GUIDEBOOK

Implementing Solar Irrigation Sustainably:

A guidebook for state policy-makers on maximizing the social and environmental benefits from solar pump schemes

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Implementing Solar Irrigation Sustainably: A guidebook for state policy-makers on maximizing the social and environmental benefits from solar pump schemes

December 2021

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Acknowledgements

The International Institute for Sustainable Development (IISD); The Energy and Resources Institute (TERI); the Council on Energy, Environment and Water (CEEW); and the Initiative for Sustainable Energy Policy (ISEP) would like to thank everyone who contributed to the formulation of this guidebook.

In particular, we would like to thank our colleagues who supported the implementation of the survey in Haryana and Jharkhand and interpreted the guidebook survey findings, including Shruti Sharma, Tom Moerenhout, Michael Aklin, Sonakshi Saluja, Johannes Urpelainen, and the team from Morsel.

We would also like to thank the many government officials, financial institutions, DISCOMs, and thematic experts who agreed to participate in in-depth interviews and share their advice and experiences.

The authors of this guidebook would like to thank the following individuals and institutions for the valuable comments and recommendations that they provided as peer reviewers:

- Michael Aklin, Initiative for Sustainable Energy Policy
- Vineet Bhandari, Dalberg
- Clementine Chambon, Oorja Development Solutions Limited
- Priya Jadhav, Indian Institute of Technology Bombay
- Meha Jain, University of Michigan
- Mrinal Krishna Chaudhury, Assam Energy Development Agency
- A.V. Manjunatha, Karnataka Evaluation Authority
- V. Geethalakshmi, Tamil Nadu Agricultural University
- Nikhil Goveas, Koan Advisory Group
- Mohinder Gulati, World Bank
- Eshita Gupta, KPMG
- Rajeev Gyani, International Solar Alliance
- Mohanaiah Paladi, ex-CGM, NABARD
- Thomas Pullenkav, Independent Consultant
- Shobhit Srivastava, Ministry of New and Renewable Energy
- Shilp Verma, International Water Management Institute

This publication could not have been undertaken without the generous support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Promotion of Solar Water Pumps (PSWP) program, including substantive inputs and support from Mandvi Singh, Florian Postel, and Nilanjan Ghose, as well as co-funding from the governments of Denmark, Norway, and Sweden. The opinions expressed and the arguments employed in this guidebook do not necessarily reflect those of the peer reviewers and funders, nor should they be attributed to them.

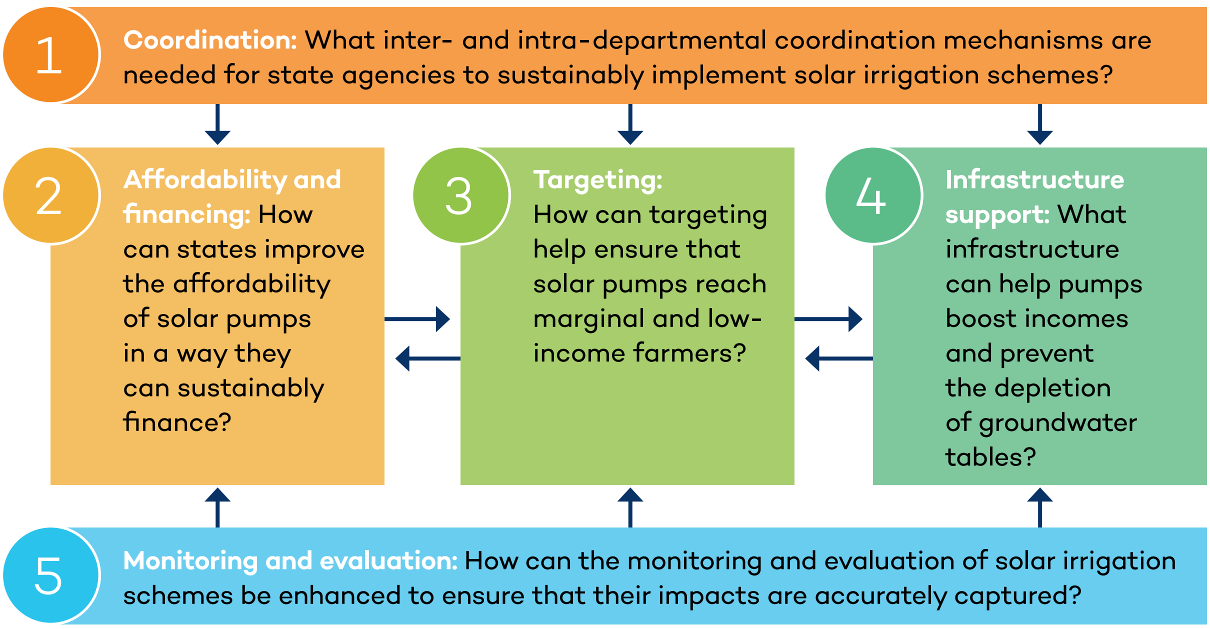
Executive Summary

The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme, launched in 2019 by the Ministry of New and Renewable Energy (MNRE), aims to usher in the sustainable transformation of India's agricultural sector through solar irrigation. The scheme has the potential to revolutionize the sector, which has been beset with the structural challenges of low farm productivity, falling groundwater tables through underpriced electricity, and stagnant farmer incomes.

This guidebook provides state policy-makers and agencies with recommendations for how solar irrigation can be implemented sustainably, focusing on standalone (or off-grid) and grid-connected pumps. It does not cover PM-KUSUM components A and C (feeder-level solarization), which will be addressed in a subsequent publication. It is designed to help achieve PM-KUSUM's main objectives in ways that maximize economic and social benefits while avoiding unsustainable water use:

- Expanding irrigation coverage and moving away from polluting diesel pumps through the deployment of 2 million standalone solar pumps by 2022.
- Boosting farmer incomes through increased agricultural productivity and the creation of alternate income streams by enabling users of grid-connected pumps to become prosumers.
- Reducing the subsidy outlay of state governments from under-priced electricity. Total electricity subsidies are estimated to have been worth over INR 195,000 crore (USD 25.7 billion) in fiscal year 2019, with around 75% of this for agriculture.

It provides practical and concise recommendations by drawing on practitioner experience through consultations with state officials and other stakeholders, as well as synthesizing previous research on state experiences with solar irrigation and the water–energy–food (WEF) nexus. This is focused into guidance and illustrative examples of good practice over five main focus areas:



1 Coordination

WHY DOES IT MATTER?

Good coordination—between state agencies and vertically from field-level officials to senior bureaucrats—ensures that schemes consider WEF interlinkages and convergence with allied schemes on micro-irrigation and crop diversification.

KEY RECOMMENDATIONS:

- Leverage expertise of at least six critical state agencies: (1) renewable energy development agencies, (2) departments of agriculture and horticulture, (3) electricity distribution companies (DISCOMs); (4) departments of water resources, major and minor irrigation and groundwater, (5) departments of rural development, and (6) departments of finance. For grid-connected pumps, system integrators should also be involved in implementation.
- Establish formal coordination mechanisms, such as interdepartmental bodies and convergence and steering committees for WEF nexus policies. Similar mechanisms have been adopted for other schemes, such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY).
- Consider decentralizing the implementation responsibility for standalone pumps to district collectors in states with strong local administrative capacity to improve ground-level coordination.
- Focus on the same beneficiaries and districts for solar pumps and micro-irrigation to create financial savings and promote water use efficiency in agriculture.
- Integrate solar pumps into state and comprehensive district agricultural plans, district irrigation plans, and state training programs for district officials to ensure they are part of the agricultural transformation agenda and can bolster farmer incomes.

2 Financing and affordability

WHY DOES IT MATTER?

Affordability and financing are closely intertwined. The more public support there is to reduce the capital cost of solar pumps, and therefore make them more affordable for farmers, the higher the financing challenge for states and the harder it will be to maintain support over time.

KEY RECOMMENDATIONS:

- A joined-up approach between central and state agencies and financial institutions to decrease subsidies by reducing pump costs, increasing buyer resources, and sustainably financing schemes.

- Reduce pump costs by (1) exploring bulk procurement to achieve economies of scale, (2) establishing payment security facilities for financial institutions to lower the cost of capital and disburse subsidies on time, (3) establishing a loan default guarantee fund to reduce the risk perception of lending to farmers, (4) providing interest subsidies to lower the cost of borrowing, and (5) swapping subsidies for grid electricity with support for solar irrigation.
- Increase buyer resources by (1) issuing clear prosumer metering policies for grid-connected pumps to reduce payment uncertainty, (2) coordinating with other agriculture and irrigation policies to increase crop productivity and farmer incomes, and (3) boosting financial inclusion by pairing schemes with Kisan Credit Cards and building awareness with ground-level information services.
- Finance schemes by: (1) linking up resources from agriculture, horticulture, and irrigation policies, such as PMKSY and the National Horticulture Mission; (2) reducing subsidies as solar pump costs fall and social acceptance increases; and (3) subsidy reforms or surcharges for grid electricity.
- Explore partnerships with financial institutions, such as the National Bank for Agriculture and Rural Development, to help finance subsidies through the Agriculture Infrastructure Fund and scale up implementation.

3 Targeting

WHY DOES IT MATTER?

Targeting is essential for social and environmental objectives, including making sure that pumps benefit low-income and small and marginal farmers and that pump size and location are appropriate in light of a region's available groundwater resources.

KEY RECOMMENDATIONS:

- Prioritize standalone solar pumps in areas where farmers lack access to irrigation and by avoiding areas where groundwater tables are low or declining. Grid-connected pumps should be prioritized in areas where electricity supply is unreliable and the cost of supply is high.
- Prioritize support for pump sizes that meet small and marginal farmers' needs, avoiding both oversizing and undersizing. Linking a state's subsidy contribution to pump capacity with a higher share for lower-capacity pumps can discourage the practice of oversizing pumps.
- Consider the following eligibility criteria: (1) reserving a share of pumps for low-income farmers, (2) relaxing land-ownership rules so tenant and women farmers can benefit, and (3) requiring solar pumps to be paired with efficient irrigation practices, such as micro-irrigation technologies.
- Address barriers to participation, including (1) promoting ownership models, such as community and entrepreneurship models, and (2) increasing digital literacy and

awareness by leveraging networks of Common Service Centres, agriculture extension officers, Bank Sathis, or Yuva Mitras.

- Build demand for pumps through education, awareness, and engagement, as only a small percentage of farmers may know about solar pumps and associated government schemes.

4 Infrastructure support

WHY DOES IT MATTER?

In some cases, the right infrastructure must be in place for solar pumps to work at all. In others, it can significantly improve benefits for farmers and enhance water use efficiency.

KEY RECOMMENDATIONS:

- Enhance water use efficiency by 1) bundling solar pumps with micro-irrigation technologies like drip and sprinkler systems; 2) leveraging surface water sources and creating water storage capacity, and 3) promoting regular cleaning and maintenance to prevent leakages and breakdowns.
- Enable metering for prosumers for grid-connected pumps by 1) deploying smart meters, 2) designing clear metering mechanisms that give prosumers sufficient incentives, 3) building institutional capacity to boost farmer participation, 4) selecting the appropriate feeder and boosting grid reliability, and 5) addressing the free-rider challenge by installing watchdog transformers for non-participating farmers.
- Explore new solutions to promote the efficient use of energy and water, such as 1) universal controllers for standalone pumps so energy can be used for non-irrigation activities, including micro-cold storage and food processing; 2) financial incentives to discourage groundwater extraction; and (3) technologies to remotely curtail pumps. For all such innovative approaches, there is limited evidence, so states should carefully pilot and monitor impacts.
- Capacity building of farmers on the effective use of solar pumps and groundwater management, as well as DISCOM staff through the Suryamitra program for grid-connected solar pumps.

5 Monitoring and evaluation

WHY DOES IT MATTER?

Monitoring and evaluation is essential to track the impacts of solar irrigation schemes on farmer well-being and water, and as such, must go beyond only collecting technical data on the performance of pumps. Solar Energy Data Management (SEDM) platforms, alongside complementary data collection, can be used to evaluate outcomes in these areas.

