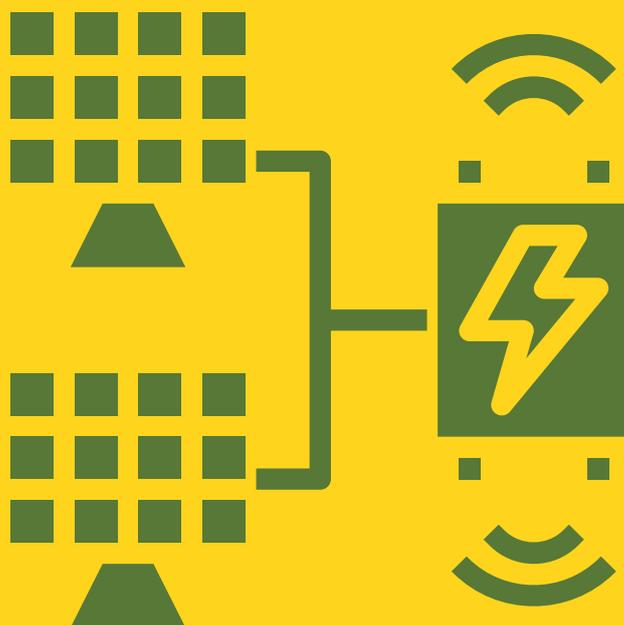
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Acknowledgement: **Koan Advisory Group**

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, India

OWNING ENERGY DECENTRALISED- INDIVIDUALLY OWNED SOLAR SYSTEMS

With reducing the cost of solar PV technology and increased focus on solar energy generation by the government of India, the decentralised solar-powered irrigation system (SPIS) grew at a compound annual growth rate (CAGR) of 64 percent in the last five years. Involving subsidies of the order of 50-90 percent, the majority of the SPIS have been installed (more than 99 percent) with the support of union and state governments. However, small in number civil society organizations and multilateral agencies demonstrated different operational and subsidy delivery models for promoting solarization of irrigation. Cases 5-8 cover models in which SPISs are promoted through individual ownership supported by higher capital subsidy support.





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DECENTRALISED SOLAR POWERED IRRIGATION SYSTEM

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INTRODUCTION

Solar PV technology coupled with current policies and programs is enabling farmers to install decentralised solar water pumps at individual levels. Having access to this technological boom saves them from spending money either on exorbitantly priced diesel or subjecting themselves to the erratic power supply. In the last 5 years, the state-wise distribution of SPIs has increased differently to different rates of SPIP deployment. Figure 5.2 shows total SPIP installations in India from 2014-15 to 2018-19. Table 5.1 presents the numbers of the SPIPs supported by the union government in different states as of 2019.

SPIP consists of multiple solar panels (or solar array) mounted on a structure, connected to a controller, which is then connected to an AC or DC motor pump for pumping water. The capacity of a solar array is in accordance with the capacity of the motor pump to be energized. In India, MNRE provides a 30 percent capital subsidy for availing any pump up to a size of 10 HP. This subsidy is topped up by state government subsidy of the order of 30-60 percent depending on the pump sizes. In principle, any SPIP up to 10 HP size is eligible for MNRE subsidy but most of the states do not support decentralised SPIPs of more than 5 HP size. Therefore, the majority of 2.37 lakhs SPIP installed are less than 5 HP in size (2, 3, 5 HP).



Figure 5.1: Location of SPI installations across India

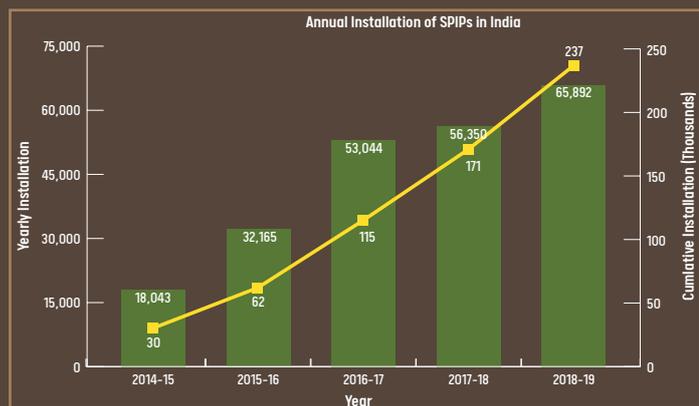
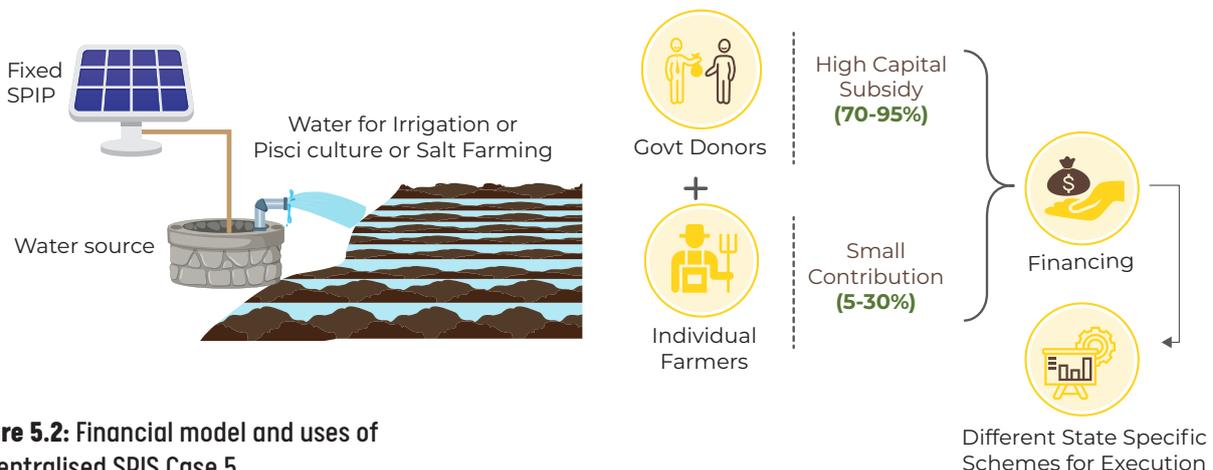


Figure 5.2: SPI Installation in India 2015-19 *Source [MNRE 2019]*



DESIGN OF THE INTERVENTION

The deployment of SPIPs is done by the state governments under state-specific policies guided by the MNRE policy and annual quota of SPIPs. Different states employ a different mechanism for selecting the beneficiaries and SPIP providers. But in the majority of the states,

decentralised SPIPs are availed by farmers via submitting an application to the district administrative office which is then sent to the state renewable energy development authority for processing. In some states like Rajasthan, promotion of SPIP is done by the horticulture department and is considered as an agriculture intervention coupled with micro-irrigation and other agri-tech interventions, in other states like in Gujarat it was considered as an electricity intervention and was spearheaded by the state power utilities. Depending on what a state considers the main department to handle SPIS promotion -agriculture, water or energy department , regulates the design of promotion of SPIS.

Table 5.1: Distribution of SPIS in different states and corresponding scheme in the state

State	Number	Scheme	Capital Subsidy
Chhattisgarh	61,970	Saur Sujala Yojana: 2-5 kWp decentralised SPISs	70-90%
Rajasthan	48175	2-10 kWp decentralised SPISs	70-87%
Andhra Pradesh	34045	2-5 kWp decentralised SPISs	70-90%
Uttar Pradesh	20465	2-5 kWp decentralised SPISs	70-90%
Gujarat	11522	3-10 kWp decentralised SPISs for farmers waiting for grid connections	95%
Orissa	9327	1-5 kWp decentralised SPISs	70-100%
Madhya Pradesh	17813	2-10 kWp decentralised SPISs	70-90%
Karnataka	6343	3- 5 kWp Decentralised SPISs	70-90%
Tamil Nadu	4984	2-10 kWp decentralised SPISs	70-90%
Jharkhand	3957	2-10 kWp decentralised SPISs	70-90%
Maharashtra	4315	Saur Krishivahini Yojana: 3-5 kWp Decentralised SPISs	80%
Bihar	2107	Bihar Saur Kranti Sinchai Yojana (BSKSY): 2-3 kWp Decentralised SPISs	90%
Punjab	3857	2-10 kWp decentralised SPISs	75%
Haryana	1293	2-10 kWp decentralised SPISs	90%
Rest of India	6,947	2-10 kWp decentralised SPISs	70-95%

A subsidy of 30% is being offered by the central government (MNRE) under the aegis of Jawaharlal Nehru National Solar Mission, which is further topped up by the share of state government (30-65 percent), further reducing the economic burden to farmers. The final amount to be paid by the farmers ranges from 5-10% (in some cases even less) to 40% based on the amount of subsidy offered by respective state governments. This amount can further be financed by banks as a loan if need be, with a relatively low-interest rate. But still, the bank loans are not hassle-free or easily available for SPISs, therefore, the majority of pumps are installed at higher capital subsidy mode only.

Once invested in SPIS, farmers are relieved from the recurrent expenditure on fuel for irrigation if SPIS can become the primary source of irrigation. But it has been observed that SPISs due to their size are not always able to replace diesel or electric pumps but can end up being a back-up or secondary pump only. Nevertheless, the zero-marginal cost of pumping and negligible maintenance costs result in savings in irrigation expenditure while providing reliable irrigation. Since farmers often pay only 5-10 percent of the capital cost, they are usually able to recover the cost in 1-2 years and sometimes even earlier if their asset utilization is high. For governments, it is attractive and economical to deploy SPIS where grid infrastructure has not expanded.

ECONOMICS OF THE MODEL

CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- SPIS offers a cheap reliable energy source for irrigation to farmers if they are off the grid.
- The zero marginal cost of pumping can be a boon for regions having abundant water resources but the scarcity of affordable electricity. Though, it poses the risk of overexploitation of water resources in water-scarce regions.

DEMERITS:

- The maintenance of decentralised systems is difficult, poor after-sale service by different agencies has been observed to pose a great challenge to farmers in sustaining the usage of SPISs.
- There is a threat of theft to SPISs especially solar panels, as they are installed in the fields.
- The cost of SPIS is still high compared to conventional grid electricity, therefore it is expensive for the government to promote decentralised SPIS in grid-connected regions.

SCALABILITY

The deployment of decentralised SPIS has by far been the most scaled-up intervention in the solarization of agriculture. This is largely because of the ease of policy implementation. Higher capital subsidy to make SPIS affordable to farmers reduces the number of systems that can be supported therefore the density of SPIS is not high at the village level. As fewer systems are allotted in each village, it usually goes to large or progressive farmers of the villages and ends up being the secondary pumps in their array of electric and diesel pumps with a much lower utilization rate (Durga et. al 2016). Also, lower density makes the maintenance of SPIS difficult and expensive which has resulted in a large chunk of dysfunctional SPISs over the years. Despite being an attractive model to scale up given its ease of implementation, better design of subsidies and interventions are needed to effectively leverage the opportunity solarization of irrigation provides, which is not just limited to the elites of the village but is accessed by the marginal agrarian communities also.

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SOLAR PUMPS POWERING PISCICULTURE IN BIHAR

Sakshi Saini, CCAFS¹

INTRODUCTION

Pisciculture thrives in the Singhia village of the Samastipur district- Bihar since the installation of SPISs. In this area, two fish ponds have been formed on a three-acre land. Groundwater is pumped in these ponds with the help of 3 solar and 1 electric pump. Each of the installed solar water pumps has a capacity of 2 HP (DC). The water being pumped from these solar water pumps is solely being used for fish farming.

The owner of these ponds is a journalist by profession who took this previously unutilized land on lease from a farmer and converted it into fish ponds. He has been able to avail government subsidy (of 75%) to install each of the solar pumps, without any third-party support. Fishes such as Golden, Rohu, Bhakti dwell and procreate in these ponds.



Figure 6.1: Location of Samastipur in Bihar

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DESIGN OF THE INTERVENTION

In 2017, two fish farms were developed on a three-acre land which was not being used for agriculture by the farmer who owned it. Thus, when approached to lease out this land at the cost of INR 63,000 per year, the farmer agreed with immense pleasure. At the same time, it was a profitable venture for the journalist, who had planned to develop fish farms on the leased land.

He got the area dug up and made two ponds out of a 3-acre area. With continuous water availability, water loss due to seepage or evaporation has not been the prime concern for the pond owner. Thus, no measure to reduce water seepage has been implemented. To prepare the site for ponds, trees, bushes, and rocks were removed from the area. Earth was excavated and has been used to construct dykes and a plodding slope. Thereafter, inlet and outlet points were constructed to allow fresh water to be poured into the pond and excess water to be drained, respectively.

Following the construction, the owner contacted a fisherman, who introduced different varieties of spawn (3 days old fish) into the pond. These spawns will then be reared for around 30 days to attain the desirable length. The fisherman also had an arrangement with the owner to do fishing and purchase the fishes.

ECONOMICS OF THE MODEL

Pisciculture has proved to be a very remunerative business model for the pond (cum SPIS owners) as well as the landowner. The ponds have been built on leased out land at a consolidated amount of INR 63,000 per year. This amount is the income of the farmer, who owned this land but was not using it for farming.