KEY RECOMMENDATIONS:

- Use data from SEDM platforms, alongside supplementary data collection efforts, to monitor and evaluate outcomes for farmer well-being and groundwater impacts. Supplementary data collection efforts should include annual or biannual representative surveys of farmers and water conditions, including a review of non-scheme factors that also affect outcomes.
- Monitor and evaluate social impacts by examining if schemes are well targeted to low-income farmers; do not create undue costs for farmers, such as multiple office visits and excessive paperwork; are well coordinated with allied social policies; and have created income benefits.
- Monitor and evaluate water impacts by examining if schemes are effectively targeted to areas with low stress on water resources, are coordinated with allied water policies, and do not result in declining viability of groundwater resources.
- Conduct random field testing at regular intervals to validate the data from remote monitoring systems. Previous state experiences with remote monitoring systems suggest that this will be necessary to ensure the reliability of the data that is being fed into the system.
- Beyond contributing to data collection, involve stakeholders in M&E through capacity building for farmers and vendors on using the SEDM platforms, site visits to explore challenges, and quarterly or biannual written analysis of social and water platforms that is shared through multistakeholder discussion forums.

Box A1. Key implementation-focused tools to support states in decision making on solar irrigation

1. **The Council on Energy, Environment and Water solar pumps site selection tool** – A comprehensive web-based analytical tool to assist stakeholders in geographically targeting the adoption of PM-KUSUM and solar irrigation in specific districts across India. Link to the tool: https://portal.ceew.in/
2. **The International Water Management Institute (IWMI) solar pumps sizing tool** – The solar-powered irrigation system sizing tool is a decision support system that is designed to help states provide guidance on the appropriate sizing of solar pumps to farmers. An Excel version of the tool is available from IWMI, and it can be downloaded as a mobile app.
3. **The SEDM platform** – The SEDM platform hosts data on scheme processes, such as progress with applications, subsidy disbursal, and management of complaints, as well as technical parameters from each pump's remote monitoring system. As of November 2021, seven operational state portals were integrated with the national SEDM portal. The national SEDM platform can be accessed through the following link: https://pmkusum.mnre.gov.in/landing.html

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Abbreviations and Acronyms

AC	alternating current
AIF	Agriculture Infrastructure Fund
APEPDCL	Andhra Pradesh Eastern Power Distribution Company Limited
BEE	Bureau of Energy Efficiency
BLDC	brushless direct current solar pumps
CADA	Command Area Development Authority
CADWM	Command Area Development and Water Management programme
CEEW	Council on Energy, Environment and Water
CREDA	Chhattisgarh State Renewable Energy Development Agency
CSO	civil society organizations
DC	direct current
DCC	District Consultative Committees
DISCOM	distribution company
DRE	distributed renewable energy
EESL	Energy Efficiency Services Ltd.
FiT	feed-in tariff
FPO	Farmer Producer Organization
FY	fiscal year
GERMI	Gujarat Energy Research and Management Institute
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GUVNL	Gujarat Urja Vikas Nigam Limited
IISD	International Institute for Sustainable Development
IRENA	International Renewable Energy Agency
IWMI	International Water Management Institute
JOHAR	Jharkhand Opportunities for Harnessing Rural Growth
KCC	Kisan Credit Card
KVK	Krishi Vigyan Kendras
M&E	monitoring and evaluation
MGNREGA	Mahatma Gandhi Natural Rural Employment Guarantee Act

MNRE	Ministry of New and Renewable Energy
NABARD	National Bank for Agriculture and Rural Development
NGO	non-governmental organization
OLTC	on-load tap changers
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahaabhiyan
PMKSY	Pradhan Mantri Krishi Sinchai Yojana
REDA	Renewable Energy Development Agency
RIDF	Rural Infrastructure Development Fund
RKVY-RAFTAAR	Rashtriya Krishi Vikas Yojana Remunerative Approaches for Agriculture and Allied Sectors Rejuvenation
RMS	remote monitoring system
SEDM	solar energy data management
SKY	Suryashakti Kisan Yojana
SLBC	State Level Bankers' Committee
SIA	State Implementation Agency
SPIS	solar-powered irrigation system
TERI	The Energy and Resources Institute
UJALA	Unnat Jyoti by Affordable LEDs for All
UP	Uttar Pradesh
USPC	universal solar pump controller
UT	Union Territory
WEF nexus	water–energy–food nexus

1.0 Introduction

In 2019, the Government of India launched a major scheme to promote solar-powered irrigation, Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahaabhiyan (PM-KUSUM), including:

- A – 10 GW of decentralized ground-mounted, grid-connected renewable power plants
- B – 2 million standalone solar-powered agriculture pumps
- C – 750,000 solarized grid-connected pumps and 750,000 pumps under feeder solarization.

Solarizing irrigation has huge potential. Cost-effective and reliable irrigation can significantly improve farmer incomes and well-being. Shifting away from highly subsidized grid electricity can relieve financial pressure on electricity distribution companies (DISCOMs)—a review of tariff orders in 17 states and Union Territories (UTs) found that 75% of all such subsidies go to agriculture (Aggarwal et al., 2020). Furthermore, solar-powered irrigation can help India shift to clean energy, reducing air pollution and greenhouse gas emissions. At the same time, care must be taken to implement solar irrigation sustainably. There are complicated interconnections between water, energy and food—often called the "water–energy–food nexus" or WEF nexus—where interventions in one area can cause unexpected impacts in another.

This guidebook has been developed in cooperation with the Ministry for New and Renewable Energy (MNRE) and is dedicated to supporting state policy-makers and agencies in sustainably implementing solar irrigation by achieving economic objectives while considering both social and environmental sustainability. First, on social outcomes, how can schemes maximize benefits for low-income farmers? Second, on environment, how can schemes minimize risks of over-withdrawal of groundwater? Based on an initial needs assessment, it considers these objectives over five major themes:

1. **Coordination:** What inter- and intra-departmental coordination mechanisms are needed?
2. **Affordability and financing:** How to make pumps affordable within state financial constraints?
3. **Targeting:** How to make sure the right-sized pumps go to the right beneficiaries and locations?
4. **Infrastructure:** What infrastructure can boost farmer benefits and reduce groundwater risks?
5. **Monitoring and evaluation (M&E):** What aspects of schemes should be monitored and evaluated?

Photo: GIZ/Vipin Singh

As a guidebook, this publication is based on the best available evidence, but it is not a research paper. We focus on practical suggestions for state policy-makers and implementing agencies with illustrative examples, drawing on a combination of secondary and primary research, including:

- Reviews of existing policy research literature
- 40 in-depth interviews with state and central officials, scheme stakeholders, and policy experts
- Case studies on state schemes in Andhra Pradesh, Gujarat, and Rajasthan (see Annex)
- A telephone survey of 3,200 farmers in Haryana and Jharkhand
- In-depth interviews with 20 farmers in Uttar Pradesh (UP) who have been using solar pumps
- Two multistakeholder roundtables with policy-makers and experts in Haryana and Jharkhand.

This guidance is focused only on standalone and grid-connected pumps, while a future publication will address feeder solarization. It is intended to directly assist with implementing PM-KUSUM but also to be relevant for any solar irrigation scheme, including future policies once PM-KUSUM is completed.

2.0 Coordination

2.1 Why Does Coordination Matter?

Implementing solar irrigation is challenging because of complex interconnections between water, energy, and food—the WEF nexus (Beaton et al., 2019). Coordination between state institutions and stakeholders can ensure that such linkages are considered. In turn, this helps to achieve core policy objectives and prevent negative externalities, such as risks of groundwater depletion when solar pumps replace conventional pumps in water-stressed areas.

Coordination can also focus on convergence between solar irrigation schemes, such as PM-KUSUM, and allied WEF nexus schemes, such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Rashtriya Krishi Vikas Yojana Remunerative Approaches for Agriculture and Allied Sectors Rejuvenation (RKVY-RAFTAAR), and Atal Bhujal Yojana. This can generate financial savings for state agencies by co-financing solar irrigation schemes (Alam et al., 2020) and help achieve better environmental outcomes by pairing solar pumps with efficient water use and crop diversification practices.

Box 1. Coordination to build on existing expertise: JOHAR in Jharkhand

Coordination can also build on the expertise of state agencies or civil society organizations (CSOs) that have previously deployed solar pumps, providing useful lessons for state implementation agencies (SIAs). For example, Jharkhand State Livelihood Promotion Society, the state's rural development department, implemented community models for solar pumps in a project called Jharkhand Opportunities for Harnessing Rural Growth (JOHAR). Under PM-KUSUM, Jharkhand State Livelihood Promotion Society's inputs could help the SIA improve outreach to marginal farmers and tribal communities.

2.2 Who Needs to Be Involved in Solar Irrigation Schemes?

PM-KUSUM guidelines say that states must designate a single department to act as the implementation agency for each scheme component. This does not, however, mean that other departments and stakeholders should not be involved. SIAs can work with many different actors to effectively implement solar irrigation schemes. Drawing on in-depth interviews with numerous stakeholders, Table 1 elaborates on the expertise of the six most critical departments to include in scheme coordination, if they are not themselves acting as the lead agency:

- State renewable energy development agencies (REDAs)
- Departments or agriculture or horticulture
- DISCOMs
- Departments of water resources, minor and major irrigation, and groundwater
- Departments of rural development
- Departments of finance.

Aside from these main agencies, other organizations that can be involved in scheme coordination include financial institutions such as the National Bank for Agriculture and Rural Development (NABARD), public sector units, Krishi Vigyan Kendras (KVKs or farm science centres), agricultural universities, experienced state-level CSOs, and system integrators.

Institutions are well suited to specific points in a scheme, as shown in Figure 1.

Figure 1. Key agencies that should be involved across the value chain of a solar irrigation scheme

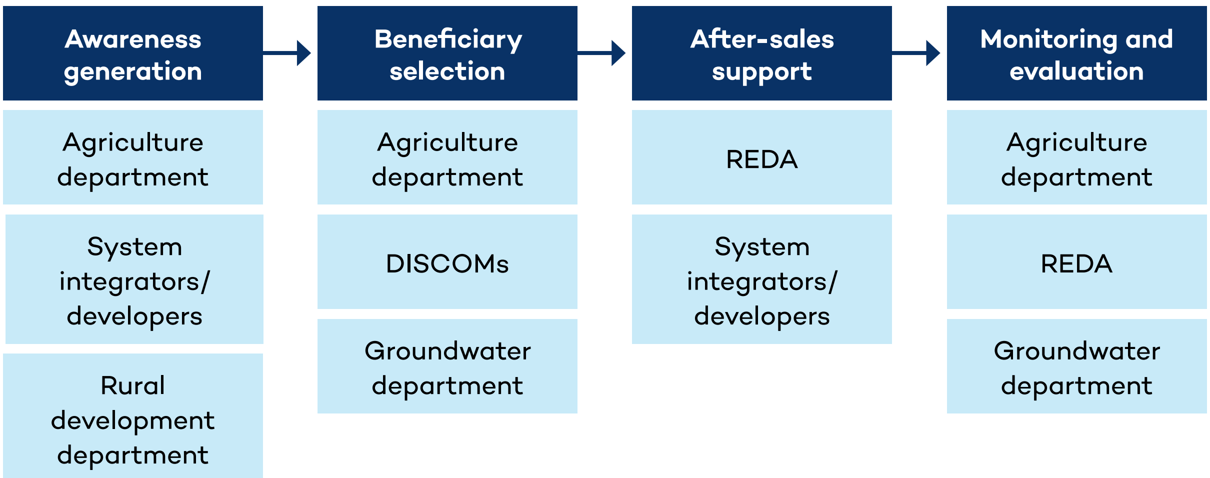
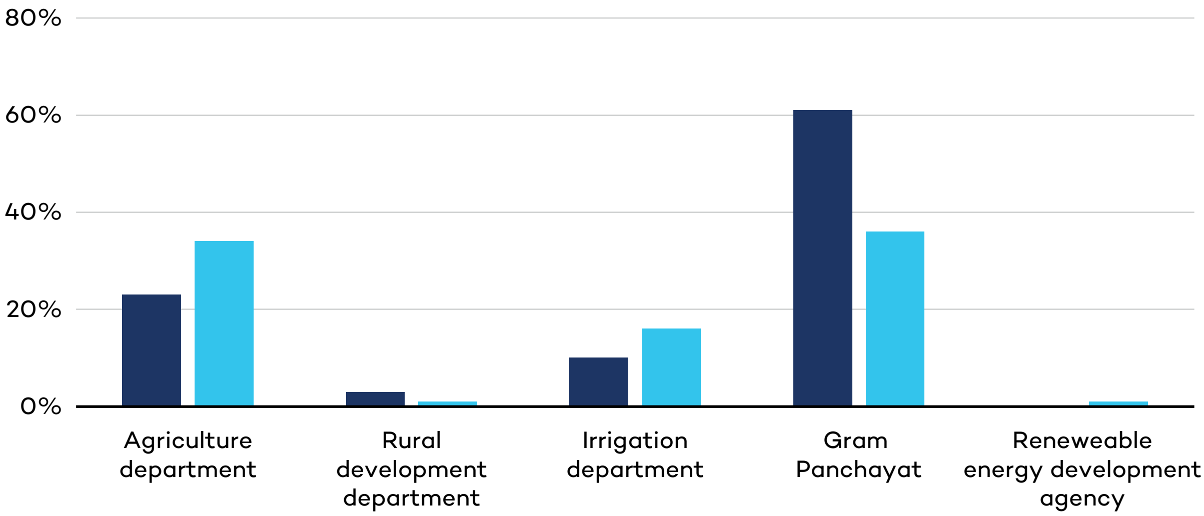


Table 1. The roles of six critical departments in sustainably implementing solar irrigation

Institution	Role	Allied Policies
Renewable energy development agencies (REDAs)	In many states, REDAs are nodal agencies for component B of PM-KUSUM, focused on standalone solar pumps. They have experience in deploying decentralized renewable energy in rural areas, including formulating regulatory and policy frameworks, liaising with the private sector, and developing ecosystems for monitoring and after-sales services.	PM-KUSUM component B, Atal Jyoti Yojana
Departments of agriculture and horticulture	These departments have established relationships with farmers, making them well suited to identify small and marginal farmers and anticipate their concerns, particularly on changing existing pumps and diversification toward high-value and low-water-intensive crops. Their strong field presence through KVKs and district-level agricultural officers can help build awareness about schemes, train farmers on pump use and water conservation, and enable site visits to complement data from remote monitoring systems (RMSs). They are also responsible for micro-irrigation schemes, such as PMKSY, that can be converged with solar pumps and the formulation of district and state agriculture plans.	PMKSY, RKVY-RAFTAAR, National Horticulture Mission, National Food Security Mission, National Mission for Sustainable Agriculture

Institution	Role	Allied Policies
Electricity distribution companies (DISCOMs)	DISCOMs play a key role in implementing PM-KUSUM components A and C and help SIAs target standalone pumps to farmers with erratic power supply. For grid-connected pumps, they are essential in developing metering for "prosumers"—so farmers can sell solar electricity back to the grid, incentivizing efficient water consumption—as well as billing, timely payments, and investing in feeder infrastructure. Experience with rooftop solar schemes may help tackle deployment challenges.	PM-KUSUM component A and C, Rooftop solar, Saubhagya
Departments of irrigation, water resources and groundwater resources	These departments have a mandate to prevent overexploitation of state groundwater resources, build surface irrigation resources and water recharge points, and enhance irrigation access. They can help SIAs improve scheme targeting by identifying districts and villages that have adequate groundwater resources and those that are overexploited. They can also provide support for monitoring impacts, with scientific expertise in technical areas like water depth, groundwater recharge rates, and irrigation intensity, as well as issuing early warnings to communities. They are responsible for formulating district and state irrigation plans.	Jal Shakti Abhiyan, Atal Bhujal Yojana
Departments of rural development	These departments are well connected with low-income, marginal, and tenant farmers through the National Rural Livelihoods Mission, which can assist in targeting, as well as communication and building awareness. They can also support the productive use of pumps by promoting universal solar pump controllers (USPCs), identifying financing sources, creating market linkages, and holding demonstrations. They can help converge pumps with the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) public works scheme to create farm ponds to store water and promote community- and village-level models for schemes, such as under Project JOHAR in Jharkhand (Singh, 2020).	National Rural Livelihoods Mission, MGNREGA
Departments of finance	Finance departments' buy-in is needed to ensure adequate multi-year budgetary allocation. They can also help SIAs avail loans for capital subsidies for pumps and micro-irrigation and leverage existing relations with financial institutions to facilitate lending, such as NABARD, the Micro Irrigation Fund, and the Agriculture Infrastructure Fund (AIF).	Financial inclusion schemes

Figure 2. Which agency is most trusted for information on irrigation?



Source: Authors, guidebook survey.

Apart from "horizontal" coordination, which works between institutions, case studies and interviews suggest it is important to consider "vertical" coordination, from the top to the bottom of each institution: from the secretary level, down to the district- and field-level implementing officials. Senior officials have regular interaction with political leaders, whose buy-in can expedite decision making. District- and field-level officials are the primary touchpoints for farmers, with key insights for policy implementation, particularly around monitoring and evaluation—see Section 5 for detailed recommendations. It is also important to ensure vertical coordination externally with central ministries such as MNRE in order to highlight any scheme-related concerns and share beneficiary details.

A survey of farmers in Haryana and Jharkhand undertaken to support this guidebook—henceforth the "guidebook survey"—confirms the importance of horizontal and vertical coordination (see Figure 2). Farmers reported most trust in agriculture and irrigation departments, reflecting their frequent interactions and established relationships. The highest trust, however, was with Gram Panchayats, confirming the importance of ground-level institutions. Nonetheless, SIAs must still be proactive in developing direct engagement: another survey, focused on pump users, found that the after-sales experience was better with good communication between the SIA and beneficiaries (KPMG & GIZ, 2021).

2.3 What Strategies Can Help to Improve Coordination Between Departments?

Several states have successfully implemented solar irrigation schemes. Interviews with officials in these states identified four formal and informal mechanisms that were important for coordination.

Strategy #1 – Interdepartmental bodies

A dedicated working unit can ease scheme implementation, helping areas such as targeting, beneficiary selection, M&E, and grievance redressal, such as the Rajasthan Agriculture Competitiveness Project (RACP) in Rajasthan (see Box 2). Such bodies can be chaired by a senior state secretary or joint secretary-level official to expedite decision making, facilitate timely approvals, and gain necessary support from other departments and financial institutions. This requires adequate financial resources and should be budgeted as part of the scheme design. Alternatively, a dedicated state-level working unit can be created to implement complementary WEF nexus schemes, such as the PMKSY, PM-KUSUM, and Atal Bhujal Yojana, with the participation of implementing officials from relevant SIAs. This can help conserve resources, promote convergence, and facilitate information-sharing across state agencies.

Box 2. Rajasthan Agriculture Competitiveness Project

The RACP was a World Bank-supported project on solar irrigation that involved an interdepartmental body (Government of Rajasthan, n.d.). It was steered by a consortium of officials from departments such as agriculture, horticulture, animal husbandry, water resources, and energy. In interviews, RACP officials were strongly positive about this approach, noting that it helped leverage each department's unique strengths, with agriculture and horticulture departments helping to understand farmers' needs while water resources and energy departments provided expertise on efficient water management and solar pumps. According to officials, the project contributed to the productivity and income of farmers and encouraged crop diversification to facilitate a reduction of water use. The project is estimated to have resulted in a 25% increase in crop productivity and a 47% reduction in the water used in agriculture over the baseline in selected locations in Rajasthan (World Bank, 2020).

Strategy #2 – Convergence and steering committees

Convergence and steering committees have been used regularly by states in the past for tracking the implementation of specific schemes; they are a lighter option than dedicated working interdepartmental bodies. Such committees typically include senior officials from different departments and are convened monthly or quarterly to monitor scheme progress, discuss challenges, and take decisions on next actions, such as Haryana's steering committee for the Atal Bhujal Yojana scheme (see Box 3). Such committees may involve departmental secretaries presenting details on a range of schemes, making them a good place to identify opportunities for convergence between policies. These committees typically report to a state's chief secretary or departmental secretary, and it is recommended that the committee should convene once a month for effective monitoring.

Box 3. Haryana: Steering committee for the Atal Bhujal Yojana scheme

In in-depth interviews in Haryana, state officials described how the Department of Irrigation and Water Resources recently established a steering committee under the Atal Bhujal Yojana scheme, including representatives from departments responsible for irrigation, energy, and agriculture. They recommended a similar approach for PM-KUSUM, with a high-level committee under the guidance of a secretary or joint secretary and representatives from different departments to resolve implementation challenges and promote convergence between allied WEF nexus schemes.

Strategy #3 – Delegation of planning and implementation responsibilities to different departments

SIAs should establish clearly defined responsibilities for departments involved in implementation, ideally drawing on the respective strengths of different agencies, such as Rajasthan's efforts to include major relevant departments in the planning of its 2011 solar pumps scheme (see Box 4) or Chhattisgarh's efforts to delegate specific functions to agencies based on their technical strengths (see Box 5). These responsibilities may need to be assigned at both the state level, through interdepartmental bodies or steering committees, and the district level, under the purview of district collectors in states with strong local administration capacity. Coordination and time-bound implementation can be facilitated by developing a dashboard for tracking progress on tasks that is visible to all stakeholders.

Box 4. Rajasthan: Coordination mechanisms at the secretary level

Under Rajasthan's 2011 scheme to subsidize solar pumps, the Department of Horticulture (the nodal agency) developed well-defined roles for the agriculture and renewable energy departments. This created a sense of equal ownership by involving department officials in planning meetings and field visits from inception. As a result, secretaries from all three departments regularly monitored the scheme's progress. In interviews, officials suggested that this sense of equal ownership and active involvement from secretaries is a good model that can help tackle coordination challenges and ensure seamless ground-level implementation. The involvement of secretary-level officials and political leadership, in particular, was thought to be key in achieving high impacts: Rajasthan had installed 16,852 standalone solar pumps by 2019, the third-highest quantity in the country (Prasad, 2020).

Box 5. Chhattisgarh: Coordination mechanisms at the district level

Under the Saur Sujala Yojana (SSY) in Chhattisgarh, the Chhattisgarh State Renewable Energy Development Agency (CREDA) worked closely with the agriculture department, NABARD, MNRE, and system integrators. CREDA devolved responsibilities for beneficiary selection to the agriculture department, given their better networks with farmers. System integrators were encouraged to undertake surveys to identify potential beneficiaries and motivate them to apply. Responsibility for coordination and monitoring was given to district collectors. Inter-agency issues were sorted out during weekly meetings chaired by the district collector, in which officials from all departments were present. In interviews, CREDA officials suggested that this decentralized model had worked well and could be replicated elsewhere. With this approach, Chhattisgarh managed to deploy 60,430 standalone solar pumps by 2019, the highest in the country (Prasad, 2020).

Strategy #4 – Partnerships with financial institutions

In addition to coordination between state departments, an overlooked but critical mechanism for the success of solar pumps schemes is coordination between states and financial institutions. This can help both with loans that are provided to improve affordability for farmers and for financing the state's subsidy contribution—for experiences with this in Chhattisgarh, see Box 6 and Section 3.

In particular, SIAs can leverage SLBCs to promote coordination with financial institutions at the state level, while District Consultative Committees (DCCs) that are chaired by the district collector can act as a forum for the coordination of activities between government agencies and financial institutions at the district level. Under PM-KUSUM, for example, SIAs can formalize a partnership with SLBCs and DCCs by signing a Memorandum of Understanding and participating in discussions with financial institutions regarding the disbursement of PM-KUSUM loans through the SLBC's subcommittee on energy. This would help promote lending for solar irrigation schemes and improve the monitoring of loan disbursal targets by financial institutions.

Box 6. Chhattisgarh: Partnerships with NABARD for SSY scheme

Institutional loans from NABARD have been critical in financing Chhattisgarh's subsidy contribution under the SSY scheme. NABARD has provided low-interest loans to the state government under its Rural Infrastructure Development Fund (RIDF) fund program, which has helped the state cover nearly 70% of the capital cost of the standalone solar pumps. In in-depth interviews, CREDA officials explained that the proposal for this loan was agreed through the state's Department of Finance, which also receives the loan amount from NABARD and then releases it to the Department of Energy. This experience underscores the importance of SIAs working with state departments of finance to pursue partnerships with financial institutions to finance their subsidy contributions.