The three SPIS along with one electric pump are ensuring a continuous supply of water to the ponds, ensuring smooth and sustainable fish farming. The SPIS owner hires 8-10 fisherman for a day in a month (at the cost of INR 300 per day per person), to come and catch the fish from the pond. The fishermen catch and then buy these fishes from the owner and sell them on the market. The owner is paid based on the weight of each variety being caught from the pond. On an average INR 25,000-30,000 is earned by the owner, in each fishing cycle. Large scale fishing (catching of around 2 quintal fish) in the pond, is done around 6-7 times in a year, leading to an annual income of around 2,00,000 for the owner. Till date, fish farming has proved to be a lucrative offer for the owner of SPIS integrated pisciculture.

MERITS

- Less resource-intensive initiative as compared to farming with no requirement for pesticides, seeds, fertilizers, tractors, etc.
- The high utilization rate of SPIS is resulting in substantial economic gains.
- The land was fallow and put to use thru fish-farming; thus, it provides a feasible option for putting non-agricultural land to better use.

DEMERITS:

- Fishing being a water-intensive activity can be environmental benign only if done in water abundant regions. Also, the market should be near the production site otherwise storage and transportation costs will be exorbitantly high.
- High usage of medicine like antibiotics can contaminate the soil, rivers, and groundwater. This is sometimes practiced to keep the fishes alive while increasing the recommended number of fishes per cubic meter of water, or in cases of bad water cycling.

CONCEPT SPECIFIC MERITS AND DEMERITS

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SCALABILITY

Using a solar-powered irrigation system for fish farming has created quite a buzz in the area around. Farmers with a landholding of more than 1 acre seemed quite keen during field visits on practicing fish farming. Motivated by such initiatives around the area, 2 farmers in Haharo village of Vaishali district Bihar have got the solar-powered irrigation system installed in April 2017, with the support of a local NGO VASFA. They are now using this water for agriculture as well as fish farming. Firstly, the availability of fisherman and their willingness to purchase fish from the owners, secondly demand of fish in the nearby market due to the consumption of fish as a daily routine, and lastly, the availability of more than one acre of land per farmer has been the prime factors supporting the replication of fish farming using solar-powered irrigation systems.

In Bihar, the subsidy offered by the state government coupled with the subsidy from the central government accounts for a substantial 75% of the capital cost of a Solar Powered Irrigation Systems (SPIS). Even though a high subsidy is being offered to the farmers, accessing it has been a challenge in Bihar. In the present case, high level of education, as well as exposure of the pond owner, has significantly facilitated the process of getting a subsidized SPIS installed without any external help. Access to information has been one of the major enabling factors for this model to get actualized.

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MAXIMIZING USE OF SOLAR WATER PUMPING TECHNOLOGY IN WEST BENGAL

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| Nilanjan Ghose, GIZ GmbH³

INTRODUCTION

Electricity supply in West Bengal is erratic therefore farmers often rely on diesel-operated pumps. Thus, the field adoption of Solar Water Pumps (SWPs) in West Bengal is primarily driven by the comparative cost-effectiveness of the service delivery, which is further determined by the initial capital requirement and financing options for the purchase of SWP technology. Present case discusses a secondary intervention i.e. means and measures adopted to improve an existing intervention implemented at three locations: Mairadanga, Phersabari and Ghogarkuthi. The current intervention targets at improving the economic viability of SPIS by provisioning additional services using a localized holistic enterprise-driven model. The pilot integrates enterprise units using electric-powered machines with the SPISs. The machines /productive loads are customized to be operated using the electrical energy generated by the PV unit of the SPIS during non-pumping operation.



Figure 7.1: Location of solar water pumping technology installations in West Bengal

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DESIGN OF THE INTERVENTION

As a part of the pilot intervention, three existing and operational SPISs with a low utilization rate of less than 30 days per year were customized for productive load integration in West Bengal, India. The three SPISs were selected after a detailed business idea assessment, institutional capacity mapping and understanding the level of interest amongst farmers. The productive services were selected after a detailed market ecosystem research, technical feasibility assessment, stakeholder consultation, interventions risk assessment and economic viability assessment of the business ideas.

The energy utilization of the three SPISs was between 1% and 13% of the net energy generation potential before the intervention. Stitching machines, pulverize/animal fodder and water purification plants were added in the three respective SPISs at Mairadanga, Phersabari and Ghogarkuthi to improve energy utilization. The first and third sites have both AC and DC loads whereas the second site has only DC loads, which are always connected with the SPISs. Technical and financial support was extended to operationalize the respective activities.

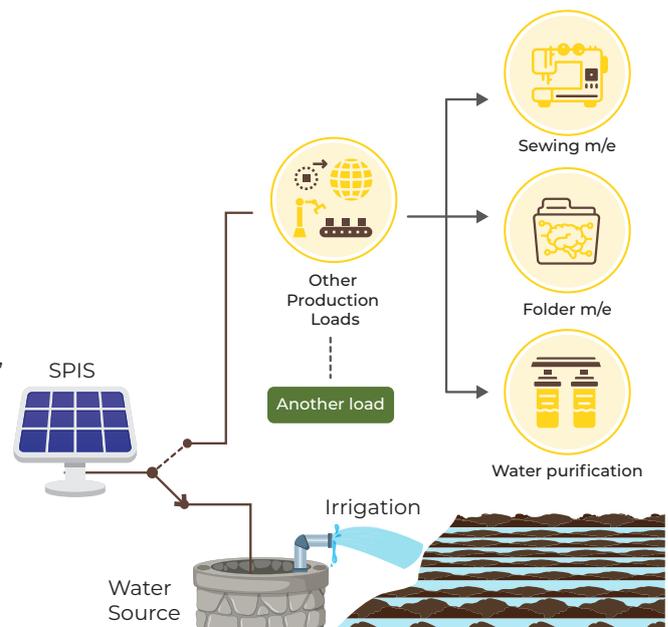


Figure 7.2: Design of the intervention

ECONOMICS OF THE MODEL

In addition to the equity contribution from the Farmer Clubs (FCs), equity has been contributed to procure the machinery, solar pumping circuit modification, irrigation network expansion, and the construction of demo-centers with fixtures for housing the machinery. GIZ contributed Rs. 5.77 lakhs; Rs. 4.88 lakhs and Rs. 4.29 lakhs for site Mairadanga, Phersabari and Ghogarkuthi, respectively, whereas FCs contribution to these sites was Rs. 0.51 lakhs, 0.82 lakhs, and Rs. 0.31 lakhs respectively (Table 7.1). With these interventions adopted, the Mairadanga site is expected to utilize 18.08% of available unutilized energy and reduce GHG of about 0.66 t CO₂ per year, the Phersabari site will utilize 23.28% energy and will be able to reduce 0.76 t CO₂ per year, whereas the Ghogarkuthi site is expected to utilize 34.58% of energy with a reduction in GHG of 1.12 t CO₂ per year. At two project sites, the utilization rate of the SPIS has more than doubled because of agricultural and water management training. This has helped to reduce the break-even point substantially compared to a diesel-powered water pump, considering the water resale price of the farmers' club. One site has however not yet shown any significant improvement in the utilization rate.

Table 7.1: Activities, finance and energy utilization at three sites of the intervention

Site	Activity added	Contribution by GIZ (INR lakh)	Equity by Farmers' Clubs (INR lakh)	Energy Utilization (%)	
				Before	After (expected)
Mairadanga	Stitching machine	5.77	0.51	Less than 13	18.08
Phersabari	Pulverize/animal fodder cutting	4.88	0.82		23.28
Ghogarkuthi	Water purification	4.29	0.31		34.58

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MERITS

- The potential impact of irrigational outreach has been improved by increasing the number of farmers and area under irrigation. The break-even point of these interventions decreased from 20 to 6.15 years for Mairadanga, 11.26 to 5.29 years for Phersabari, and 5.74 to 3.76 years for Ghogarkuthi.
- The interventions made in these areas have created employability to 21 persons (12 male and 9 female members) on a full-time basis and 15 persons (13 male and 2 female members) on a part-time basis (36 persons in total).

DEMERITS:

- Intensive training and capacity building is required to streamline the process.
- The initial capital cost of setting the infrastructure is on a higher side, as compared to the installation of an SPIS unit alone.
- Customization of the machines /productive loads is required to operationalize the system using the electrical energy generated by the PV unit of the SPIS.

CONCEPT SPECIFIC MERITS AND DEMERITS

SCALABILITY OF THE MODEL

SPIS are only utilized for **1/3rd** of the total time in the year resulting in low asset utilization

Decentralised SPIS has been the most scaled-up intervention in the solarization of agriculture in India. Nevertheless, irrigation requirement and hence energy requirement is not constant throughout the year with a utilization of usually less than 60-100 days in a year. Hence, SPIS is only utilized for max 1/3rd of the total time in the year resulting in low asset utilization. Given that most SPIS are supported by high capital subsidies by government or donors, increasing their utilization improves their economic viability. The clean electricity generated in the non-irrigation period can successfully support other enterprises that can mechanize some of their functions. The case presents the concept of utilization of surplus electricity for other income-generating activities apart from irrigation.

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SOLAR WATER PUMPS FOR SALT FARMING IN LITTLE RANN OF KUTCH (LRK), GUJRAT

Devesh Shah, GTNfW¹ | Heena Ben Dave, SEWA²

INTRODUCTION

India is the third-largest salt producing country after the US and China and about 70% of it comes from Gujarat. The salt production in Gujarat is spread along the coast and around the Little Rann of Kutch (LRK). The salt production process in general consists of the activities of site selection, digging of wells, installation of pumps, pumping out brine, passing brine to evaporation pans for crystallization, and finally collection and storage in heaps. The salt production process traditionally used diesel engines to pump brine from the aquifer, which (brine) is then spread in basins (patas) for evaporation. Salt workers were trapped in poverty because of the high cost of diesel as this cost is the largest of their production costs. Therefore, replacing diesel pumps with solar-powered water pumps offers opportunities for improving the economic viability of small-scale salt farming.

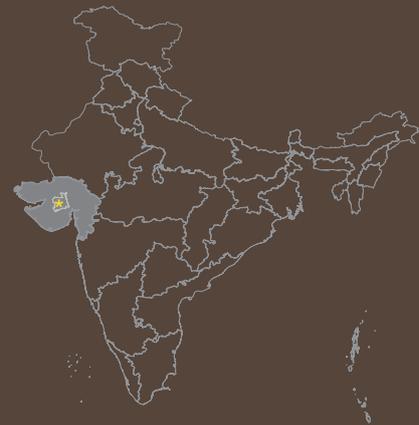


Figure 8.1: Location of Rann of Kutch in Gujarat

DESIGN OF THE INTERVENTION



SEWA

launched a pilot in 2013 with **14 SOLAR PUMPS**

The Self Employed Women's Association (SEWA) in partnership with NRDC, SE4ALL, the World Bank, and solar energy company Sun Edison provided aagariyas, a cost-effective and clean energy alternative: 1kWp solar-powered water pumps for pumping brine instead of diesel pumps. Earlier, saltpan workers borrowed money from salt traders to buy diesel, food and drinking water for the salt production season i.e. October to May. This transaction, on one hand, provided them with working capital but on the other hand it trapped them in the vicious cycle of debt. With the solar pump, their requirement of working capital reduced significantly. With little savings from previous years, they could go to the desert and start salt farming without getting into the debt trap. This empowers them to sell salt, to a trader who offers better prices and terms, etc.

SEWA launched a pilot in 2013 with 14 solar pumps. In this pilot, farmers were given an interest-free loan to acquire solar-powered water pumps. The findings of the initial pilot in terms of profitability to the aagariyas, social and environmental benefits were promising. This led to an accelerated expansion over the years which led to SEWA installing over 1100 solar water pumps in the Little Rann of Kutch (LRK) by 2018.

SEWA has identified women salt workers and worked out the techno-economic feasibility. The economic models were based first on interest-free loan and interest subvention, which was further supported by bank loans with capital subsidies from state and central government and NABARD support in structuring commercial finance by IFC.

ECONOMICS OF THE MODEL

Over the past five years, the prices of solar water pumping system saw a substantial decline. The financial models also evolved over the years: it largely relied on capital subsidies, vendor financing, and low-cost loans. Since salt farming is a seasonal activity the financial model was restructured so that loan installments were payable only during the salt production time. The loan tenures were approximately 5 to 7 years. The SEWA/NRDC reports a massive increase in income of aagriyas (+94% or approx. NR 35,000 per salt pan); this massive increase was a result of huge savings on diesel/ kerosene. The diesel consumption earlier accounted for about 40% of the annual income. Using solar water pumps in hybrid mode with the diesel pump resulted in an increased yearly income of 35,000 rupees and once loan installments are fully paid, with the rise in annual net income to 71,000 rupees.

MERITS

- Huge reduction in salt production costs because of cutting down the diesel consumption leading to Increased income of salt producers (approx. 94 units)

DEMERITS:

- Given the remoteness of the activity, pump-related repair and maintenance issues force aagriyas to keep standby diesel pumps.
- Subsidy delivery is difficult as Aagriyas do not have land ownership since the LRK region comes under protected areas.