Figure 3. A summary of coordination strategies

Interdepartmental bodies

- Dedicated working unit
- Officers on deputation from state departments
- Implementation-focused
- Require adequate financial resources

Case Study: Rajasthan Agriculture Competitiveness Project (RACP)

Steering committees

- Secretary-level officials
- Convened every month
- Monitor scheme progress and resolve coordination challenges
- Identify convergence opportunities

Case Study: Atal Bhujal Yojana scheme in Haryana

Delegation and devolution of KUSUM responsibilities

- Leverage each state department's unique strengths
- Promote coordination at the district-level in states with strong local capacity

Case Study: Rajasthan's 2011 solar pumps subsidy scheme

Partnerships with financial institutions

- Help in financing states' subsidy contribution
- Improved access to credit for farmers
- Leverage SLBCs and DCCs for coordination with banks

Case Study: Saur Sujala Yojana in Chhattisgarh

2.4 What Strategies Can Help to Improve Coordination Between Policies?

Strategy #1 – Targeting the same beneficiaries for solar pumps and micro-irrigation

As recommended by PM-KUSUM guidelines, combining solar pumps with micro-irrigation can, if operated properly, improve water use efficiency. SIAs can do this by targeting similar districts and beneficiaries—the Council on Energy, Environment and Water (CEEW) Solar Pumps Tool can help identify such locations (see Section 4) (CEEW, n.d.). SIAs are recommended to share data on beneficiaries with departments for agriculture, horticulture, and water resources, and vice versa. They can also explore incentives: for example, a higher subsidy for farmers who adopt water conservation measures. States in water-scarce regions can also consider mandating micro-irrigation, but this would likely require support to ensure affordability for low-income farmers and not remove the need for complementary measures, such as incentives on crop choices and careful monitoring (see Box 7).

Photo: GIZ/Vipin Singh

Box 7. Rajasthan: Mandating water efficiency to qualify for solar pump subsidies

In Rajasthan, the Department of Horticulture made it mandatory for beneficiaries of the 2011 solar pumps scheme to install drip irrigation and create a *diggi*, a water storage mechanism. This was facilitated by a 90% subsidy on drip-irrigation systems and 50% subsidy or INR 2 lakh for constructing a *diggi* (Kishore et al., 2014). The department estimates that the migration to drip irrigation saved 48 million m^3 of water because of its higher efficiency (Goyal, 2013). A later study found that although the irrigated area expanded and crop productivity increased, the total volume of water use did not go down (Kishore et al., 2014). This suggests that mandating micro-irrigation may not reduce overall water extraction and needs complementary measures.

Strategy #2 – Identification of the right WEF nexus policies for convergence with PM-KUSUM

The irrigation needs of different districts can vary significantly, so it is vital for SIAs to identify the right policies for convergence. The CEEW Solar Pumps Tool can help identify these policies (CEEW, n.d.). For example, Har Khet Ko Pani falls under the PMKSY scheme and focuses on improving access to groundwater irrigation. SIAs can use the tool to filter for all districts where the "unirrigated net sown area" is more than 50%. The tool also covers schemes on Per Drop More Crop and Doubling Farmers' Income.

Figure 4. Har Khet Ko Pani

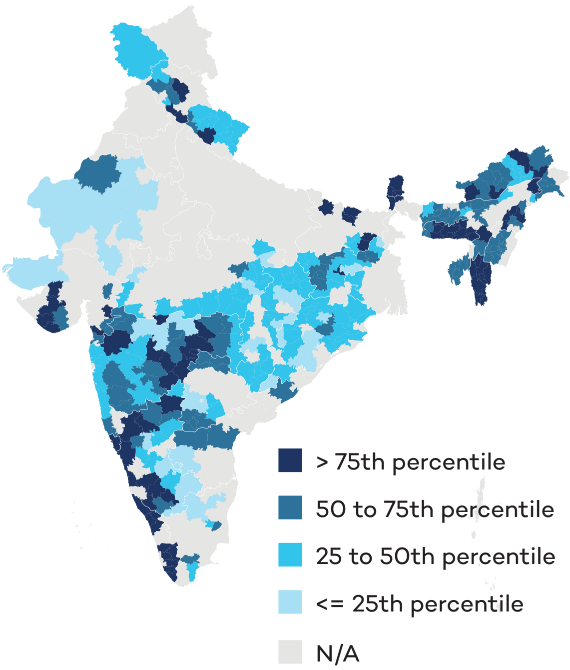
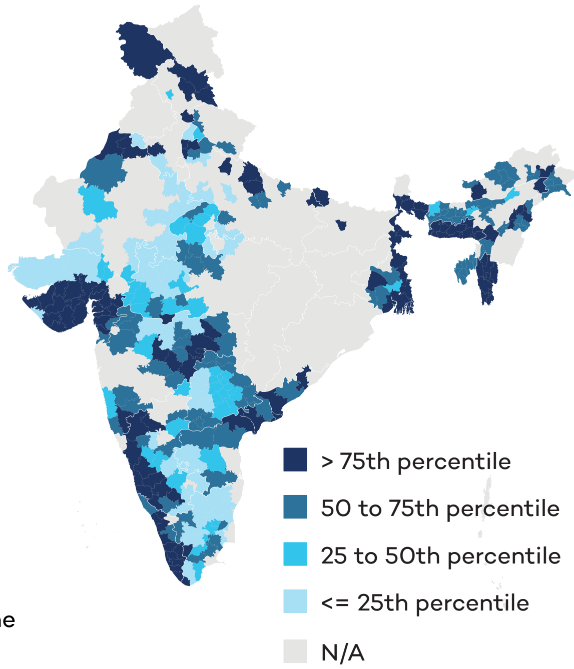


Figure 5. Per Drop More Crop



Source: CEEW, n.d. The darker the district is shaded, the more suitable it is for scheme convergence.

Strategy #3 – Integration with agricultural plans and irrigation plans

Solar pump schemes can be integrated into broader agendas on agricultural transformation. The Ministry of Agriculture schemes such as RKVY-RAFTAAR aim to promote holistic rural development by increasing public investment in agri-infrastructure and mandating state- and district-level agricultural plans (Ministry of Agriculture & Farmers Welfare, n.d.). Similarly, under Ministry of Jal Shakti schemes, states are creating district irrigation plans to identify gaps in infrastructure based on district agricultural plans and highlighting water sources, distribution networks, and water use applications, including irrigation. SIAs can ensure that solar pump schemes are included in planning by engaging with these departments (see Box 8).

Box 8. Chhattisgarh: Inclusion of SSY in district agricultural plans

In Chhattisgarh, CREDA decided to devolve the entire responsibility for beneficiary selection to the agricultural department under SSY. This, alongside regular communication between both agencies, has led frontline agricultural staff to incorporate the SSY scheme into their annual agriculture plans, alongside other agricultural schemes being implemented in the district. Interviews with state officials suggested that this facilitated the integration of solar pumps into the state's agricultural strategies.

Strategy #4 – Training programs and guidelines on convergence

Interviews suggest that convergence between schemes is often not reflected on the ground due to a lack of awareness among district- and block-level officials. Training could help address this gap and enable field officials to better inform farmers. Interviews also suggested that clear guidelines from state agencies outlining steps to operationalize convergence could help reduce ambiguity at the ground level. It is recommended that procedures for training and capacity building are built into state policies and implementation plans (Box 9). SIAs must assign responsibilities to specific departments for undertaking training, developing a training syllabus, providing budgetary allocation, and procuring training materials. Monthly or quarterly monitoring meetings with secretaries or joint secretaries can help ensure accountability and tackle coordination challenges.

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Box 9. Training and capacity building in the National Health Mission

Training and capacity building of frontline health workers or accredited social health activists is outlined in detail in the National Health Mission policy (National Health Mission, n.d.). The policy mandates that state- and district-level officials regularly conduct training and capacity-building activities of accredited social health activists to upgrade their skills and outlines mechanisms for collaboration with non-governmental organizations (NGOs).

2.5 Key Recommendations

Coordination mechanisms, such as interdepartmental bodies and convergence and steering committees, can ensure that the inputs of different state departments are reflected in the design and implementation of PM-KUSUM and solar irrigation schemes.

Partnerships with financial institutions through an MoU with SLBCs and DCCs can help states finance their subsidy contributions and boost lending.

Vertical integration strategies within a state agency from senior bureaucrats to district-level officials, and externally with central agencies like MNRE, can complement horizontal integration across departments.

Focusing on the same beneficiaries can help converge solar pump and micro-irrigation schemes, which can yield financial savings and promote water efficiency—the CEEW solar pumps tool can assist in this planning.

Integrating solar pumps into state and district agricultural and irrigation plans and training programs for district officials can ensure that they are viewed as an essential component of states' agricultural transformation.

Coordination

Further guidance and resources

The CEEW Solar Pump Site Selection Tool – https://portal.ceew.in/. If any state wishes to organize a demonstration or workshop for the tool, please contact CEEW at info@ceew.in.

Beaton et al. (2019), *Mapping Policy for Solar Irrigation Across the Water–Energy–Food (WEF) Nexus in India:* https://www.iisd.org/publications/solar-irrigation-wef-nexus-india

Alam et al. (2020), *Convergence and Co-Financing Opportunities for Climate-Resilient Water Management:* https://cgspace.cgiar.org/handle/10568/109072

3.0
Affordability and Financing

Photo: GIZ/Vipin Singh

3.1 Why Do Affordability and Financing Matter?

One of the main barriers to the uptake of solar-powered irrigation is that many farmers cannot afford the high upfront capital cost of a solar pump, even if it could save them money in the medium term. In Jharkhand, for example, 55% of surveyed farmers stated that the main reason for their lack of interest or indecision in buying a solar pump was its high cost. States can help address this affordability barrier by providing capital subsidies—but this creates a new challenge: how to finance such support?

For standalone pumps in components B and C of PM-KUSUM, MNRE has benchmarked a 3 HP solar pump at INR 1,68,300 in fiscal year (FY) 2021 (Clean Energy Access Network, 2019; MNRE, 2020a). The Central Government will cover 30% of pump costs, and states will cover a further 30%. The remaining 40% (INR 67,320 for a 3 HP pump) is to be paid directly by farmers or partly by a loan (up to 30% of the pump cost) and partly from farmers (the remaining share). It is not always easy for farmers to qualify for loans: they have few assets to pledge as security, and banks are worried about farmer defaults, which stood at INR 83,153 crore in FY 2018 and have been growing (Mathew, 2018). This reluctance is despite the fact that institutional credit for solar pumps can contribute to commercial banks' priority sector lending targets. States can pay more than 30% of the cost of solar pumps if they think it is necessary to ensure affordability.

Financing and affordability are therefore closely intertwined. The more support there is for affordability, the higher the financing challenge for states and the harder it will be to maintain support over time. If support is lower, financing will be less of a challenge, but farmers may struggle to participate—particularly small and marginalized farmers, a key target group for PM-KUSUM. This challenge has intensified as a result of COVID-19. Farmers have seen incomes fall at the time that state government finances are stressed by many new demands.

3.2 Two Key Strategies

There are two major strategies that can help address challenges in this area:

1

A joined-up approach to tackling affordability
In most states, solar irrigation is still heavily dependent on a "high subsidy" model to overcome affordability barriers and achieve targets. But this cannot be sustained indefinitely. For solar irrigation to operate at scale, efforts are needed to reduce subsidies over time (Agrawal & Jain, 2018). This requires joined-up thinking between central and state agencies and financial institutions across the factors that determine affordability.

2

Strategies to sustainably finance solar irrigation
There is no "magic bullet" to overcome states' financing challenges. But a number of states have adopted different financing approaches to raise revenues and reduce costs over time. Their strategies can be looked to as a set of options to help overcome financing barriers for solar irrigation schemes.