CONCEPT SPECIFIC MERITS AND DEMERITS

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SCALABILITY

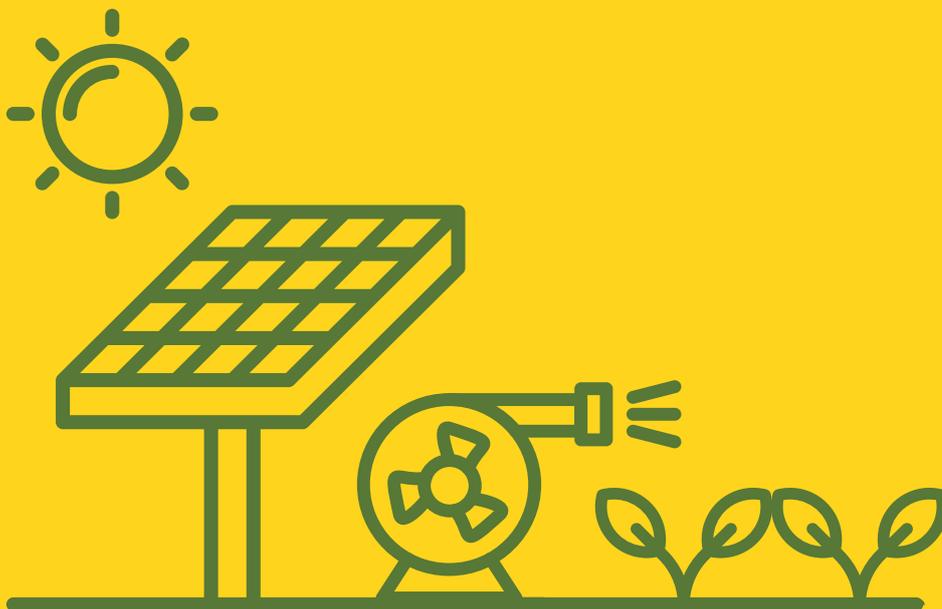
Salt production traditionally relied on diesel or kerosene for water pumping, and this dependence on energy often forced poor saltpan workers in debt cycles. Huge savings on diesel costs together with financing options tailored to salt pan workers are the key scalability factors of this model. There has been some progress in connecting the solar-powered water pumps in the off-season to microgrids to enable the use of energy in the non-pumping period to improve the financial viability of the intervention.

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Acknowledgement: **Self Employed Women's Association(SEWA)**, Surendranagar, Gujrat
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POLICY PILOTS

Cases 9-13 are different subsidy delivery models aiming to showcase potential policy ideas to scale -up solarization of agriculture. They present different opportunities to reduce the capital subsidy required to accelerate and promote solarisation in agriculture.





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SOLAR AGRICULTURE FEEDERS IN MAHARASHTRA

Sakshi Saini, CCAFS¹ | Paresh B Shirsath, CCAFS²

INTRODUCTION

Even though farmers have access to highly subsidized or free electricity supply, the vagaries of electricity supply have been an escalating challenge. In addition the subsidy mechanism lays significant economic implications on government. Uncertain electricity supply coupled with the brunt of climate change enhances the vulnerabilities of farmers, further exposing them to live a resource deprived life.

Maharashtra State Power Generation Corp. Ltd (MPGCL), a state company is trusted to undertake solar capacity addition of 2500 MW, through Public-Private Partnership (PPP). Realizing that 30% of the energy generated is meeting the irrigation demands of the agricultural sector, an innovation of supplying power for this purpose from localized Solar Plants was ideated. This thought was formalized as a policy titled Mukhyamantri Solar Agricultural Feeder Scheme in June 2017.



Figure 9.1: Location of solar agriculture feeders installed in Ahmednagar and Yavatmal districts of Maharashtra

DESIGN OF THE INTERVENTION

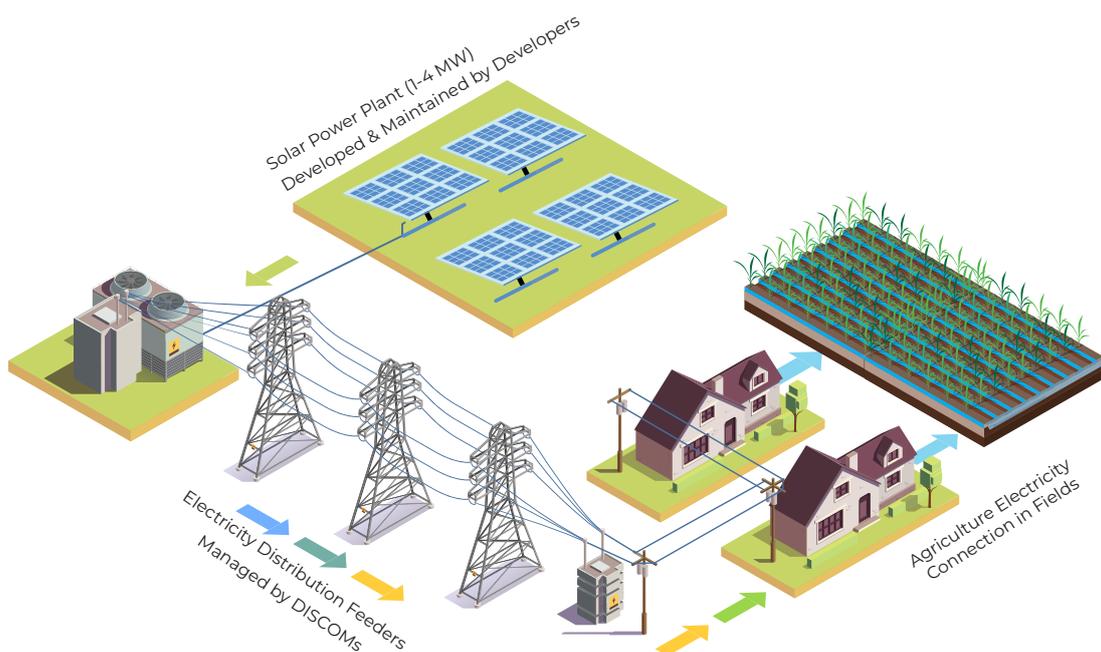


Figure 9.2: Pictorial representation of the intervention

Two pilot Solar Agriculture Feeder programs being implemented in Ahmednagar and Yavatmal districts of Maharashtra strive to bring about inclusive prosperity by providing uninterrupted day time power supply to the farmers in the area. The program engages private parties (entrepreneurs/ business persons/ community groups etc.) to set up a solar power plant to energise an agriculture feeder. The necessary impetus and support to take this initiative forward have been provided by the Chief Minister's Solar Agriculture Feeder Program.

Solar feeders have been set up in Ahmednagar and Yavatmal with target of reaching 2 MW capacity, however, plant in Ahmednagar has installed capacity of only 1.5 MW as of May 2019. These are similar to conventional Solar Power Plants but are located at the feeder level which negates the requirement of transmission. They can be called a distribution level solar power plants as they are to energise agriculture feeders. In case the requirement of energy for agriculture is lesser than what is being produced, the surplus energy will flow to DISCOM's grid. On a cloudy/rainy day DISCOM can fill in the energy deficit, and an uninterrupted supply of day time electricity to the farmers will be ensured.

As per the state government scheme, capital support (in the form of land for setting the solar feeder) has been provided for established entrepreneurs to join the program and install Solar Agriculture feeders at the commercial level. The scheme offers land for installing the solar panels on lease for 30 years, practically with no cost (INR 1). They have been exempted from the formalities of converting the agricultural land to non-agricultural land to establish a Solar Agriculture Feeder. Existing grid connectivity with agriculture feeder separation served as a cherry on the cake. In addition to this, the entrepreneurs have been saved from the hassle of money collection from the end-users by retaining DISCOMs in this role. For the end-users, DISCOM will be the face of the energy supplier and revenue collector. It will be the responsibility of DISCOM to disburse the sum amount of energy evacuated into the system by the feeders. With these benefits displayed on a platter many entrepreneurs participated in the competitive bid for setting up solar power plants for energising agriculture feeders.

The power generated under this scheme by the developer will be supplied to MSEDCL (Maharashtra State Electricity Distribution Company Ltd) for further distribution to agricultural consumers. The power developer gets paid by the MSEDCL for the annual generation as per the power purchase agreement. The status quo remains for MSEDCL i.e. it gets paid by the government for the subsidized electricity supplied to the farmers. Farmers get day time reliable electricity at the earlier negligible tariff.

Land required for setting the solar power plant is identified by MSPGCL within the periphery of 5-10 KM of 11kV to 132kV substations in Maharashtra. Additional economic support is provided to the investors by MEDA Green Cess Fund, in the form of reimbursement of power evacuation system expense.

ECONOMICS OF THE MODEL

CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- Developers can quickly set up power plants and support government in achieving the targets for the production of renewable energy.
- No capital subsidy is required
- Farmers get day time uninterrupted electricity.
- The maintenance is easier compared to the decentralised small-scale systems.

DEMERITS:

- Investment cost to set up the plant is high, as large infrastructural set-up is required for setting the system
- With continuous power supply and no significant incentive for farmers to conserve energy, there is a higher possibility of exploitation of groundwater.

This model presents a centralised way of solarising irrigation in agriculture. Given the high capital requirement, it centres around developers, who can invest in solar power plants and support the government in achieving the solar energy deployment targets quickly. The policy pilot is intended at presenting a developer-centric model in improving electricity supply in agriculture and with a net reduction in capital subsidy requirements. This being a public private partnership project does not have any subsidy by government to support the capital cost of the system, although the land for installation of the solar power feeder has been provided by the government at practically 'no cost' for 30 years.

In addition, with no structural or behavioural changes required at the farmers end in terms of demand generation, technology adoption, installation of individual solar pumps etc. the time and effort for the same is negligible. It appears to be a good business model, to provide solar power, though its implementation requires the pre-requisites of; grid connectivity, feeder separation mechanism, availability of space/land. Absence of these will be a limiting factor, hindering the scalability of this approach. Though, in areas where these parameters are available, the scalability of the model is high given the ease of implementation and support from the government, though sustainability of the model in terms of availability of groundwater resources is yet to be studied.

SCALABILITY

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Government of Maharashtra
Prayas Energy Group (PEG)**

SURYA RAITHA SCHEME IN KARNATAKA

Neha Durga, IWMI¹ | Shilp Verma, IWMI² | Manjunatha A.V., BESCO³

INTRODUCTION

In the last quarter of 2014, the Government of Karnataka announced a pilot scheme for an entire feeder which entailed replacing inefficient electric pumps with net-metered solar pumps and called the scheme 'Surya Raitha Pilot Scheme'. The pilot was executed in the Nallahali Panchayat of Ramanagram district of Karnataka. The electricity supply feeders are already segregated in the region. Harobele F2 11KV feeder supplying electricity supply for agriculture to the seven villages namely Harobele, Muthurayanapura, Rayappana Doddi, Kadle Doddi, Nalahalli, Uyyamballe, Doddahalhalli was selected for the experiment. This region falls under the command area of Arkavathy river/dam and has no groundwater scarcity or irrigation deprivation. Total 310 electric connections totaling a load of 1777.5 HP were solarized with 1.5 times of solar PV capacity. Therefore around 2681 kWp was installed in 310 farms on the Harobele feeder. BESCO (Bangalore Electricity Supply Company Ltd) was the nodal agency for the project and erstwhile SunEdison India was contracted to carry out the pilot.



Figure 10.1: Location of Ramanagram district in Karnataka

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DESIGN OF THE INTERVENTION

The installed solar pumps are with AC motor and fixed solar PV structures. All the systems are net-metered and tied with a grid with independent transformers to enable high voltage injection (HVDS system). Also, the system includes a programmable controller which can be adjusted to fix the percentage of evacuation at all times. Therefore, the system is designed with the capability of technically fixing the percentage of a real-time generation dedicated to evacuation. The feeder starts from the Harobele substation and all the data of the feeder is collected via a remote monitoring system installed in the solar system.

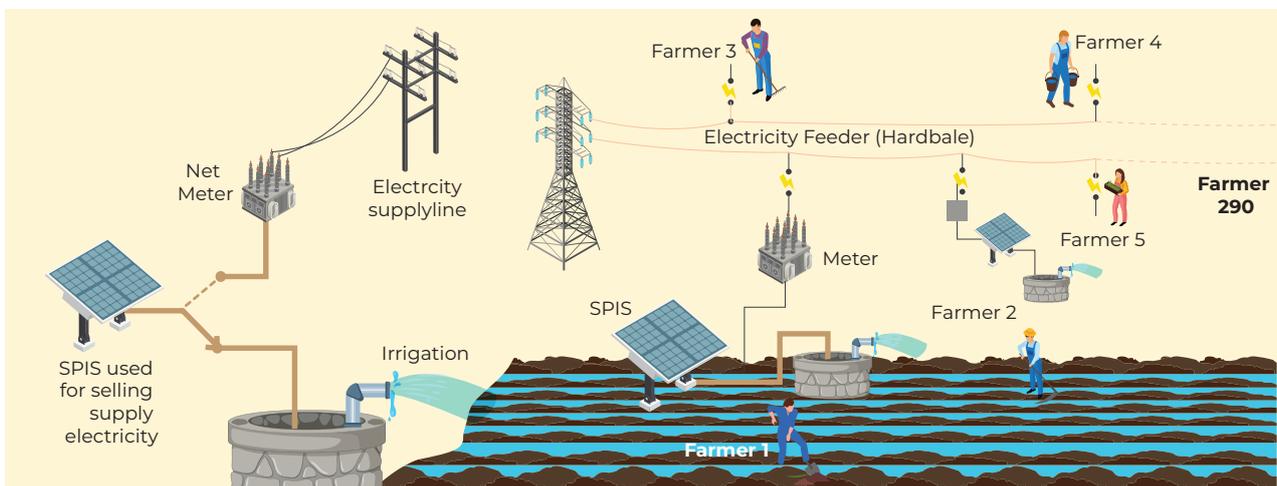


Figure 10.2: Pictorial representation of the intervention

The Surya Raitha Pilot Program faced multiple challenges since its inception, primarily because the scheme designing focussed on technical and financial aspects but the institutional aspect was not given due attention. Also, the project treated farmers like passive beneficiaries when their required role was much larger. As a result, when the project reached the ground, farmers did not sign up for contributing Rs 50,000 -70,000. Also, the farmer institution was made by the implementing agency and not by farmers themselves, therefore it ended up being a namesake institution without much hold on farmers groups.

ECONOMICS OF THE MODEL

The policy was designed expecting 30 percent subsidy support from MNRE and Government of Karnataka (GoK), 10 percent farmer contribution (~Rs 50,000 for 5 kW) and rest as an interest-free loan from BESCO to the feeder level farmer institution (Harobele Farmers' Cooperative), which was created to aid the implementation of the pilot and act as interface between farmers and BESCO. Farmers did not agree to pay the upfront contribution, so the 10 percent was partly funded by the government of Karnataka as one-time subsidy support and partly was taken up in the loan given by BESCO. Farmers signed a power purchase agreement with BESCO for 20 years to sell the surplus electricity at Rs 7.2/kWh escalating at 3 percent every year for 20 years out of which:

- | | | |
|--|---|--|
| <p>a. Rs. 1/ kWh was to be directly paid to the farmer as Generation Based Incentive (GBI)</p> | <p>b. The balance net-metered revenue was to be used to pay off the interest-free loan taken by the farmer; the loan was expected to be repaid within 15 years in this manner</p> | <p>c. Once the loan is repaid, the farmer will be able to retain the entire net metering revenue as GBI.</p> |
|--|---|--|

Farmers got solar pumps and therefore got access to day time high-quality electricity for irrigation as promised. Also, the change in inefficient electric pumps with efficient solar pumps resulted in electricity savings for BESCO. But it failed the target of transforming the energy-water nexus because of the weak incentive structure designed in the scheme. Rs 1/ kWh was too low an incentive for a farmer to change his water-energy use behavior. Since the region under Harobele feeder falls under the sericulture belt, the water use is extremely high and so is the value generated by irrigation. Therefore Rs 1/kWh was a negligible incentive offered. Also, this incentive was never realized as BESCO never paid anything to farmers for the surplus evacuation. As farmers did not contribute anything and also participated passively in the execution of the project, they were not well equipped with the technical know-how of the system. The fieldwork in the region revealed that farmers did not know how to read meters, they were not aware of the electricity generated, used or sold by them.

CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- Reduction in the carbon footprint of groundwater irrigation by reducing electricity and diesel use in pumping water;
- Improve finances of the power sector by liberating DISCOMs from the deadweight of farm power subsidies
- Improve agrarian livelihood by providing farmer cash income for “growing” solar energy as a remunerative cash crop;
- A cheaper and clean source of energy, saving money by lesser expenditure on diesel.
- Enhance the quality of irrigation by providing farmers reliable, uninterrupted, daytime power supply

DEMERITS:

- Institutional support to operationalise selling of electricity is required
- Large infrastructural cost, in terms of providing electricity evacuation mechanism
- Grid connectivity is a pre-requisite for this model to work.

SCALABILITY

Surya Raitha was the first feeder level, solar irrigation pilot, in the country. It had huge potential for upscaling but it did not upscale in its current form in Karnataka. Primarily because it turned out to be an expensive experiment for BESCO, where they had put capital and they only are buying electricity from their own asset. Also, some unexpected complications with SunEdison going bankrupt also affected the design and implementation of the project. However, farmers are happy since they paid nothing to get day time high-quality free power and now also they aren't putting any effort into maintaining the system because they have no incentive for doing so. Even if they become net importers, they will not be liable to pay anything towards net import.

The model of net-metered solar pumps, experimented first in Dhundi village and then in Surya Raitha pilot, is scalable if right incentive and institutional mechanisms are built in the design. This is evident from the fact that the idea has already been upscaled in the form of SKY (Suryashakti Kisan Yojana) in Gujarat and KUSUM (Kisan Urja Suraksha evan Uthaan Mahabhiyan)- Component C at national levels.

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Acknowledgement: **IWMI-Tata Water Policy Program (ITP) and CGIAR Research Program on Water, Land and Ecosystems (WLE), Anand, Gujarat, India**
Bangalore Electricity Supply Company Ltd (BESCO), Karnataka

SOLAR POWER AS A REMUNERATIVE CROP (SPaRC) INITIATIVE

DHUNDI SAUR URJA UTPADAK SAHAKARI MANDALI, GUJRAT

**Neha Durga, IWMI¹ | Shilp Verma, IWMI² |
Gyan P. Rai, IWMI³ | Rahul Rathod, IWMI⁴**

INTRODUCTION

Dhundi Saur Urja Utpadak Sahakari Mandali (DSUUSM) was formed in June 2015 with 6 farmer members who were supported by IWMI and CCAFS to acquire solar irrigation pumps with a total panel capacity of 56.4 kWp. These were formed into a micro-grid, for which the cooperative was created to manage on behalf of members.

Madhya Gujarat Vij Company Limited (MGVCL), the local power utility, connected this microgrid to its 11 kV line at a single metered point and offered the cooperative a 25 year solar power purchase contract at ₹4.63/kWh. In return, the cooperative members surrendered, in writing, their right to apply for subsidized grid power (at ₹0.60/kWh) for 25 years. In addition to the tariff offered by MGVCL, IWMI offered ₹1.25/kWh as Green Energy Bonus and another ₹1.25/kWh as Water Conservation Bonus, taking the effective buy-back tariff to ₹7.13/kWh.

DSUUSM was part of a research pilot implemented by the IWMI-Tata Water Policy Program with funding and technical support from CCAFS. The total investment in the solar grid and system was around ₹50 lakh; of this, six farmer members contributed roughly ₹5 lakh; the rest was provided as a grant by CCAFS to IWMI-Tata Program.



Figure 11.1: Location of Kheda district in Gujarat

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DESIGN OF THE INTERVENTION

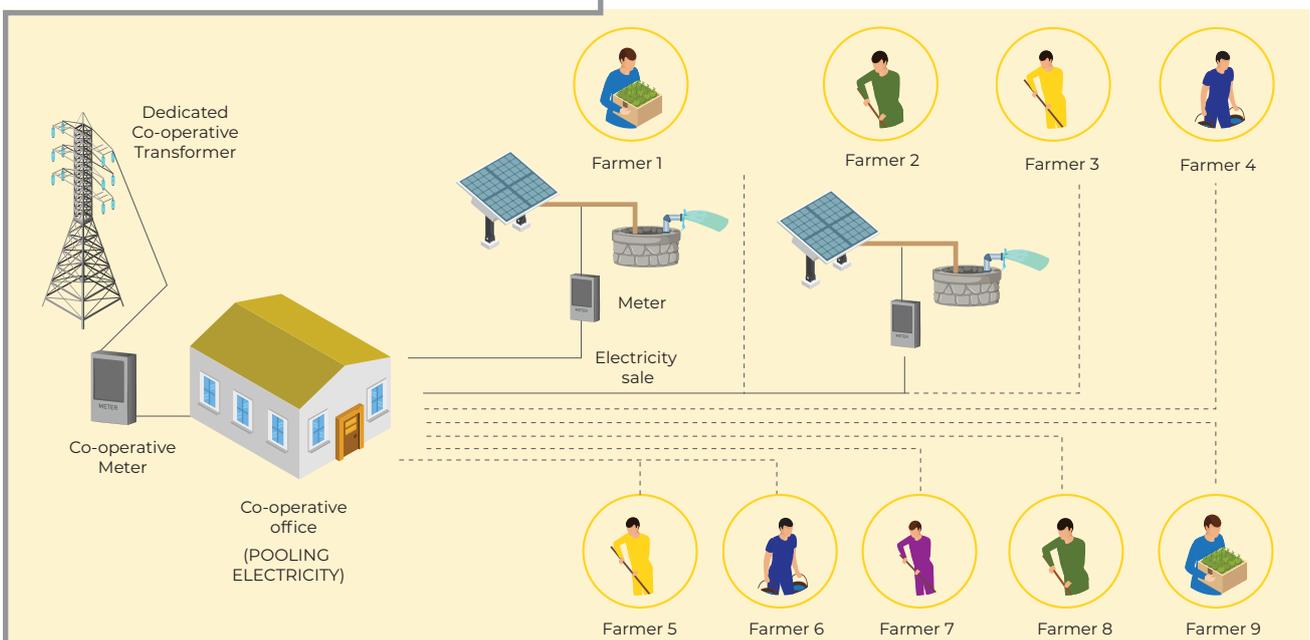


Figure 11.2: Pictorial representation of the intervention

Dhundi is a small Gujarat village where all 50 irrigation wells — except 1 — were mounted with diesel pumps. Landholdings here, have up to 30 owners, all of whom need to a x signatures to apply for electricity connections. Since this is not possible, Dhundi farmers have given up on grid electricity for irrigation costing ₹0.60/unit and were designed to use diesel pumps that deliver power at up to ₹16-20/unit depending upon pumping head and efficiency. Thus, for these farmers dwelling in Dhundi, solar pumps offering free day-time energy were a Godsend.

DSUUSM members' solar pumps began operating in December 2015. However, the MGVL's power purchase guarantee came into effect only at the beginning of May 2016. ITP's members tracked the economic decisions of DSUUSM members during December 2015 and May 2017 by compiling daily, weekly and seasonal data. Moreover, using memory recall, they also constructed members' cropping and irrigation profile for three crop seasons for 2014-15.

The present initiative has been implemented by ITP with the funding from CCAFS. Before this intervention in Dhundi, ITP had implemented another small field pilot in Thamna village where one farmer, was given a solar pump for irrigation. In this initiative, there was an option of evacuating the surplus solar power to the grid, for which ITP paid him ₹5.0/kWh from their research funds. ITP organized for a group of farmers from Dhundi to visit Thamna and discuss these issues with the farmer and learn from his experience of using a solar pump for irrigation.

After the visit to Thamna, six farmers agreed to make a token contribution of ₹5,000/kWp and were offered solar pumps under the ITP-CCAFS research project on 'Climate Smart Agriculture'. In all, the six farmers installed pumps with a combined capacity of 56.4 kWp; the installation work completed in mid-December 2015. In early February 2016, the Dhundi Saur Urja Utpadak Sahkari Mandali was formally registered and the evacuation of surplus power to the grid started on 10th May 2016.

The ITP-CCAFS project invested around ₹46 lakhs while the member farmers contributed around ₹5 lakhs. Of the total investment, the solar pumping system (pumps, panels, VFDs, inverters, mounting structures, switches, meters, etc.) cost around ₹35 lakhs. A 2.8 km long micro-grid was also constructed which facilitated the pooling and evacuation of surplus solar power to the grid. This cost around ₹15 lakhs, including the cost of a dedicated transformer. As the unit cost of solar technology is constantly declining, it is likely that the costs will be lower today and even lesser in the future. It is also important to note that since this cooperative started at a very small scale, the unit cost of our micro-grid was quite high (₹27.7/wat-peak). Larger cooperatives, with more members, should be able to spread the micro-grid costs over higher solar capacity, thus reducing the unit costs.

CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- Decentralised generation of clean energy
- DISCOMS can meet the energy deficit.
- Revenue generation by selling electricity
- A cheaper and clean source of energy, saving money by lesser expenditure on diesel.

DEMERITS:

- Institutional support to operationalise selling of electricity is required
- Large infrastructural cost, in terms of providing electricity evacuation mechanism
- Apprehensions on outnumbering the electricity demand of the country, with more supply of solar energy than the electricity demand, if the project is scaled out countrywide.
- Grid connectivity is a pre-requisite for this model to work.
- For far flung farmers, with no grid connectivity, this will not be a viable model.

SCALABILITY

Farmers from nearby areas have keenly watched the performance of DSUUSM and many are now eager to adopt solar pumps. Initially, farmers have been very skeptical about investing money in this kind of initiative, they were also not sure if they will be able to sell the electricity to the DISCOM. With the success of this initiative, many farmer groups are now approaching IWMI to form a solar cooperative. These farmers are also willing to pay a higher amount of money (as compared to the share of ₹5,000/kWp to capital investment paid by 6 farmers in Dhundi). Farmers have also observed the efficiency of solar pumps, and have seen that solar pumps deliver 50 percent more water than diesel pumps of similar capacity. The added remuneration generated by selling surplus power to the grid is an added advantage. Observing these perks, three new members have already come forward to join DSUUSM and contributed ₹25,000/kWp towards capital investment. This suggests that farmers would be happy to invest in solar technology if it is shown to be profitable.

The government of Gujarat has shown its appreciation and acceptance for this approach by launching Suryashakti Kisan Yojana – SKY Scheme. The scheme proposes setting up grid-connected solar pumps and offers subsidy support for such projects being implemented in Gujarat. Currently close to 50 feeders have already been solarised using the Dhundi model in Gujarat.

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CGIAR Research Program on Water, Land and Ecosystems (WLE)

NALANDA COMMUNITY TUBE-WELLS: ELECTRIFICATION OF SOLAR PUMPS – REVERSING THE BENEFITS?