3.3 A Joined-Up Approach to Tackling Affordability

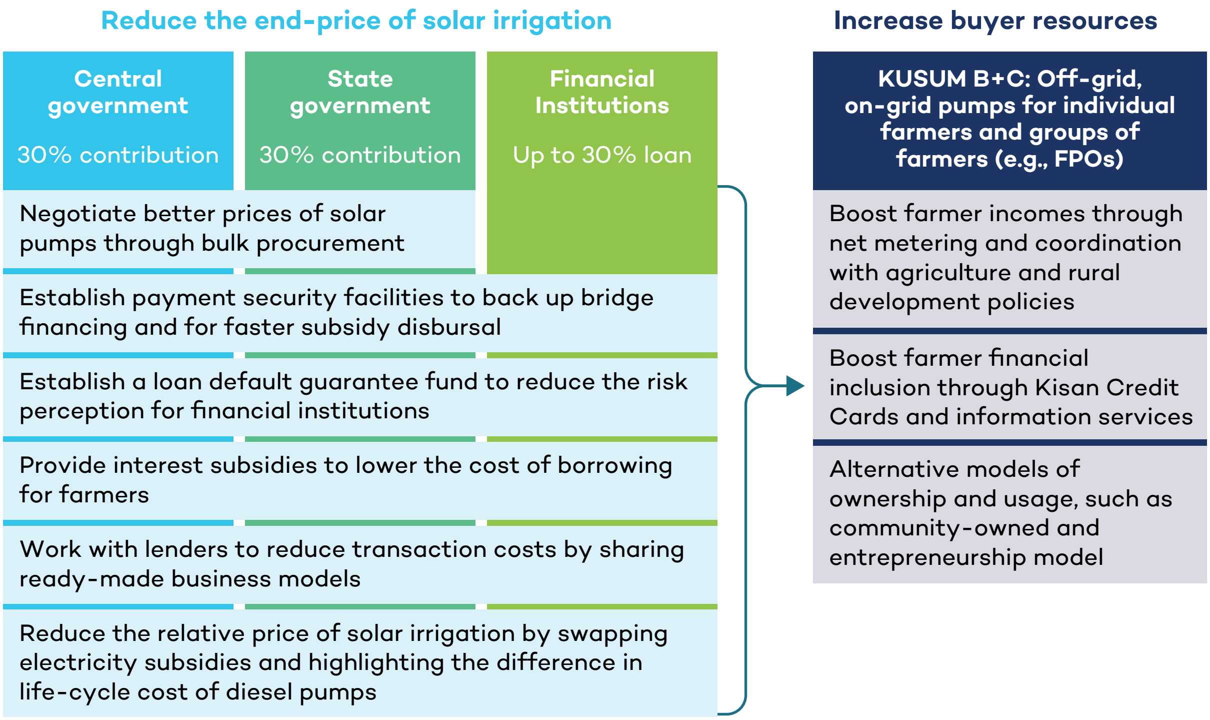
"Affordability" is determined by many different factors, most of which fall into one of two categories: first, factors that influence the price of solar pumps; and second, factors that influence the resources of "buyers"—farmers. Figure 6 illustrates some key interventions in each category. Individually, each one may have a small impact—but together, they are practical steps to exit a "high subsidy" model.

3.3.1 Reducing the End Price of Solar Pumps

3.3.1.1 NEGOTIATE BETTER PRICES WITH BULK PROCUREMENT

A large institution can usually negotiate better prices for solar pumps than many individual buyers if it buys in bulk, creating economies of scale. This can also standardize the market and reduce the need for highly specialized last-mile services. The success of Unnat Jyoti by Affordable LEDs for All (UJALA) is a good example: it reduced LED bulb prices by 75% in 4 years (Energy Efficiency Services Limited & International Energy Agency, n.d.). PM-KUSUM already involves large central and state tendering processes, so this is principally a strategy that future schemes should also seek to adopt. Bulk procurement must be complemented with a streamlined process for distribution to ensure it does not affect the pace of deployment and is complemented with proper quality control.

Figure 6. A joined-up approach to tackling affordability



Source: Authors.

Additionally, SIAs need to adjust the portfolio of pump types they procure based on local conditions and the needs of state farmers. For example, in eastern states with a relatively high water table, lower-capacity pumps can be sufficient for most farmers (Shakti Sustainable Energy Foundation, 2018). The selection of companies must be determined by their service centre network, with regular performance review mechanisms specified as a pre-requisite in the tender process.

3.3.1.2 REDUCE COSTS OF LENDING IN COOPERATION WITH FINANCIAL INSTITUTIONS

- **Payment security facilities:** Many PM-KUSUM stakeholders anticipate late payment of subsidies. This would create serious cash-flow problems for suppliers, lenders, and beneficiaries, driving up risk and increasing the cost of finance (cKinetics & Climate Policy Initiative, n.d.). States can reduce risk perceptions by establishing a payment security facility at institutions like NABARD, Solar Energy Corporation of India Limited or the Indian Renewable Energy Development Agency Limited to provide guarantees for lenders who provide "bridge financing"— that is, loans that cover cash flow needs from the point of project approval through to deployment and eventual receipt of subsidies (cKinetics & Climate Policy Initiative, n.d.). This would also enable smaller financial institutions to lend, such as scheduled commercial banks, regional rural banks, and cooperative banks—which provide most loans to agriculture and allied activities (CEEW, 2018).

- **Loan default guarantees:** Interviews with PM-KUSUM stakeholders found that ground-level staff in financial institutions may hesitate to offer loans to farmers with poor or uncertain credit scores. SIAs can help by establishing a loan default guarantee fund. This will reduce the risk for financial institutions and facilitate the flow of finance to low-income farmers who lack collateral to qualify for solar pump loans. SIAs could pay for the loan default guarantee fund by reducing a portion of their subsidy contributions. A similar loss default guarantee fund was created by SwitchON Foundation, a not-for-profit organization, with Punjab National Bank for lending to farmers for solar pumps (See Box 10). It has been previously used by the Ministry of Micro, Small and Medium Enterprises (n.d.) to improve access to the financing of small and medium-sized enterprises.

- **Interest subvention:** Apart from capital, states can channel subsidies toward reducing the interest rates for solar pumps, boosting affordability for farmers. A similar program was pursued by MNRE for solar water heaters by fixing the interest rate at 2% for domestic users. Under the scheme, banks and financial institutions provided loans at the prescribed rates to beneficiaries and claimed the interest subsidy (difference between banks' lending rates and MNRE-prescribed interest rates) from the Indian Renewable Energy Development Agency Limited (MNRE, 2019).
- **Work with lenders to reduce transaction costs:** Interviews suggested that financial institutions often do not fully understand solar pump business models. SIAs can work with research institutes, such as the Bankers' Institute of Rural Development, to establish standard products with training materials to improve loan application efficiency. Some institutions are also developing automated processes for approving solar pump loans, such as the State Bank of India, which has a formula based on responses to a standard questionnaire. Such standardization among major lenders can establish models that smaller banks can then adopt, diversifying sources of finance.

Box 10. Loss default guarantee fund between the SwitchON Foundation and Punjab and National Bank

In partnership with the Punjab and National Bank, the SwitchON Foundation has developed a Loss Default Guarantee Fund for lending to solar pumps. According to news media, the fund has contributed to Punjab and National Bank offering a longer-than-usual payback period of 7 years to farmers and comes with a zero down-payment for a loan of up to INR 1.6 lakh for small and marginal farmers (EQ International, n.d.). Interviews with the SwitchON Foundation highlighted the importance of farmer sensitization and awareness programs in successfully implementing the Loss Default Guarantee mechanism. They also reported that they experienced zero defaults in loans given to farmers.

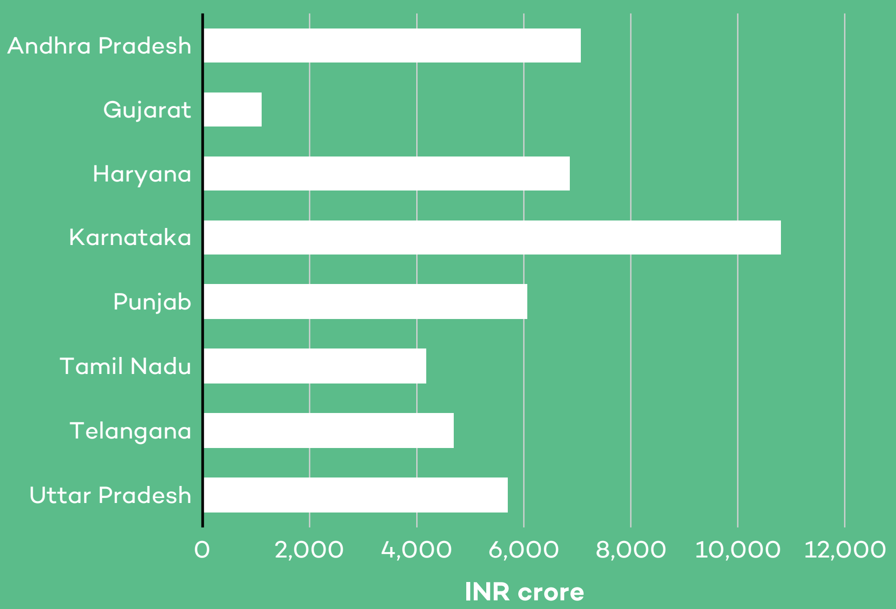
3.3.1.3 FOCUS ON BRINGING DOWN THE RELATIVE PRICE OF SOLAR IRRIGATION

Affordability is not just about absolute prices—it is also about the relative price versus alternatives. Multiple studies have found that solar pumps are cheaper than diesel pumps on a life-cycle cost basis, depending on their rate of use (KPMG, 2014). For standalone pumps, SIAs should quantify this cost differential and share it with farmers during awareness building. In states that provide substantial electricity subsidies to farmers or even free unmetered power, solar pumps can be less economical (see Box 11) (Agrawal & Jain, 2015). In these states, for both standalone and on-grid pumps, SIAs can prioritize swapping subsidies away from electricity and toward solar irrigation—a move that can also help finance schemes. This is a sensitive area that requires consultation with farmers around both price reforms and meter installation. Nonetheless, the guidebook survey found that around 50% of farmers in Jharkhand and Haryana preferred solar pumps, significantly higher than the share preferring diesel and electric pumps (See Figure 8). One of the most appealing elements of PM-KUSUM was that solar pumps are more reliable and provide guaranteed pumping during daylight hours.

Box 11. Agricultural electricity subsidies

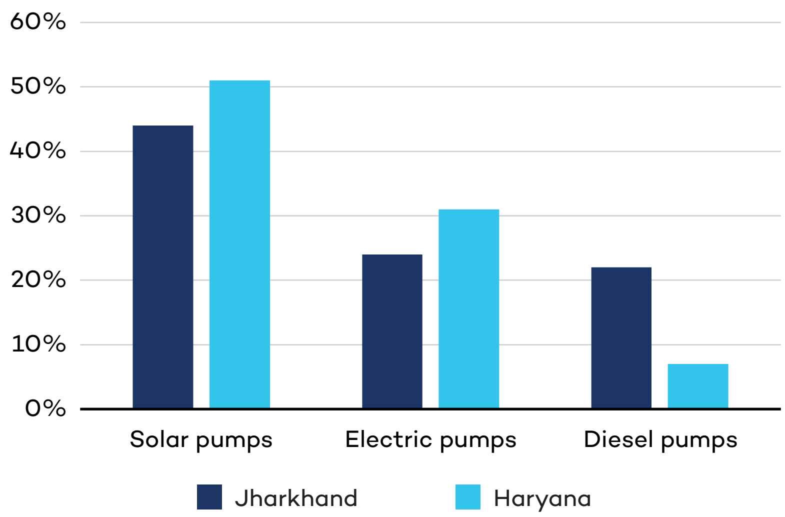
A recent review of tariff orders in 17 states and UTs found that 75% of all electricity subsidies are for farmers (Aggarwal et al., 2020). Figure 7 illustrates the states with the largest support levels.

Figure 7. High-subsidizing states for agricultural electricity



Source: Aggarwal et al., 2020.

Figure 8. Percentage of farmers preferring solar pumps in Jharkhand and Haryana



Source: Authors, guidebook survey.

3.3.2 Increasing resources of "buyers": Farmers and DISCOMs

3.3.2.1 BOOSTING FARMER INCOMES: NET METERING AND COORDINATION WITH OTHER AGRICULTURAL POLICY

- **Metering for prosumers:** For grid-connected pumps, metering for prosumers will increase farmer incomes, thereby improving affordability (Sen, 2018). But not all states have clear policies. If they have not done so already, states should prioritize clarifying metering for prosumers so farmers and lenders can confidently estimate financial returns. Feed-in tariffs (FiTs) need to establish an adequate incentive for farmers to switch to solar from subsidized electricity while also being viable for DISCOMs and states; other state experiences can provide useful lessons (see Box 12).
- **Increased agricultural productivity through coordination:** Solar pumps alone can play a key role in increasing farmer incomes: a survey of pump users across four states found that around 70% of farmers who experienced an increase in profits identified solar pumps as the primary cause (KPMG & GIZ, 2021). Nonetheless, in many cases, farmer well-being will only be influenced significantly if a wide array of interlinked factors are addressed, such as soil quality, cropping patterns, irrigation efficiency, market conditions, and infrastructure. SIAs should work with agricultural, irrigation, and rural development agencies to exploit synergies for increasing farmer incomes.

Box 12. FiTs used in different grid-connected solar pump policies

Surya Raitha scheme, Karnataka: This 2015 scheme solarized 310 pumps of up to 7.5 HP capacity through an MNRE subsidy and DISCOM loans (Institute of Social and Economic Change, 2018, as cited in Rahman et al., 2021). Beneficiaries could sell power to the grid at INR 7.2 per unit—but the DISCOM earmarked INR 6 per unit for loan repayment. This approach was found to provide a FiT that was too low for farmers and too high for the DISCOM. The scheme was not scaled up due to multiple implementation challenges, with state officials favouring a feeder solarization approach under PM-KUSUM component C (Rahman et al., 2021).