Neha Durga, IWMI¹ | Shilp Verma, IWMI²

INTRODUCTION

In March-April, 2012, Department of Minor Irrigation, Government of Bihar solarised 34 community (or public) tubewells in 10 blocks of Nalanda district. Field setup of SPIS was done by Claro Energy Pvt Ltd.. The 34 tubewells initially set up in 2003-04 under a program of NABARD were solarised under this experiment. This entailed installing of 7.5 HP AC pump powered by 8.35 kWp Solar PV coupled with 1000-1500ft of underground pipeline network costing close to Rs 10 lakh per system. Until 2012, this systems was powered by diesel engines. In 2012, the program was revamped technically and institutionally. The off-grid, AC type, solar pumps were to be operated by the selected personnel, called operators, who were to be given a fixed salary of Rs 2500 per month and they were supposed to sell irrigation service to the community at Rs 5/Katha or Rs 400/ha for one watering, and pass on the revenues to Claro Energy Pvt Ltd. Nalanda region owing to its proximity to the capital region of Bihar has had access to better connectivity and government services such as roads, markets, and electricity. However, in 2012, the electricity scenario in the entire state was abysmal and only for a few hours of electricity with poor quality voltage was supplied in the rural areas. The poor-quality rural power supply environment and expensive diesel were restricting adequate irrigation supply and adoption of high value cropping systems in the state (Kishore 2004, Durga et. al 2016).



Figure 12.1: Location of Nalanda district in Bihar

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DESIGN OF THE INTERVENTION

Until 2012, the community tubewells were running on diesel engines and therefore faced the high marginal cost of pumping owing to the fuel and high maintenance cost of diesel pump-sets. The water buyers, constituting the majority of the farmers in Bihar (Kishore 2004) faced even higher prices as it included the service cost of the operator. Replacement of diesel pump sets with solar pumps resulted in two technical changes in the system i) Energy Source – Solar PV replaced diesel, therefore access to a daytime, free and predictable form of electricity was made available for pumping water ii) Pump and motor-submersible pump-motor system was installed in 300 ft deep tubewell, however, the pump was placed at 60 ft. The water table in the region is 15-20 ft, therefore the submersible pump resulted in high discharge of water.

Operators were hired and trained to operate solar pumps to sell irrigation service to a command area of close to 35-40 acres of land. The operators were supposed to operate the solar pumps, keep it clean, sell irrigation

by laying pipes and opening/closing valves/outlets, maintain the sale records and recover the irrigation fee which was decided to be Rs 5/Katha by the authorities in 2012. The operator was supposed to get Rs 2500 as a monthly salary and the accumulated revenue from irrigation sale was supposed to be handed over to Claro Energy. Most of these activities were not done and the business of the public tubewells evolved as per the local condition and incentives of the stakeholders.

In studies done by the IWMI-Tata Water Policy Program in 2014, it was revealed that the operators weren't charging just Rs 5/katha but up to Rs 15/katha. Also, Claro Energy Pvt Ltd had stopped visiting these tubewells to collect the revenue or pay the salary. Therefore, the revenue generated by the operator was kept by him towards his service. However, there was a skepticism regarding Claro Energy returning for recovering the revenue accumulated over the months. Hence operators lacked the sales maximising tendency as their incentives were not aligned with the same.

In 2018, the electricity scenario drastically improved in the region and majority of the solar tubewells were electrified. Electrification of Solar Irrigation System changed the dynamics of the irrigation systems and also impacted the behaviour of stakeholders towards the solar systems or assets.

It was observed that electrification has significantly improved in the region and all the seven solar pumps studied have been electrified. Five out of the seven solar pumps had become defunct because of faults in the controller or the system. Hence, they were solely running on electricity which is now provided 22-24 hrs in the region. Since Claro Energy was contracted to maintain the system only for five years, they had stopped responding to the operator's queries and complaints for the last few years.

Even though feeder segregation has not happened in the region, the community tubewells have been connected with the 11kV feeder using an independent transformer which ensures good voltage quality and therefore good water discharge. The five solar pump operators who now run the community tubewells on electricity reported the difficulty in handling the high-water discharge while using electric pumps. Also, it was seen that multiple individual 2-3 HP electric pumps have come up in the vicinity of the community tubewell.

Operators have not paid or were not asked to pay for the electricity they had consumed for selling irrigation. However, the electricity is metered and sometimes the DISCOM official goes to note the reading. Operators are skeptical that they might be required to pay for the electricity bill in near future. The price charged for irrigation is around Rs 10-15/katha. The revenue has improved after electrification through the sale of irrigation. With solar pumps, around 1800 equivalent hours of irrigation were available but with electricity, the hours have gone up to 6000-6500 hrs. However, all five operators preferred selling irrigation with solar pumps as they suggested in the discussions. The main reasons behind their preference for solar irrigation are i) their ability to control the discharge which they cannot with electric pump, which results in flooding of neighbouring fields if the demand is low ii) the record of electricity through meters make them skeptical about any future payment they will be required to make.

CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- Efficacious use of already installed pumps
- Reduced cost of installation of solar pumps
- Less time required to set up the plant
- Revenue generation by selling water

DEMERITS:

- With around 22 hours of electricity supply, the solar pump becomes a less lucrative source of energy
- In the presence of a cheaper alternative source of energy, many farmers are electrifying their solar pumps
- The market of selling water might be impacted in the future, with the lower cost of electric pumps.
- Many pumps have been rendered dysfunctional, as power supply scenario in the area improves drastically.
- Government investment in providing grid connectivity to the area is having contraindicative impacts on the investment made to solarize the pumps in Nalanda

SCALABILITY

Similar to majority of the public minor irrigation schemes, there is little incentive for the operator in Nalanda experiment to maximize returns by selling irrigation. Also as the operators did not contribute anything for acquiring these systems, they could not justify their ownership on the system and recover the irrigation charges from the beneficiary farmers. Hence, where the solar system was functioning well, operators were running the system not for selling irrigation but for their own use. Therefore, the scalability of this model remains restricted due to a lack of robust institutional model, which could legitimise the ownership of solar systems, enabling the operator to recover the irrigation charge from the buyers. Also, the electrification of these community tubewell made the solar systems redundant.

Bihar state seems to adopt the messy route of farm power subsidy to expand affordable irrigation access as done earlier by the majority of the states in the western and peninsular India. As the number of electric pumps using subsidized electricity increases, in the absence of feeder segregation, the anarchy on the feeder increases. Gross underreporting of pump size, hooking etc deteriorates the overall rural power supply quality.

Solarisation provided an alternative to bypass this messy route of subsidized farm power for expanding affordable irrigation. But because of lack of a rational incentive structure and robust institutional mechanism, the Nalanda experiment could not leverage on solarisation.

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National Bank for Agriculture and Rural Development (NABARD)

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CATALYSING COMPETITIVE IRRIGATION SERVICE MARKETS IN NORTH BIHAR: THE CASE OF CHAKHAJI SOLAR IRRIGATION SERVICE MARKET

Neha Durga, IWMI¹ | Gyan P. Rai, IWMI² | Shilp Verma, IWMI³ | Sakshi Saini, CCAFS⁴ | Dhiraj Kumar, AKRSP-I⁵

INTRODUCTION

Despite having deep and under-developed aquifers, the eastern region of India, comprising of eastern Uttar Pradesh, Bihar, Jharkhand and Assam have not been able to utilize the irrigation potential and yield benefits of the same, primarily because of lack of affordable and reliable irrigation options. Even today, most of the irrigation in Bihar is done through diesel pumps and the majority of farmers buy expensive irrigation from these diesel pump owners. This lack of access to affordable irrigation makes their livelihood more vulnerable to climate change. Therefore, affordable and reliable irrigation can provide the bare minimum resilience needed in times of climate change. Competitive Irrigation Service Markets (ISMs) have bypassed Bihar due to a lack of affordable electricity.



Figure 13.1: Location of Samastipur district in Bihar

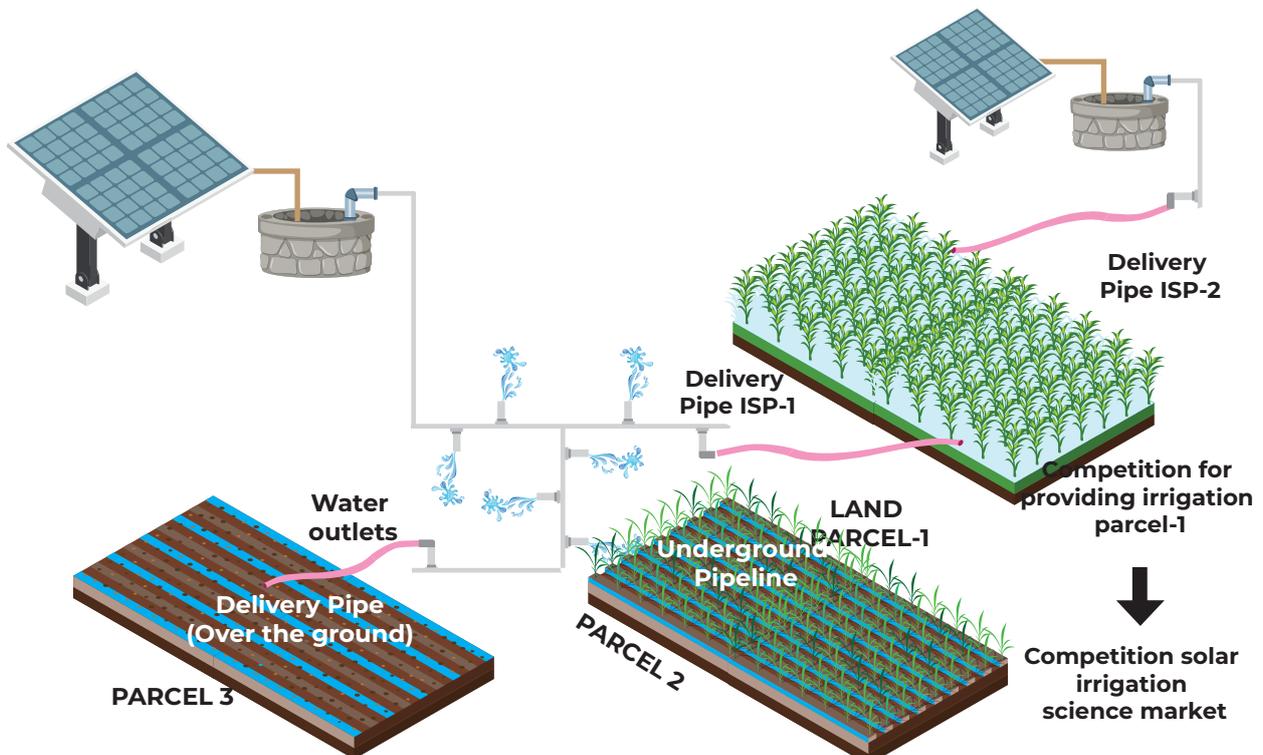


Figure 13.1: Schematic of solar irrigation service market

DESIGN OF THE INTERVENTION

The current case presents one such Solar Irrigation Service Market (SISM) catalyzed by supporting five solar entrepreneurs in Chakhaji village of Samastipur block and district and discusses its relevance in the present times and its contribution to agriculture growth of the village. IWMI-Tata Program designed this Solar Irrigation Entrepreneurs Scheme in partnership with Aga Khan Rural Support Program (AKRSP), India towards the end of 2016.

Members of Kushwaha community, who are well known for vegetable farming, constitute the majority of the population of Chakhaji village. Earlier a predominantly diesel irrigated village, it has close to 65 hectares of cultivated land, divided into more than 2,400 smaller parcels. Average landholding per household in the village is around 0.5 acre in 7 to 8 parcels, in different locations in the village. Due to high land fragmentation, even the well owners are water buyers for some of their parcels, which is a usual trend in North Bihar.

There were only diesel pumps for irrigation before December 2016 in Chakhaji village. Even today, 18 diesel pumps, mostly Chinese made are operational in the village. These Chinese made pumps have a life of not more than 3-4 years and high annual maintenance cost of around INR 5000; they are an expensive water-extracting mechanism. The farmers who buy water from diesel pump owners are worse off than the pump owners as they have to pay around INR 120-150 per hour of irrigation which translates to INR 2600-3300 for irrigating an acre per season. Annually, diesel irrigation expenditure amounts to 20 percent of the annual revenue generated per acre. Also, the water extraction it self is unreliable (even though expensive) in pre-monsoon season (as diesel pumps cannot pump water from greater depths) not only exposes crops to production risks but also discourages farmers doing pre-monsoon sowing of kharif (rainy season) crop.

In December 2016, IWMI-Tata Program along with AKRSP(I) offered five solar pumps of the desired size (5 HP) at 60 percent subsidy to farmers who were willing to contribute 10 percent upfront payment and also agreed to pay 8 percent of the capital cost each year for four years. Also, 1000 ft of the buried pipeline was to be given in the desired direction to the interested farmers. The cost of 5 HP solar pump was around INR 5 lakh, which meant farmers who were willing to become solar irrigation service providers (SISP) had to contribute 50,000 as an upfront payment and INR 30,000-40,000 annually for four years. The hypothesis behind the offer was that an adequately sized pump with a buried pipeline network could not only offer a farmer an opportunity to sell irrigation and earn a decent income but may also catalyse an equitable and competitive irrigation market. It was expected that upfront cost and annual payment would mimic a high flat tariff to be paid by the SISPs, which will push them to earn enough from the irrigation sale, to

ECONOMICS OF THE MODEL

pay the annual installment of the pump. They could increase revenue by charging a much higher price than their marginal cost (which is negligible in case of solar pumps) but since it was not just one farmer having a solar pump but few more farmers and all with buried pipeline network to reach longer distances, they could compete with each other. Thus, it was expected that competition among SISPs to acquire more market share to maximize revenue would keep the irrigation prices low, hence resulting in a pro-poor irrigation service market.