Suryashakti Kisan Yojana (SKY) (Gujarat): This 2018 scheme solarized grid-connected pumps with bidirectional metering, so pumps could run both on solar and grid power. In interviews, officials explained that beneficiary farmers made an upfront contribution of 5% of the capital cost, MNRE contributed 30%, and the DISCOMs covered the remainder through loans to farmers. The FiT was INR 3.5 per kWh, alongside a state government evacuation-based incentive to farmers of INR 3.5 per kWh (with an upper limit of 1,000 units per HP per year) (Rahman et al., 2021). A CEEW (2021) study found low power-purchase savings for the DISCOM under this model due to the size of the high FiT. Additionally, net benefits turned negative for farmers with high hours of pump usage. SKY was implemented in 91 feeders, and the state plans to cover the remaining feeders under PM-KUSUM (Rahman et al., 2021).

BLDC grid-connected solar pumps (Andhra Pradesh): This 2016 pilot replaced 216 grid-connected pumps of up to 5 HP capacity with solar panels and brushless direct current (BLDC) pumps. Farmers could only run the pumps on solar power and sell power to the grid for a FiT of INR 1.5 per kWh (Saibaba, 2019). A CEEW (2021) analysis suggested that this incentive was too low, making it more attractive to use surplus power for alternative purposes, like selling water to neighbours. A higher FiT may incentivize farmers to sell power to the grid but would impact the scheme's viability since the DISCOM fully financed the scheme (Rahman et al., 2021). The state did not scale it up beyond the pilot and now plans to pursue grid-scale plants to solarize agriculture (Bhaskar, 2020).

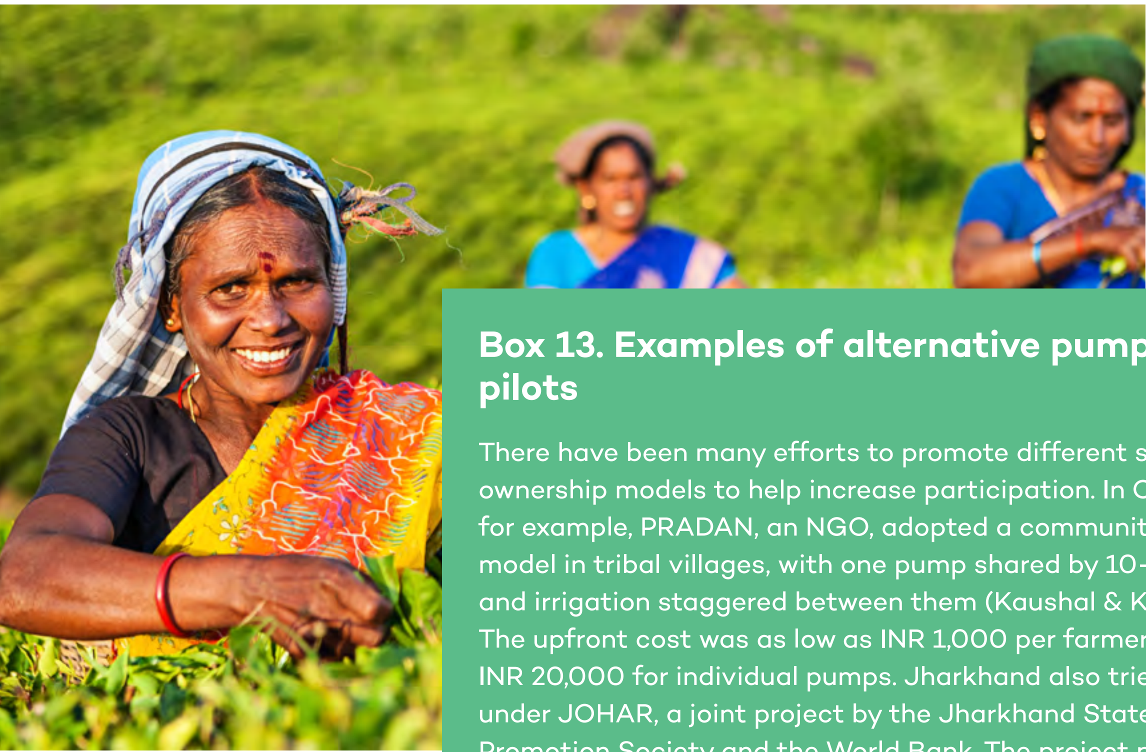
3.3.2.2 BOOSTING FARMER FINANCIAL INCLUSION: KISAN CREDIT CARDS AND INFORMATION SERVICES

- Kisan Credit Cards (KCCs): In February 2020, a campaign was launched to issue all Pradhan Mantri Kisan Samman Nidhi (PM KISAN) beneficiaries with KCCs (Ministry of Agriculture & Farmers Welfare, 2020a). Some banks already offer credit up to INR 3 lakhs, which can cover pump costs and tenure up to 5 years (BankBazaar, n.d.). The general limit for KCC collateral-free agriculture loans is INR 1.6 lakh, which would enable farmers to cover their solar pump contribution under PM-KUSUM (Press Information Bureau [PIB], 2020a). Bundling PM-KUSUM loans with KCCs can reduce transaction costs and appraisal periods and improve farmers' bankability. It can also reduce indebtedness linked to large loans that use gold as collateral (RBI, 2019). The beneficiaries of PM KISAN—landholders with less than 2 hectares of land—are well matched with the target beneficiaries of PM-KUSUM.
- Information services: The guidebook survey findings revealed that only 13% of farmers in Jharkhand and 10% in Haryana were aware of PM-KUSUM. This information gap can impede willingness to pay for solar pumps, despite the economic benefits. Grassroots organizations like KVKs, Farmer Clubs, Common Service Centres, and Nehru Yuva Kendra Sangathan (NYKS) run district-level centres that provide access to information and digital services. They can help connect regional financial institutions with farmers and disseminate information. One focus area of NYKS is COVID-19 post-lockdown campaigns to accelerate economic recovery (Ministry of Youth Affairs & Sports, 2020). PM-KUSUM could play a role in such initiatives. States could also enlist the support of relevant CSOs and private sector organizations to build farmer awareness.

3.3.2.3 ALTERNATIVE MODELS OF OWNERSHIP AND USAGE

- **Community-ownership model:** Under community ownership, a solar pump is purchased by a collective of farmers, usually a self-help group or farmer cooperative. It can be located in a pump house with pipelines transporting water to multiple farmers. A community-based ownership model can help share the capital cost of a solar pump between marginal and low-income farmers. The fragmented nature of land ownership among small farmers, particularly in eastern India, further bolsters the case for a shared ownership model in specific contexts (Aga Khan Foundation, 2020). Interviews with financial institutions found that deploying solar pumps to farmer cooperatives and groups can also lower the risk of lending. If a group of farmers gets organized as a self-help group, joint liability group, or water user association, they are also eligible for availing of the interest subvention facility under the AIF (Ministry of New and Renewable Energy, 2020b). States must play a proactive role in encouraging farmers to organize themselves in a group or cooperative and build awareness of the interest subvention facility offered under the AIF.

- **Entrepreneurship model:** Under an entrepreneurship model, a village-level entrepreneur (who may be a farmer or a Farmer Producer Organization [FPO]) purchases the pump and supplies water to neighbouring farmers for a fee. A slight variation involves a private enterprise that franchises installations to a local entrepreneur. It is suitable for areas with a high density of small and marginal farmers such as in states like Bihar, UP, Odisha, and Assam, where over 90%, 80%, 75%, and 70% of landholdings are small or marginal, respectively (Bhushan et al., 2019). In this model, an agreement between an entrepreneur and the state should be the basis for receiving subsidies.
- **Irrigation-as-a-service model:** Under the service model, an entity such as a private enterprise or organization (including a farmer collective or FPO) invests in and owns the pump and sells irrigation as a service to neighbouring farmers for a fee. Service-based models are suitable for geographies with high proportions of smallholders who face high irrigation costs and erratic rural electricity supply. It supports the adoption of solar pumps by small and marginal farmers, whose combined irrigation demand can increase utilization to a level where such models become financially sustainable. Suitable early adopters may be farmers who are dependent on buying water or renting pumps since they face the highest cost of irrigation (Jain & Shahidi, 2018).
- **Promotion of alternate revenue streams:** Aside from using solar pumps for irrigation, farmers can generate additional revenue by using pumps for non-irrigation livelihood activities, such as micro-cold storage, if they are able to access USPC devices. MNRE has extended the subsidy for solar pumps under PM-KUSUM to include USPC devices. It is also recommended that SIAs prepare a list of approved non-irrigation activities that are optimized for distributed renewable energy (DRE) in consultations with private developers to avoid any insurance claim rejections and violations of warranty clauses and share this list of activities with farmers.



Box 13. Examples of alternative pump ownership pilots

There have been many efforts to promote different solar pump ownership models to help increase participation. In Chhattisgarh, for example, PRADAN, an NGO, adopted a community-ownership model in tribal villages, with one pump shared by 10–15 farmers and irrigation staggered between them (Kaushal & Kumar, 2020). The upfront cost was as low as INR 1,000 per farmer, as opposed to INR 20,000 for individual pumps. Jharkhand also tried this model under JOHAR, a joint project by the Jharkhand State Livelihood Promotion Society and the World Bank. The project provides a template for leveraging state livelihood missions to promote community ownership. In a variation of the model, a social enterprise called Mlinda worked with tribal villages in Gumla in Jharkhand to establish an isolated mini-grid, where a mini solar plant powered multiple pumps and surplus power could be used for other productive purposes (Mlinda, n.d.).

In Bihar, the Aga Khan Rural Support Programme (AKSRP) and International Water Management Institute (IWMI) implemented a project with an entrepreneur model. This supported five farmers to use solar pumps as entrepreneurs, providing water to neighbours with a network of underground pipelines. It benefited about 400 farmers, creating a new water market, and is 60%–70% cheaper than alternative options (Durga et al., 2020).

Oorja Development Solutions, a for-profit company, implemented a project under a pay-per-use service model in UP. Groups of 15–20 farmers each shared one solar pump, typically of 5 HP capacity, owned and operated by the company, avoiding any upfront cost to farmers. In interviews, company officials explained that they sell irrigation services to small and marginal farmers at a tariff that is up to 50% cheaper than the life-cycle cost of diesel-based pumps. They have also introduced a price on water to disincentivize the over-extraction of groundwater and reached over 400 farmers under this model. In interviews, the company stated that their internal impact study found that farmers who transitioned from diesel to solar pumps increased their crop yields by up to 15% and income by up to 29% in one year.

SIAs can support village-level or community-owned models through awareness-creation programs and by broader state efforts to promote the collectivization of farmers. This requires continuous and long-term capacity building so that groups are cohesive and can carry out their managerial and financial responsibilities. This can involve local NGO partners acting as community-based business organizations or under National Rural Livelihood Missions. States can operationalize these partnerships through close coordination between the SIA and the Rural Development department, as elaborated in Chapter 2 on coordination.

3.3.2.4 OVERCOMING THE COSTS OF SUPPORTING INFRASTRUCTURE BY CONVERGING WITH OTHER SCHEMES

As elaborated in Chapter 4 on infrastructure support, farmers in solar pump schemes must have prior access to water sources like a borewell. This can be a barrier for farmers who cannot afford to invest in one. Eligibility criteria around water efficiency can create similar barriers. This can be overcome by promoting convergence with borewell and water-efficiency schemes, which have been implemented by several states (see Box 14). Community borewells are also appropriate for community-ownership models. States can explore packaging them for such groups and creating a village-level resource management committee (Paani Panchayat). This committee can set up rules for the allocation of water to farmers from community wells in areas of water scarcity or low recharge rates.

Box 14. Borewell support schemes: Andhra Pradesh and Chhattisgarh

To provide reliable irrigation source access to small and marginal farmers, the state government of Andhra Pradesh launched the YSR Jala Kala Scheme to provide financial assistance to set up borewells. The scheme's selection criteria are targeted at small and marginal farmers having land holdings below 2.5 acres and depend on farming as the only source of income. In Chhattisgarh, for instance, the Department of Agriculture prioritizes farmers who have applied for borewell schemes for the solar pump scheme, with the help of Rural Agriculture Extension Officers (RAEO).