Five farmers formed the first cluster of SISPs in Chakhaji village. They paid an upfront payment of INR 50,000 in two installments and gave an undertaking that they will be paying annual installments for the coming four years. They also finalized the network of 1000 -1200 ft pipeline and began operations in mid-December 2016. The five SISPs are serving close to 400 farmers and providing irrigation close to 75 Ha of the area against the designed command of 55 Ha. Together they have earned a revenue of INR 9,34,291 by providing 9,497 hours of irrigation. This also includes their self-consumption which is less than 5 percent for four SISPs and 8 percent for the fifth one.

As the density of solar pumps is still low in the area, the competition between the SISPs is negligible. Each SISP has enough untapped market to expand into, and are not bothered about the little overlaps in command areas. As the density of the solar pumps will increase, the competition between the SISPs will increase and the service may improve further for buyers. .

MERITS

- Solar irrigation operation could complete four agriculture seasons and result in multiple changes in the agriculture practices and income from the same
- The benefits were not concentrated in their livelihoods of only five farmers but they got distributed among all their customers, who are largely resource-poor and marginal farmers
- The cost of irrigation decreased significantly for the water buyers as they could irrigate more area per hour .
- Availability of irrigation on credit which was not possible with diesel irrigation because of the marginal cost of running diesel pumps
- The buried distribution network has relatively much lesser chance of leaks compared to the over-ground delivery pipes.

DEMERITS:

- The competition between the SISPs may happen with increased density of solar pumps which may decrease the price of the irrigation for water buyers but water sellers might not be able to earn enough to repay the annual installment.
- The competition between the SISPs may happen with increased density of solar pumps which may lead to underutilization of energy

CONCEPT SPECIFIC MERITS AND DEMERITS

A competitive ISM catalyzed by supporting multiple SISPs has shown positive early changes in the Chakhaji village and the adjoining area. It has boosted the income of both water sellers and buyers by allowing them to produce more from the scarce land resource they possess. Also, solar pumps provide an irrigation assurance for many years and are free from market risks of prices like diesel pumps. This strengthens the resilience of farmers in the times of adverse weather i.e. in case of less rainfall, they can irrigate their crops more without increasing the expenditure exorbitantly and therefore maintaining the crop viability.

Also, the distributive impacts of ISMs will make agriculture more viable as farmers having access to the market will be able to change crops frequently given that irrigation will be assured. Thus, farmers will have more flexibility in choosing crops. Also, the increase in cropping intensity because of affordable irrigation will result in more labour requirement throughout the year, thus generating more employment for the landless farmers.

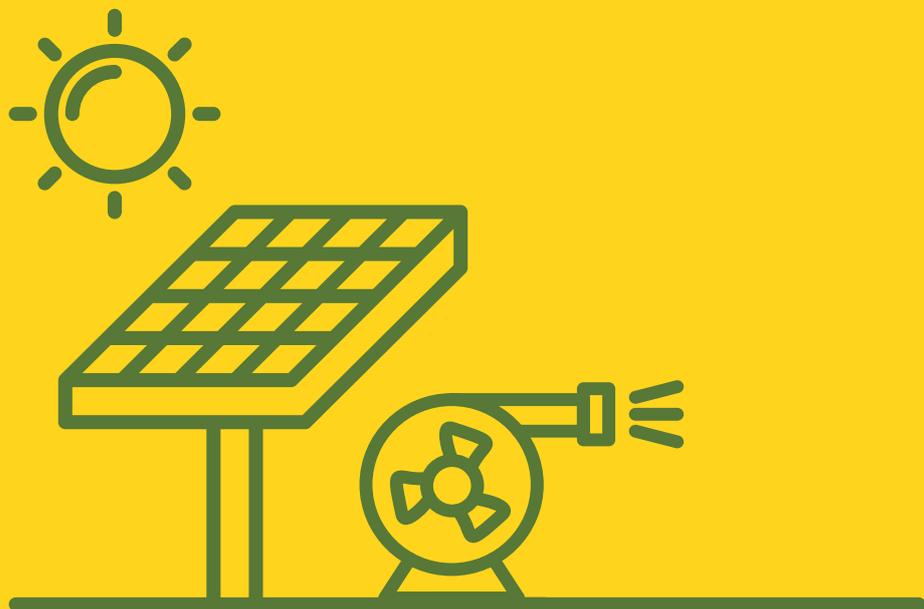
Competitive and effective SISMs can transform the energy-irrigation of the Ganga-Brahmaputra-Meghna basin and can impart the much-needed dynamism in its agriculture, which will have multiple cascading benefits. In fact this model of catalyzing ISM by supporting multiple SISPs is relevant for all the regions having scarcity of affordable electricity and an abundance of groundwater. Expanding grid electricity and supplying high-quality electricity to agriculture at tariffs viable for both farmers and electricity utilities is a long-standing dream and the political economy associated with tariffs makes it even more distant. SISPs can bypass the messy and slow route of electrifying agriculture, as the ultimate objective is to provide affordable and reliable energy and therefore irrigation to farmers which bolster their capabilities to adapt to climate change.

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Aga Khan Rural Support Program (AKRSP-I)

MISCELLANEOUS CASES

Cases 14-16 are different miscellaneous cases showcasing innovation of using solar power in agriculture. These three cases showcase three distinct innovations of solar power utilization in agriculture through community led solar powered lift irrigation, an innovative solar tree structure and an agri-voltaic system for cultivating crop, harvesting solar energy and rainfall.





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COMMUNITY LED CO-INVESTMENT MODEL OF SOLAR POWERED LIFT IRRIGATION SYSTEMS IN KHUNTI, JHARKHAND

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| Sakshi Saini, CCAFS³

INTRODUCTION

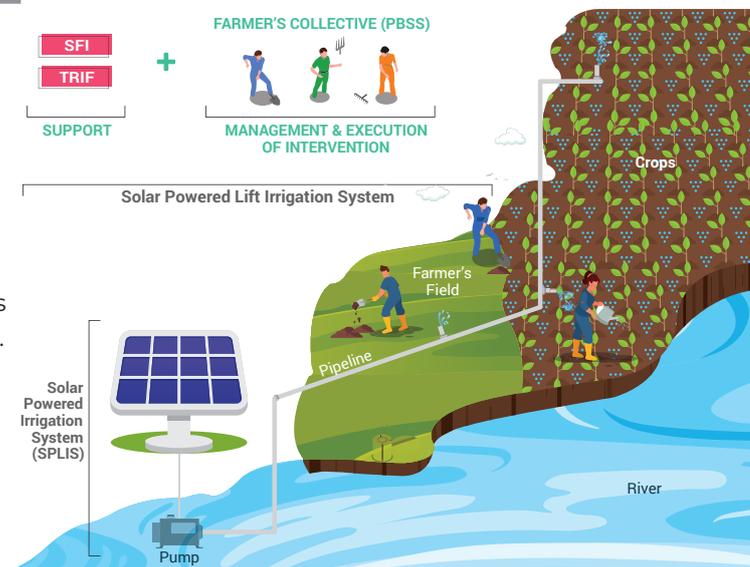
Emasculating the power envisaged in the subsidy, Solar Powered Lift Irrigation System (SPLIS) installed in Sisitola hamlet of Chandarpur village of Khunti district, Jharkhand, has been a beacon of hope for the farmers in Jharkhand. The 5 HP, AC solar pump installed by a farmers' collective who have been a member of the water users' group (WUG) titled "Panch Bandhu Sichai Samiti" has been irrigating farms of 23 farmers for the past one year. Syngenta Foundation India (SFI) has acted as a catalyst and enabling institution for this life-changing installation.



Figure 14.1: Location of Khunti district in Jharkhand

DESIGN OF THE INTERVENTION

This initiative employs participatory investment as an alternative finance mechanism, where farmers' collective bear forty percent of the total capital cost in addition to providing the human resource required for installing one SPLIS. Remaining 60% of finance is provided by Syngenta Foundation India (SFI). Ownership of the installed solar pump rests with all the farmers who paid for the pump. In addition to the installation of the solar pumps, SFI has also provided technical support and guidance to lay pipeline water supply systems for pumping and distributing surface water from the nearby river. This system aims to increase water conveyance efficiency by reducing seepage loss of water while irrigating an area of more than 12 acres. Farmers' involvement in the process right from GPS based irrigation site surveying to the installation of the solar pumps, has also ensured that the installed solar pump meets the requirement of the farmers.



Majority of the farmers staying in this region have been part of either a self-help group or a water user association (WUA), formed with the support and facilitation of an NGO Pradan. As a member of this group, they have been saving a minimum sum of INR 10 every week, for the past two decades. These savings turned into a boon and provided required money for the farmers to pay the part installation cost of the solar-powered irrigation systems. Most of the farmers could arrange their share of money from the savings done as a self-help group member, while only a few had to take a loan from their self-help groups.

ECONOMICS OF THE MODEL

Fields once barren due to lack of water have turned lush green with access to solar-powered irrigation systems. Plummeted cost of irrigation has led to a significant increase in the area under irrigation. Fields where only rice was being cultivated, are now giving space to vegetables. These vegetables (once seen as a luxury) are now a mundane portion of farmers' diet, besides selling surplus supply of the produce has led to an increase in the income of farmers. Compared to years previous to the installation of SPLIS, as reported, farmers' are earning double the money they earned earlier. This augmented inflow of money is paving way for an improved lifestyle for farmers. Pertaining to increased income, the majority of the farmers have enrolled their children in private schools, some share of income also supported the upgrading of clothing and shelter.

Collective investment and ownership of the asset, has motivated farmers to work together in a cognizant manner. In addition, they are also willing to put in the effort to make the best out of this technology to improve their incomes and reach the break-even point soon. With the support and guidance of SFI and TRIF (Transform Rural India Foundation), Agri-Entrepreneurs (AE) are encouraging farmers for diversifying the crops grown in the field. Crops like strawberry, watermelon, broccoli, etc. which were not even known to the tribal farmers of Jharkhand are now seen budding in their fields. These farmers not only practice crop diversification but also collectively decide on the area of land, on which this crop should be grown and in-turn the number of farmers to grow this crop. This is decided based on the quantity required to meet the requirement of one to two vehicles of a trader. Producing enough quantity to meet the demand of one trader, proves to be a lucrative offer for traders to themselves organize pickup of the crop, thus reducing the cost of travel for farmers. Hitherto, care is being taken to produce the quantity just enough to meet the existing demand of traders yet doesn't lead to a reduction in price due to oversupply. This collective planning is reducing the conflict of interest and competition between farmers. Farmers' collective group is emerging as a powerful entity that is able to excise the autarchy of traders and get the right price for the produce.



**COLLECTIVE
INVESTMENT AND
OWNERSHIP OF
THE ASSET, HAS
MOTIVATED FARMERS
TO WORK TOGETHER IN
A COGNIZANT MANNER**

CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- Community ownership is more as compared to fully subsidized models being implemented
- Farmers reported reaching break-even point within one year of installation
- Aftercare and maintenance is led by the community
- Capital investment of 40% (Subsequently 25%) is motivating farmers to take initiatives for improving agricultural practices and thereby income
- Group ownership reduces the individual vulnerability of the farmer, allowing them to make decisions that are perceived as risky.

DEMERITS:

- The involvement of a third party to interact with farmers, for demand generation is required.
- Intensive involvement of an NGO, the first installation required more than 30-35 meetings with farmers

Functional community groups (Self-help groups or water users group), had elucidated a pathway for financing such community-led initiatives. Existing camaraderie amongst the farmers enabled SFI to actualize their vision of facilitating shared ownership of the SPLIS to promote equity. Community groups in Jharkhand in addition to the coherent community structure has been the most important factor in supporting the implementation of this project. With shared ownership, per farmer cost of the solar pump was significantly reduced, yet the contribution of the farmers' to purchase SPLIS was high (40%), as compared to other individual ownership projects. This also made SPLIS an economically viable option for smallholder farmers.

Schneider Electric India Foundation (SEIF) approached SFI to contribute 35 % cost of capital cost, thereby reducing the farmer's contribution to 25% and SFI's contribution to 40%. Thus helping to scale up this project across Jharkhand state. Till date, 5 such systems under 40:60 financial model have been installed and another 30 groups have deposited 25% of the capital cost to SFI (under the revised model being implemented with support from SEIF), who in turn have submitted the same to the government registered installation company for setting up the system. The average duration between initiating the discussion and installation of one SPLIS has been around 1 month.

SCALABILITY

THE CONTRIBUTION OF THE FARMERS' TO PURCHASE SPLIS WAS **40%↑** AS COMPARED TO OTHER INDIVIDUAL OWNERSHIP PROJECTS

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Transform Rural India Foundation (TRIF)
Professional Assistance For Development Action (PRADAN)
Panch Bandhu Sichai Samiti (PBSS)

SOLAR TREE FOR IRRIGATION

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INTRODUCTION

An aesthetically appealing solar panel assembly in form of solar tree has been developed by CSIR-Central Mechanical Engineering Research Institute, Durgapur for power generation. The solar panels are arranged on a metal pillar further bifurcating in the form of branches, giving it the resemblance of a 'tree', hence the name 'solar tree'. One tree with 20 panels can generate power of a capacity of 5KW, enough to efficiently run a solar pump of 5HP. Dr. Rajendra Prasad Central Agriculture University (RPCAU), Pusa (Samastipur) later modified this technology for using it for irrigation in flood prone area of the Diara and Tal land situation of eastern India. The system has been specially designed for diara areas to firstly minimize the space consumption in placing panels, secondly to reduce the chances of intentional damage to panels and thirdly to protect the panels in case of flooding in the area. These benefits come at a cost of reduced efficiency of 10% as the present alignment of solar panels is such that few panels will fall under the shadow of the other solar panels. In addition, the direction of the panels cannot be changed with the course of Sun's path during the day. A sprinkler has been installed at the tip of the pump, as a cleaning mechanism for solar panels.