3.4 Approaches to Sustainably Financing Solar Irrigation

Some state strategies for financing solar irrigation include:

- **Coordinating efforts with other policies:** This can help crowd together funds and reduce transaction costs. It may also create new management costs and risk burdening a project with many objectives—but, as noted in section 2 on coordination, it can also help balance multiple objectives across the WEF nexus, such as between PM-KUSUM and PMKSY, promoting efficient irrigation.
- **Mechanisms to reduce subsidies to changing costs and attitudes:** Solar photo voltaic (PV) costs are falling rapidly: by 80% from 2012 to 2015 and up to 59% further by 2025 (IRENA 2016b). Pump costs may also fall as high deployment achieves new economies of scale. States can regularly review and adjust subsidy policy to conserve resources, including when farmer attitudes change (Box 15).
- **Funding solar irrigation with electricity subsidy swaps and surcharges:** Swapping subsidies for grid electricity into solar irrigation can increase the incentive for farmers to switch. While this is a highly sensitive area, it should improve equity for all: with solar pumps, power reliability improves, and off-grid farmers receive a share of benefits for the first time. By contrast, the guidebook survey in Haryana showed that existing electricity subsidies are regressive: the largest benefits went to farmers in the highest wealth quintile who used the most power. Alternatively, states can levy new surcharges for non-agricultural consumers and dedicate revenues to solar irrigation. This is also sensitive but has been implemented in at least one context (Box 17).

Box 15. Rajasthan: Coordination, subsidy reductions over time, and subsidy swaps

In Rajasthan's Solar PV Pumping Scheme 2011–12, the horticulture department initially provided an 86% subsidy, financed under various programs, such as the Rashtriya Krishi Vikas Yojana and the National Horticulture Mission. It reduced this over time to 70% and 60%. In an interview, the department suggested this was possible because, as time passed, pump prices fell, and the scheme was well-accepted by farmers, proving its financial viability. In 2018, Rajasthan also included a conditionality: the subsidy ranged from 60% to 75%, depending on whether beneficiaries would surrender existing agricultural connections, which would reduce the state subsidy burden (cKinetics & Climate Policy Initiative, n.d.).

Box 16. Chhattisgarh: Funding pumps with savings from agricultural electricity subsidies

In Chhattisgarh, the government partnered with NABARD to avail loans under the RIDF to finance the 2016 SSY scheme. RIDF loans have low interest rates with a tenure of 10 years and allow the state to provide a 90–95% subsidy. According to interviews with officials, CREDA's calculations suggest that the large subsidy is viable because the total cost of a new grid connection and subsidized power for 25 years is higher than the life-cycle cost of a solar pump.

Box 17. Maharashtra: Financing pumps with an electricity surcharge for industry and commerce

In 2018, Maharashtra announced the Mukhyamantri Saur Krushi Pump Yojana scheme to install 100,000 solar pumps in off-grid regions by the end of FY 2021. It provides a 95% subsidy to Scheduled Caste/Scheduled Tribe farmers and 90% for other farmers (cKinetics & Climate Policy Initiative, n.d.). It was financed by an INR 0.10 per unit tax on commercial and industrial electricity use, raising over INR 1,000 crore per year—enough to pay part of but not all costs (cKinetics & Climate Policy Initiative, n.d.).

3.5 Key Recommendations

1. Take a joined-up approach to reducing solar pump costs by:

- Exploring bulk procurement through central agencies, such as Energy Efficiency Services Ltd.
- Establishing payment security facilities at financial institutions to ensure timely subsidy disbursement
- Creating a loan default guarantee fund to lower the risk perception of banks
- Providing interest subsidies to lower the cost of borrowing for farmers
- Swapping subsidies for on-grid electricity towards solar irrigation

2. Adopt a joined-up approach to increasing farmer resources by:

- Clarifying net metering policy for grid-connected pumps to bolster farmer incomes
- Coordinating with other agricultural and rural development policies
- Boosting financial inclusion with Kisan Credit Cards and information services
- Promoting alternative models of solar pump ownership and usage
- Overcoming costs of supporting infrastructure through scheme convergence

3. Take a joined-up approach to reducing solar pump costs by:

- Coordinating efforts with other policies to crowd together funds and reduce transaction costs
- Reducing capital subsidies in line with falling costs and rising social acceptance
- Raising revenue through subsidy reforms or surcharges for grid electricity

Further guidance and resources

cKinetics & Climate Change Initiative (n.d.), *Designing Financing Interventions to Catalyze Solar Pumps Market in India:* https://ckinetics.com/fileupload/Designing%20interventions%20to%20catalyse%20solar%20pumps%20market_Final_pdf.pdf

CGIAR Research Program in Climate Change, Agriculture and Food Security (2020), *Compendium on Solar Powered Irrigation Systems in India:* https://ccafs.cgiar.org/resources/publications/compendium-solar-powered-irrigation-systems-india

India Go Solar (n.d.) provides a good overview of net metering policies in a range of states: https://www.indiagosolar.in/net-metering-policies/

4.0 Targeting

4.1 Why Does Targeting Matter?

Targeting is all about *who* a scheme wants to focus on as beneficiaries, taking into account considerations like socio-economic status, existing access to irrigation services, and local geographic conditions. Efficient targeting is critical for sustainable social and environmental outcomes.

- **Social:** Many solar irrigation schemes, including PM-KUSUM, aim to benefit small and marginal farmers. But experience from past state schemes shows that disadvantaged groups are easily left out. In Bihar, for example, small and marginal farmers comprised only 16% of beneficiaries of the state solar irrigation scheme, despite making up 92% of farmers (Shakti Sustainable Energy Foundation, 2018). This reflects inequality of access to resources—such as land, water, capital, and information. Tenant farmers are often left out of schemes entirely when eligibility criteria include minimum land ownership. Solar pump schemes can also tend to perpetuate gender inequality in the ownership of agricultural assets, as women farmers are unlikely to own land and lack financial capital (Rahman & Jain, 2021a). Equally, in order to maximize benefits for agricultural output and incomes, schemes should focus on farmers who are currently deprived of reliable irrigation access or dependent on costly alternatives, like diesel- or kerosene-based pumps.
- **Environmental:** Groundwater levels in many parts of India are rapidly declining. Some geographic areas are therefore much more vulnerable to groundwater exploitation than others. Good targeting can minimize the risk of increased water stress from the deployment of solar pumps.

4.2 What Are the Main Strategies to Improve Targeting?

Targeting is complex, so to achieve objectives, states must explore multiple strategies. There is no one foolproof measure that can achieve all targeting objectives. Indeed, focusing exclusively on any one strategy can also result in unintended negative outcomes.

Strategies to improve targeting can be grouped around four main themes:

1. The geographic areas in which solar irrigation is promoted
2. The pump sizes that are subsidized
3. Eligibility rules to participate in the scheme
4. Accompanying engagement efforts.

The rest of this chapter explores these themes in detail, emphasizing, where relevant, when strategies are important for standalone or grid-connected pumps. As it does so, it makes frequent reference to the CEEW Solar Pumps Tool (CEEW, n.d.). This is an online platform that CEEW has developed to bring together a wide range of district-level data of relevance to deploying solar irrigation systems, including on crop revenue per holding, the extent of irrigation, number of diesel pumps, and water availability. State policy-makers are recommended to explore this tool as a good "one-stop shop" of key indicators to bear in mind for targeting.

4.3 What Role Can Geographic Location Play in Scheme Targeting?

Social and environmental impacts can be correlated with specific geographic locations, as follows.

- **Standalone pumps in areas with poor grid access:** Standalone pumps have the greatest benefits for farmers without access to reliable energy for irrigation or who use costly and polluting diesel pumps by increasing productivity and saving fuel costs (Box 18). Around 49% of India's total cropped lands were not irrigated in FY 2016 (PIB, 2020b), and about 9 million farmers use diesel pumps (Raghavan et al., 2011). Targeting areas with poor grid connectivity would benefit both groups. In the absence of targeting, solar pump schemes in many states have predominantly benefited farmers with electric connections (Shakti Sustainable Energy Foundation, 2018).

Box 18. Andhra Pradesh and Chhattisgarh: Experiences with geographic targeting

Many states have taken into account existing access to irrigation when choosing where to focus solar pump schemes. In Andhra Pradesh, for example, standalone solar pumps were allocated only in locations where grid electricity was not available. Chhattisgarh planned district-wise allocation of targets under the SSY scheme by taking into account the location of tribal communities, who are among the most disadvantaged in terms of irrigation access, to maximize social benefits.

- **Areas with adequate water resources:** Regions with adequate surface water sources should be prioritized for solar pumps. For standalone pumps, states should avoid areas with rapidly declining groundwater tables or low usage of efficient irrigation (Agrawal

& Jain, 2018). If groundwater levels fall significantly, a pump's water output can substantially reduce, resulting in a stranded asset. While upgrading capacity is often not financially viable for farmers, oversizing can accelerate groundwater depletion in the absence of a price on irrigation. A holistic approach to groundwater management is needed in such areas (Box 19).

Box 19. Rajasthan: A holistic approach to integrating solar irrigation with water management

The Mukhyamatri Jal Swalambhan Yojana (MJSY) of Rajasthan is a comprehensive approach to improving rural quality of life by augmenting water resources, promoting water conservation, and improving irrigation and drinking water access. Solar irrigation is one strategy under this integrated approach. The scheme provides a scalable template of converging multiple department activities to create a sustainable irrigation development model. The MJSY scheme has been recently renamed to the Rajiv Gandhi Jal Sanchaya Yojana. See the Annex for more details.

- **Grid-connected pumps for areas with high usage of electric pumps:** For on-grid pumps, schemes should prioritize areas where electric pump usage is high (typically over 700 hours per year), or a state may lose money in providing subsidies and supporting infrastructure. A recent assessment of four states found that the average power consumption for irrigation was 954 kWh per year, and over 4.5 times that number in the most water-stressed state (Rajasthan) (Agrawal et al., 2019). Consumption will likely be higher among unmetered farmers. Targeting such groups could increase savings but requires careful coordination with efforts to extend metering. In areas with low pump usage, feeder solarization may be more appropriate, along with a provision to earn money through energy savings.

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Figure 9. Proportion of marginal farmers in UP

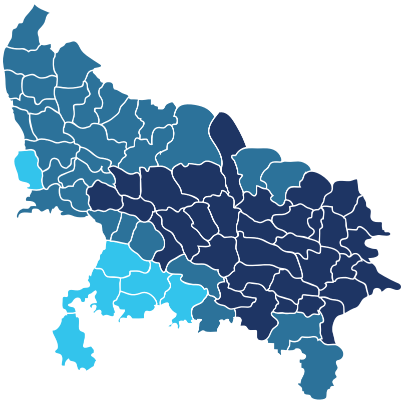


Figure 10. Groundwater availability in UP

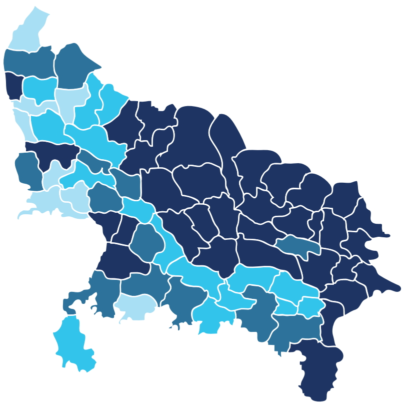
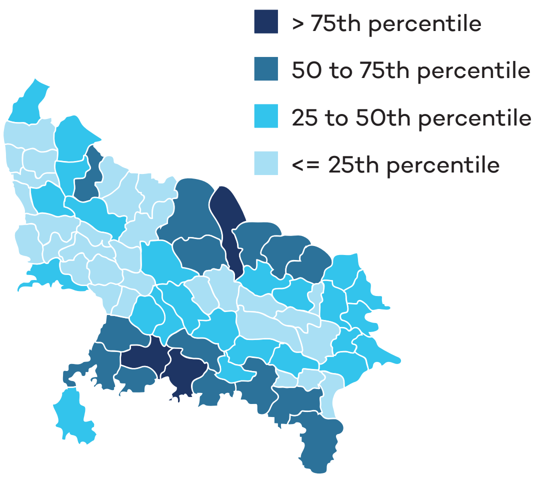


Figure 11. Unirrigated net sown area in UP



Source for all figures: CEEW, n.d. Percentiles calculated nationally.

Policy-makers can use the CEEW Solar Pumps Tool for geographic targeting based on the criteria mentioned above. As an illustration, consider UP, in Figures 9, 10, and 11:

- UP has abundant groundwater resources. Nearly 60% of districts belong to the top quartile of the country in terms of water availability.
- Most districts, except in western UP, have a high share of small and marginal farmers.
- The share of unirrigated areas is high in the northern Terai and southern districts.