Figure 15.1: Location of Samastipur district in Bihar

The system is currently being piloted in Dhab areas of river Burhi Gandak at the university's farm. Five solar trees have been installed in the region to provide irrigation to diara areas, where there is no grid connectivity and farmers are dependent on expensive diesel pumping mechanisms.

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DESIGN OF THE INTERVENTION

Solar tree though saves the space as compared to normal installation, where solar panel of 1 KW capacity requires a minimum of 10 square meter area; the cost of these structures is much higher. A system of 5KW has costed Dr. Rajendra Prasad Central Agriculture University 5.5 lakhs at the time of installation (year 2017). Biggest benefit to farmers is its safety during swirling flood water. During floods of 2017 and 2019, the tree stood fury of flood water depth of five feet. A common solar panel system would have been washed away in this flood. Thus the trade-off will not be only between saving space and saving money, but also severity of floods and safety of installation far away from homestead will be an important parameter for a farmer to opt for this technology, once it is introduced to them. As of now, it is irrigating the diara area of PUSA farm in Samastipur. The pump can irrigate 20 acre of land for cultivating breeders' seed. Before the installation of the solar tree, this land has been barren due to the lack of irrigation facilities. The pumps installed in this area were difficult to maintain partly due to high diesel cost and partly due to the fright of the area being flooded. With aesthetically appealing solar trees coming to rescue in the area, the land has been under cultivation, leading to an increase in production and income for the Institute. The institute has been investing this money in doing further research on conservation agriculture.

ECONOMICS OF THE MODEL

The solar tree installations have been done as a research initiative by the institute, which aims to provide region-specific power solutions to irrigate the fields in diara region. The system was purchased from licensee of product given by CSIR institute after some modification to increase its suitability. Investment for the installations came from the research fund of Dr. Rajendra Prasad Central Agriculture University. Till date five such solar trees have been installed in the campus, providing energy for lighting the area as well as for providing irrigation to the farms. As a pilot in the field, the institute plans to install these solar trees for farmers sometime in the year 2020.

MERITS

- Reduces the chances of intentional damage and theft.
- Protects panels in case of flooding
- Aesthetically appealing
- Less installation space is required compared to conventional solar pumping system

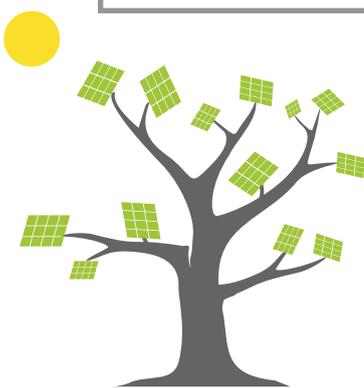
DEMERITS:

- Shadow of few panels falls on other panels, which in turn reduces the efficiency of the system. In case the shadow is to be completely avoided, the canopy of the tree has to be significantly increased.
- The cost of the solar tree based irrigation system is approximately double the cost of the regular solar pump of the same capacity but later is not useful in flood prone area.
- For cleaning of the solar panels, a sprinkler is to be installed at the tip of the structure.
- Direction of the panels cannot be changed.
- Yet to be introduced in field, thus response of the target group is yet to be evaluated.

CONCEPT SPECIFIC MERITS AND DEMERITS

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SCALABILITY



The solar tree is an innovative and attractive installation, which provides a solution to the existing power crisis of the farmers living in diara region. Though, the economic feasibility of the installation is nevertheless to be established. With other economically cheaper power options available to farmers, the solar tree will face tough competition when introduced to the farmers. The higher cost of the installation coupled with reduced efficiency (due to inability to move panels, and shadow on the panels) may limit the scaling out of this model. The solar tree model is a contextual solution targeted at a niche segment where flooding, panel theft and wastage of area under panel are the limiting factors for deployment of other SPIS models .

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AGRI-VOLTAIC SYSTEM (AVS) AT CAZRI EXPLORING THE POSSIBILITY OF CULTIVATING CROPS, GENERATING ELECTRICITY AND HARVESTING WATER

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INTRODUCTION

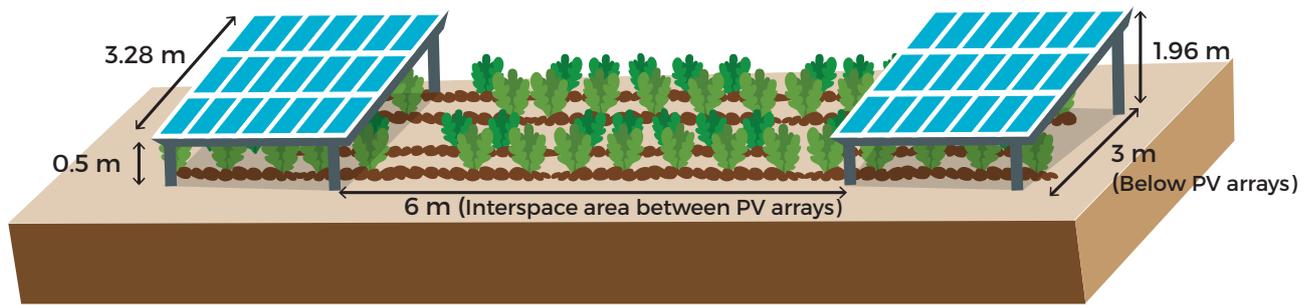
Land mounted Solar PV installation for energy production is still the dominant way of producing solar energy in the world. Locations, where land is extremely scarce, floating solar PV, has also been tried as an alternative. The ever-increasing value of land has proved to be a major impediment in scaling SPIS. A proposed mechanism to increase the return value of the land invested in SPIS installation is to improve land use and returns from the land via the co-production of food and energy. This can be easily achieved by enabling agriculture practices beneath the panels. Such systems where large scale energy production is coupled with crop production on the same land are referred to as Agro-photovoltaic (APV) systems or Agri-voltaic system (AVS). To allow farming under the panels, modifications are done in the technical design, especially the mounting structure of the solar PV. Also, only some of the crops, that thrive in partial sunlight or shade can be grown under the panels in these systems.

Keeping in mind the above requirements, AVS integrating both food production and PV generation from a single land-use system was designed and developed at ICAR-Central Arid Zone Research Institute(CAZRI), Jodhpur. The system was designed with a capacity of 105 kWp and installed in about 1 acre land (26°15'27.82" N and 72°59'34.57" E). In the AVS, crops are cultivated at interspace areas between PV arrays as well as under the PV areas. Another important feature of the AVS is the rainwater harvesting with the top of PV as a catchment area. The harvested water is stored in a water storage tank, which is used for cleaning of PV module and for providing supplemental irrigation to crops.

DESIGN OF THE INTERVENTION

The AVS was designed and experimented under a research program of CAZRI to test and demonstrate a co-generation model. The agri-voltaic system was installed with three technical designs each at a separate block of 35 kWp in an area of 32 × 32 m. PV array designs in the three blocks of the AVS were different and these are (i) single row PV array (ii) double row PV array and (iii) triple row PV array. The single row model consisted of one row of PV module in the array whereas double and triple row model consisted of two rows and three rows of PV module in the array, respectively. Performance evaluation of the systems showed that double row AVS is the most feasible system.

The double row model has the bottom row with full density whereas top row has a PV density of 60% and following this design for 400 kWp AVS can be installed in 1 ha area. The inclination of PV module was kept as 26°, which is almost equal to the latitude of the experimental site.



ECONOMICS OF THE MODEL

The AVS may bring huge opportunity to dryland farmers since rainfed agriculture is more vulnerable than irrigated agriculture because of uncertainty and scarcity of rainfall. Initial investment to install 400 kWp capacity AVS in 1 ha is about Rs 1,68,00,000/- considering the unit price of Rs 42,000/- per kWp. Annual income from selling of PV generated electricity is about Rs 29,20,000/- per year with a decrease of 1% per year considering PV generation of 4 kWh per kWp system per day and electricity tariff rate of Rs 5 kWh-1. Additional income of Rs 50,000-60,000/- per ha can be generated from crop yield in the AVS. Life cycle cost analysis of the system shows a payback period of 5.87 years, a discounted payback period of 10.4 years, and an internal rate of return of 16%.

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CONCEPT SPECIFIC MERITS AND DEMERITS

MERITS

- Increased income from farmland and land productivity (land equivalent ratio may be increased up to 1.41)
- Reduction in soil erosion by wind and dust load on PV module,
- Improvement in microclimate for crop cultivation and optimum PV generation
- Rainwater harvesting with panels serving as catchment area. The harvested rainwater can be used for cleaning PV modules and irrigating crops (1.5 lakh litre per acre and can provide 40 mm irrigation in 1 acre land)
- Soil moisture conservation by reducing the wind speed on the ground surface
- Reduction in GHG emission (598.6 tons of CO₂ savings/year/ha)

DEMERITS:

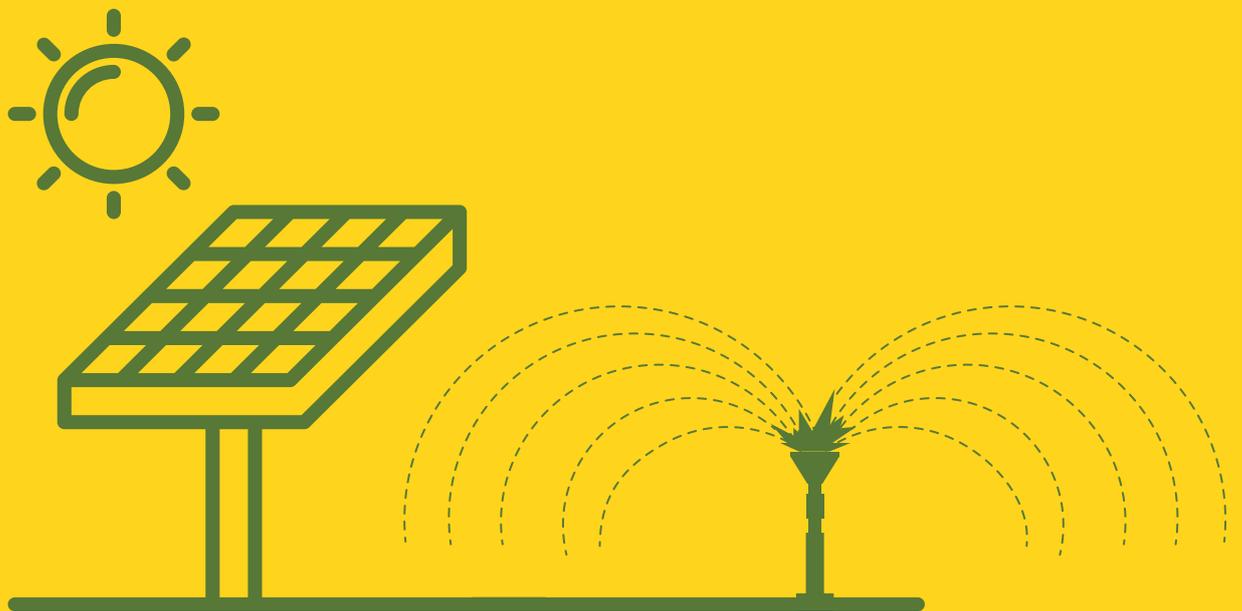
- High aeolian activity in arid zone during hot summer months poses challenges in PV generation
- Power grid network at farmer's field is limited for the evacuation of PV generated electricity.
- Off-grid agrivoltaic systems may be possible but large capacity of such a system may not be feasible.
- Safety of field workers engaged in agricultural activity
- Ownership issue: Farmer and solar power plant functionary
- High capital investment during initial establishment

SCALABILITY

The concept of AVS system may be implemented in farmers' field in arid and semi-arid regions of the country where land productivity is inherently low and solar energy is available in plenty. Renewable Energy Service Company (RESCO) model can be formulated for the installation of AVS in farmers' field for food production and PV based electricity generation from a single land unit. Recently, launched PM-KUSUM (Kisan Urja Suraksha evam Utthaan Mahaaabhiyan) scheme by Government of India promotes the integration of solar energy and agriculture through three components; – a) entailing installation of MW scale Solar Power Plants to power agriculture feeders, b) off-grid solar pumps and, c) grid-connected solar pumps respectively. In all the three components, farming under the panels can be done. In component B and C, since the solar PV will be installed in farmers' fields, farmers may experiment with growing different crops under the panels. It is more likely that farmers in arid and semi-arid ecosystem or having less land will adopt the practice first. But additional income from the sale of energy is only possible in grid-connected solar pumps (component C). But in component A, where developers will install power plants, they may or may not adopt the farming practice depending on its ease and lucrativeness.

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SYNTHESIS





THE TRINITY

Different models of SPIS deployment are addressing one or more objectives. Careful analysis of the different deployment models indicates that the objective is either to improve the accessibility of energy and through it, access to irrigation; or improve the affordability of energy and irrigation; or improve the sustainability of existing energy-water use in irrigation, or a combination of more than one of these (figure 5).

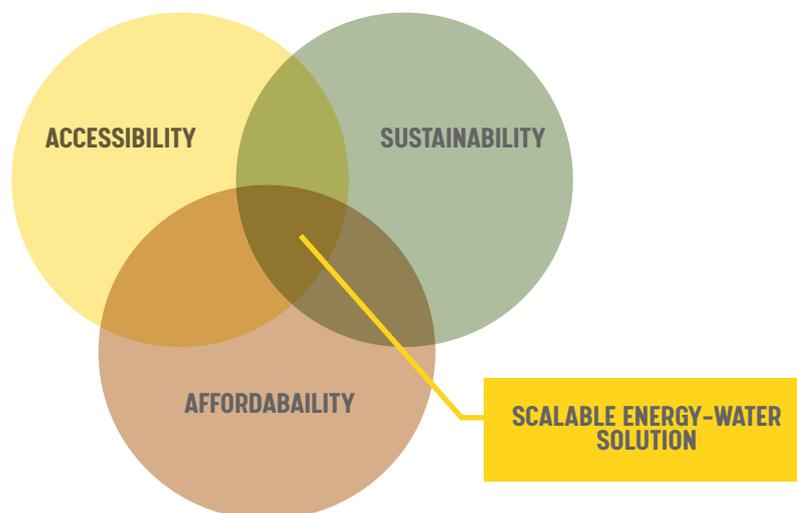


Figure 5 Requirements of a scalable water energy solution

Scalable models will be the ones that are nearing the core of the above diagram and hence achieve all the three tenets to some extent i.e., these models will improve accessibility, affordability of energy, and therefore water for irrigation without threatening the sustainability of water use. Traditional attempts at evaluating solar powered irrigation systems largely focused on economic and technical performance. Such evaluations pose significant challenges to scaling out in diverse agro-ecological conditions.

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DEFINING ACCESSIBILITY, AFFORDABILITY AND SUSTAINABILITY

Accessibility

Accessibility is a broadly accepted term in multiple fields like transportation, geography (Hu & Domns 2019) and was initially used primarily to measure potential interaction opportunities in transportation networks (Hansen 1959, Hu and Domns 2019). Later it was defined as the difficulty in reaching a destination from a given location (Ala-Hulkko et. al 2016) and was explained better by using two key attributes: spatial distribution of potential destinations and spatial resistance that needs to be overcome (Paez et. al 2012, Wang et. al 2018).

In the context of irrigation, 'potential destination' reflects water sources like wells, tube-wells, piped outlets, etc and 'resistance' reflects the distance, slopes and other physical hindrances which makes it difficult to reach the source. Indicators such as the density of wells/pumps, time taken to access a unit of water can be the indicators of understanding the accessibility of fixed irrigation pump sets. However, these indicators will not be applicable if the portability of the pumping system is ensured. This is so because, once the system is made portable, it will be able to cover a larger command area and benefit a greater number of farmers thus indicating a lower density. Therefore, in this report, if the system has portability feature, these indicators are not used instead it is taken as imperative that portability as a feature enhances accessibility.

The other aspect apart from physical accessibility, which contributes to improved access to irrigation is the ease of adoption of irrigation technology. The ease with which farmers will acquire the skills and

capacities required to understand and use the technology effectively will determine the accessibility of technology in the longer run. Therefore in irrigation, if farmers understand how to acquire, operate and maintain their irrigation systems, it results in improved accessibility of irrigation. This aspect however important is difficult to capture in the current analysis but will be covered in subsequent detailed analysis of selected cases.

Affordability

There is no universally accepted definition of energy affordability (Flues and Dender 2017) but there are some indicators or rules such as Ten Percent Rule (TPR), Minimum Income Standard (MIS) among others, which are widely used to compare the affordability of [domestic] energy and are based on the expenditure on energy. The TPR says that households spending more than 10% of disposable income on electricity face challenges in affording energy (Boardman 1991, Flues & Dender 2017) whereas MIS indicates if, after the energy expenditure, the income falls beneath the poverty line. These indicators along with several others are largely used for assessing energy poverty in the context of domestic energy. These indicators might not be useful for agriculture or livelihoods context because of the energy use intensity changes with crop, agro-climatic region, weather etc. Hence, instead of using the total expenditure on electricity (or energy) for irrigation, we will be comparing only the price per unit of electricity i.e. Rs/kWh. This price will be the levelized cost of energy (LCOE) and will account for the capital cost and maintenance cost across the lifetime of the project. The lower bound is the subsidized tariff offered for agriculture usage by the government but considering subsidy as a non-permanent policy instrument, we will be using the average cost of agriculture electricity supply which hovers around Rs 4.5-6/kWh.

Sustainability

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Sustainable systems are defined as “systems which survive or persist” in simplified context (Costanza and Patten 1995). The assessment of sustainability can be done ex-ante and ex-post, and for both types, different terminologies are indicating a lack of consensus on technicalities of defining “sustainable systems” and measuring sustainability. (Pope et al. 2017). Costanza and Patten 1995 explain that there are fundamental complexities related to defining and assessing sustainability and have captured them in three questions i.e. “(1) What system or subsystems or characteristics of systems persist? (2) For how long? (3) When do we assess whether the system or subsystem or characteristic has persisted?”. They explain that in economic systems sustainability is “avoiding major disruptions and collapses and hedging against instabilities and discontinuities” and can only be examined after the fact. Therefore only predictions of sustainability are being made about a system ex-ante and if the prediction holds true, the system is said to be sustainable. The other complexity about tagging a system sustainable is with respect to the timeline of sustainability and sustainable systems might come across as “maintenance forever” systems. Therefore it is imperative to understand that sustainability being used in absolute terms is not useful until it is assessed through a comparison. For instance solar engines will deem more sustainable than diesel engines if impact on air quality is the criterion for analysis. Hence, It is difficult to assess the sustainability of one system in isolation but few systems can be compared for relative sustainability if they share common threads.

It will be useful to understand that all the deployment models are fulfilling one or more objectives of improving Accessibility – Affordability- Sustainability of energy-water use in agriculture to some degree. Also, the distinction between these tri-objective is not very strict i.e. they are neither independent nor mutually exclusive. There would be some correlations between the three broadly identified objectives. For instance, accessibility and affordability are linked to some extent because, after a certain level, an increase in accessibility may result in an increase in affordability too. Similarly, there might be an inverse correlation between affordability and sustainability and an increase in one might result in a reduction of the other. Therefore, it is imperative to consider the objective of the pilot as envisaged by its promoters.

UNDERSTANDING DIFFERENT CASES

The 16 cases presented in the compendium were designed by their promoters with some objectives. However, as discussed, the cases reveal that their objectives are grounded somewhere in-between the improvement of the trinity - accessibility, affordability and sustainability. In this section, we have tried to compare the objectives envisaged by the promoters as revealed in the cases with respect to results achieved to understand if the models broadly achieved what they were meant to.

1. Improving Accessibility and Affordability

When there is less density of pumping devices, the portability of a pumping device can significantly enhance the accessibility of irrigation. Diesel pumps, therefore contributed to improving the access to energy regions away from grid. But the high cost of diesel did not improve the affordability of irrigation. Portable SPIS filled the gap and targeted at improving both accessibility and affordability at the same time. It can be seen that the models targeting accessibility and affordability are situated in regions having poor grid connectivity or energy supply (Table 2). Remote areas of Bihar and Jharkhand still are not well connected with grid, especially the irrigation loads. Maharashtra and Madhya Pradesh may have grid infrastructure but the electricity supply is erratic and inadequate forcing farmers to rely on diesel pumps. Hence, most of the experiments intended at improving accessibility and affordability of irrigation have been done in eastern and central regions of the country, which have poor grid connectivity and electricity supply.

It can be seen from Table 2 that portable solar pumps in Betul, Madhya Pradesh, Solar Feeders in Maharashtra and Lift Irrigation Scheme in Jharkhand have been able to provide affordable access of irrigation to farmers (owners and sellers) and also have least LCOE (landed cost of energy). The MSWPs in Vaishali, Bihar have a marginally higher rate but still perform fairly in improving the accessibility and affordability of irrigation for farming communities. However, the smaller size of MSWPs increases the time for irrigation and hence the benefit cannot be extended to others without owning the MSWP.

Table 2 Models targeted at improving accessibility and affordability of irrigation , GWD (Groundwater Development)

Experiment	State	LCOE (At 100% utilization and capital cost)	LCOE at current utilization and 100 percent capital cost	Rs/kWh (cost to owner)	Rs/kWh (cost to other farmers)	GWD (%)	Remarks
Case 1: Portable SIPs in Women Groups	Madhya Pradesh	3.33	10.00	-	10.00	57.65	Portability improves access and solarisation improved affordability
Case 2: Solar Boat	Bihar	8.33	41.67	10.00	50.00	67.55	Portability improved access but affordability is not ensured
Case 3: Portable Solar Trolley	Bihar	5.83	72.92	60.00	60.00	62.28	Portability improved access but affordability is not ensured

Case 4: Micro Solar Water Pumps (MSWP)	Bihar	3.9	3.9	-	-	62.28	Portability improves access and solarisation improved affordability but smaller pumps increase the
Case 9: Tail-end Solar Feeder Plants	Maharashtra			0	5.00	29.82, 79.45	Access to day time electricity
Case 14: Solar Lift irrigation Scheme	Jharkhand	3.33	3.33	1.33		23.13	Access to electricity when needed

2. Improving Affordability

The cases where access is not limited i.e there is a good density of irrigation structure energised with diesel pump sets, it is the affordability which limits irrigation. With an innovative financial model or intervention design, if diesel pumps can be replaced with adequately sized SPIs, the cost of irrigation and viability of associated livelihoods can be significantly improved. The majority of SPIs in this category are promoted by very high capital subsidy limiting the size and people who can use/share the pump. Also, the small size pumps are not fully able to replace diesel pumps and therefore do not become the primary pumping devices. If adequately sized pumps are promoted then, the capital subsidy will have to be reduced and some credit mechanism has to be brought in place. Table 3 shows different models aimed at improving the affordability of irrigation and almost all but Chakhaji experiments have subsidies to the tune of 70-90 percent. But all models have significantly improved the affordability of irrigation, at least for the primary beneficiary. The secondary beneficiaries are those who buy irrigation from pump owners. It can be seen that they have been most benefitted in the Nalanda and Chakhaji Experiments.

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Table 3 Models targeted at improving affordability

Experiment	State	Capital Subsidy (%)	LCOE (At 100% utilization and capital cost)	LCOE at current utilization and 100 percent capital cost	Rs/kWh (cost to owner)	Rs/kWh (cost to other farmers)	GWD (%)	Remarks
Govt Subsidized - Off Grid SIPs	India	70-95	3.33	8.33	1.25	50.00		Replacement of diesel pumps with SPIs significantly improves the affordability of energy-water, making vegetable cultivation, fishing viable livelihoods.
Off Grid Pisciculture	Bihar	70-95	3.33	3.33	0.50	-	47.25	
Donor Subsidized - Off Grid SIPs	West Bengal	70-95					20.5	
Salt Pan SIPs	Gujarat	95	5.00	9.38	0.63	-	83.37	
Nalanda Experiment- Minor Irrigation Dept.	Bihar	100	3.54	5.31	-	11.25	68.84	
Solar Irrigation Service Provider Model in Chakhaji	Bihar	50	3.33	3.33	1.00	20.00	47.25	

3. Improving Sustainability of Water Use

The two models aimed at improving the sustainability of water use employed a similar strategy of offering opportunities to farmers to utilize the surplus electricity for direct sale to the power utility. The driver of behaviour change has been assumed to be the opportunity cost of electricity. In cases where a thriving water market exists, the opportunity cost of electricity for irrigation is the rate of farmer fetches by selling irrigation to neighbours. But this transaction however recorded in most cases is not always obligated i.e the buyer might pay after the crop is harvested, might not pay if the crop fails or market price of the crop crashes etc. Hence, they are multiple transaction costs present in water markets and the recovery is seldom 100 percent. But farmers, in thriving water markets, do sell irrigation because the earnings sometimes are substantial and there is also kinship, which is maintained through this transaction. In the absence of the water markets, there is no opportunity cost of free electricity, usually supplied by the grid (similarly by off grid SPIs). The lack of incentives would not result in the sustainable use of water, therefore the models have introduced the incentive in the form Feed-in-tariff (FIT) i.e the electricity tariff to be paid to the farmers if they do not use but sell the electricity generated on their land. This FIT provides an opportunity for farmers to earn risk-free and climate-proof income. However, if the FIT is substantially low then it fails to change farmers' behaviour. The two cases revealed that where FIT was substantial and operational, farmers were incentivised to conserve water and earn additional income (SPaRC initiative) but in the other case where FIT was only notional, farmers behaviour did not change and they continued to use same or more water as earlier (Table 4).

Table 4 Models aimed at improving the sustainable use of groundwater

Experiment	State	GWD	LCOE (At 100% utilization and capital cost)	LCOE at current utilization	Rs/ kWh (cost to owner)	Rs/kWh (cost to other farmers)	Feed-in-tariff (Opportunity Cost of Surplus Electricity) [Rs/kWh]	Remarks
Case 10: Surya Raitha Experiment	Karnataka	96.56	2.5	2.5	0	-	1.00	Incentive to economise groundwater use to earn additional income
(not operationalized yet)	Notional incentive therefore no positive impact on groundwater use	96.56	2.5	2.5	0	-	1.00 (not operationalized yet)	Notional incentive therefore no positive impact on groundwater use
Case 11: SPaRC initiative	Gujarat	48.83	2.7	2.7	0.21	12.00	3.5	Incentive to economise groundwater use to earn additional income

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