Based on the identified criteria, the allocation of standalone solar pumps under the PM-KUSUM scheme should hence focus on northern, eastern, and southern districts. A higher share of small-capacity pumps (typically 2 HP and less) could be allocated to the northern and eastern districts. In the southern districts, where the share of unirrigated land holdings is high but with a low water table, solar pumps should be accompanied by water harvesting structures and conservation measures.

It should also be noted that many variables can influence outcomes, and states should always continue to adopt a precautionary approach, piloting schemes in different contexts before scaling up. For instance, in theory, farmers using grid-connected pumps should be able to sell excess power back to the grid under PM-KUSUM component C, incentivizing efficient water consumption. The actual impacts of grid-connected pumps on groundwater, however, are yet to be comprehensively studied. For example, in regions with low irrigation access, owners of on-grid pumps may find it more profitable to sell water to neighbouring farmers or to grow more crops (Rahman et al., 2021).

4.4 What Role Can Pump Size Play in Scheme Targeting?

Solar pump size is a key determinant of upfront costs and water discharge rates (Agrawal & Jain 2018), making it crucial for affordability and sustainability. In some states, SIAs report farmers oversizing pumps, anticipating falling groundwater tables or higher cultivation. In others, farmers undersize to lower costs. While oversizing increases water use, undersizing can lead to deficit irrigation. States need to adopt a scientific approach, determining capacity based on local context and keeping micro-irrigation in mind with standards for minimum flow rate as well as pressure requirements. The IWMI pump-sizing tool can help make these decisions on pump sizing (Box 20).

Box 20. The solar-powered irrigation system (SPIS) pump-sizing tool

The SPIS pump-sizing tool (online and offline versions), developed by IWMI, Indian Council of Agricultural Research, and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), can help SIAs identify optimal pump size by estimating farmers' irrigation demand. The sizing is guided by the agro-ecology of the area, effective precipitation, type and seasonality of crops, number of crops, area potential for different crops, and the pumping technology. The tool distills these factors into three modules: crop water requirement, head calculation, and scenario analysis. It is recommended that states train relevant officials in the proper use of this tool and proactively recommend appropriate pump sizes for farmers during the application process of solar irrigation schemes.

The range of optimal size requirements can vary by state. Within the overall range that is suitable, SIAs are recommended to focus on smaller capacity pumps. They are cheaper and more affordable for small and marginal farmers and have less risk for groundwater overuse. Reserving a larger share of small pumps still requires effective monitoring, as there have been problems with large farmers purchasing multiple small pumps in past state schemes. Smaller pumps can be promoted in the following ways:

1. **Reserve a higher share of total pumps for smaller pumps:** "Small" must be in reference to the range of suitable capacity, avoiding undersizing. Regions with high water tables, such as eastern India and the coastal peninsula, can consider "micropumps" with a capacity rating below 1 HP (see Box 21).

2. **Link state subsidy share to pump capacity:** Within the range of suitable pump sizes, a higher proportionate subsidy for lower-capacity pumps can incentivize those pump sizes.
3. **Demonstrate small-capacity pumps:** Demonstration projects can build confidence in smaller pumps. In Rajasthan, for example, a higher share of small and marginal farmers used solar pumps after the state successfully demonstrated their efficacy through early adopters.
4. **Incentivize adoption of efficient irrigation and water conservation practices:** This would address concerns that falling water tables could make smaller pumps non-operational after a few years.

Box 21. A case for solar micropumps

Solar micropumps have less than 1 HP capacity and typically cost INR 30,000–60,000. They are suitable for small and marginal plots, can replace diesel pumps in areas with adequate water tables, and are often portable, so they can be used in multiple plots. They have been piloted in various states, including Bihar and Jharkhand (Goveas, 2020). States can use the provision for innovative models under PM-KUSUM to pilot highly efficient solar micropumps that service smallholders at a low cost and address concerns of deficit irrigation (Efficiency for Access Coalition, 2019).

4.5 What Role Can Eligibility Rules Play in Targeting?

To improve distributional equity, rules around beneficiary eligibility need careful selection. Good practices from select states in India include:

- **Prioritize farmers without grid access:** For standalone pumps, states should formulate clear guidelines to prioritize farmers without electricity connections. This approach has already been adopted by PM-KUSUM and would be important for all future schemes to adopt as well. The absence of such criteria can result in grid-connected farmers cornering subsidy benefits (Box 22). Another proxy can be targeting farmers that are only reliant on rainfed irrigation. In Odisha, a survey of solar pump users found that 48% of pumps went to farmers practising rainfed irrigation, which led to their cropping intensity increasing by 45% (KPMG & GIZ, 2021). Giving up their electricity connection could be a pre-condition for grid-connected farmers to access subsidies for standalone solar pumps.
- **Reserve a share of pumps for small and marginal farmers:** A quota for small and marginal farmers can be fixed at the district level based on their relative proportion. This sends a clear signal that this is an important criterion for deployment targets, helping ensure that corrective measures are taken if the target is not being achieved. If the number of applications exceeds the target, priority should be given to small and marginal farmers.

Box 22. UP and Andhra Pradesh: Using eligibility criteria for better outcomes

A lack of criteria to support small and marginal farmers can weaken social impacts. In UP, for example, despite a progressive subsidy regime, most small pumps went to large farmers with agricultural connections, "stacking" different irrigation options and even multiple small solar pumps (Shakti Sustainable Energy Foundation, 2018). Similar outcomes were also seen in other states, like Tamil Nadu (KPMG & GIZ, 2021). In Andhra Pradesh, interviews with officials suggest that possessing an agricultural electricity connection disqualifies a farmer from accessing the state's solar irrigation scheme.

- **Relax land ownership rules:** For small pumps, states should relax criteria that set minimum land-ownership requirements to help small and marginal farmers participate. For portable pumps, there should not be any land requirements, so even tenant farmers can benefit. To prevent misuse of subsidies, a simple verification involving the village panchayat can be considered (Box 23).

Box 23. Catering to tenant farmers: Odisha's KALIA scheme

Tenant farmers and sharecroppers are often left out of agriculture schemes due to the informal nature of tenancy. Odisha's Krushak Assistance for Livelihood and Income Augmentation (KALIA) scheme has been an outlier in this respect. It identified landless agriculture households through a Gram Panchayat-based participatory exercise. Rural households without any farmland and not falling under some well-defined exclusion criteria were eligible through Gram Sabha certification.

- **Adopt gender-sensitive criteria:** Women constitute about 42% of the agricultural workforce, undertake about 80% of the farm work, but own less than 2% of agricultural lands (Mehta, 2018; Pachauri, 2019). Without land ownership, women can be denied access to a solar pump. A study of solar pump beneficiaries in Chhattisgarh found that only 3% were women (Rahman & Jain, 2021a). Women-specific targeting measures include promoting women's self-help group (SHG)-owned solar pumps and relaxation of land-ownership criteria for women (See Box 24).

Box 24. "A pump of my own": Promoting women-led SHG ownership of solar pumps

A pilot project in Betul, Madhya Pradesh, by the BAIF Development Research Foundation provided portable solar pumps to women-led SHGs. The members shared it among themselves and with others on a rental basis, leading to a significant increase in income (Shirshath et al., 2021). Under project JOHAR, Jharkhand provided solar pumps to about 1,000 women-led SHG members on a water-sharing basis (Singh et al., 2020). As mentioned in Section 2, effective coordination between SIA and State Rural Livelihood Missions can facilitate SHG linkages to solar pump schemes.

- **Identify indicators of deprivation and adopt criteria accordingly:** Indicators like type of ration card, MGNREGA enrolment, and access to other social security schemes are sometimes a good proxy for irrigation access. The guidebook survey in Haryana found that indicators like MGNREGA enrolment are directly correlated to farmers' access to irrigation. Uniform criteria cannot be prescribed for all states since the relevance of these indicators are very state-specific. States are recommended to identify the relevant criteria through sample surveys and target accordingly. Such criteria can also be used to target women and tenant farmers in the case of non-fulfilment of land-ownership criteria.
- **Link solar pump subsidies to efficient irrigation:** In highly water-stressed states, policy-makers can consider requiring farmers to irrigate efficiently in order to qualify for solar pump subsidies. This can include drip or sprinkler systems and the use of a water storage mechanism. As noted in Section 2, this can be supported by converging policies on solar irrigation and water efficiency, such as PMKSY. The CEEW Solar Pump Tool can help identify opportunities with "per drop more crop" for all districts. In terms of policy design, several variations can be explored, including:
    - Mandating efficient irrigation practices in critical and overexploited blocks.
    - Mandating efficient irrigation for pumps above a certain size, defined by district context.
    - For remaining blocks, mandating efficient water systems based on crops being cultivated.

Even where eligibility criteria are well designed, there can still be barriers that prevent small and marginal farmers from participating. To overcome such barriers, states should consider alternative deployment models and the complementary support measures that have been highlighted in Section 3.

4.6 How Can Engagement Efforts Help Overcome Barriers to Participation?

Information access is still one of the main barriers to participation in solar pump schemes. In the 2021 guidebook survey in Jharkhand and Haryana, about 50% and 38% of farmers, respectively, did not know about solar pumps. An even larger share—75% and 84%, respectively—had not heard of PM-KUSUM. Another study found that, in Rajasthan and Odisha, most solar pump users received information through informal networks (KPMG & GIZ, 2021).

Studies have also shown that small and marginal farmers have unequal access to information (Adhiguru et al., 2009; Jain & Shahidi, 2018) and need to be targeted by awareness campaigns and training. Such programs should focus on both the technical aspects of solar pumps and how to participate in schemes using media that can best reach poor and marginalized farmers, such as print media in local newspapers or village-level meetings. Leveraging farmers' cooperatives could be another way to disseminate information about grid-connected solar pumps for farmers on the same feeder (Gulati et al., 2020). Awareness-raising could also integrate information about related issues, such as crop cultivation, effective water management, and crop diversification practices.

In-person technology demonstration is the most effective way of raising awareness among farmers (Jain & Shahidi, 2018). KVKs and agricultural universities, in coordination with agriculture and horticulture departments, are well placed to conduct awareness activities and pilot demonstrations. SIAs, in coordination with DISCOMs, can provide basic training on the operation and proper maintenance of solar pumps. Platforms like Azadi ka Amrit Mahotsav can bring together diverse stakeholders, including farmers, to share their experiences and enable cross-learning between states (PIB, 2021).

In-depth interviews with solar pump users in UP, conducted as part of this guidebook, found that farmers had to visit government offices about 3–4 times during the application process for a solar irrigation scheme. Another study found that more than 54% of surveyed applicants faced a delay of over 3 months to receive a solar pump (KPMG & GIZ, 2021). States should adopt a "single-window" approach, with only one interface between the government and the farmer and no requirement for multiple visits to different departments. They should also ensure time-bound delivery. While an online application can reduce logistics costs, it may lead to digital exclusion. To overcome this, states can leverage existing networks of Common Service Centres, Bank Sathis, or Yuva Mitras, coordinating with the respective agencies to include the scheme in their applications and conduct training for agents.

Box 25. State experiences tackling barriers to participation in solar pump schemes

Chhattisgarh's main medium for communication has been the Jan Samadhan Shivir—a monthly village-level meeting for all departments with a special focus on technical information—as well as deploying at least one pump in each village to act as a demonstration. In Gujarat, the Green Revolution Company used a decision support system, which combined print and media advertisements with farmer interactions, to support farmer decision making on solar pumps. In Haryana, the application for PM-KUSUM is integrated into the state's Right to Service platform called Antyodaya Saral, which guarantees time-bound service delivery (HAREDA, 2020). State officials also stated that Atal Seva Kendras are being used to help farmers fill up online applications.

4.7 Key Recommendations

Take geographic location into account for targeting by deploying:

- Standalone solar pumps in areas with poor grid connectivity
- Solar pumps in areas with adequate groundwater availability
- Grid-connected solar pumps in areas with a high usage of electric pumps

Prioritize the promotion of smaller-capacity pumps within the range of appropriate capacity sizes:

- Link subsidies to pump capacity, appropriate to context
- Create caps on maximum pump size, appropriate to context
- Demonstrate small-capacity pumps to build confidence
- Encourage water-efficiency practices to ensure continued feasibility of smaller pumps

Follow good practices in the design of eligibility rules:

- Reserve a share of pumps for small and marginal farmers
- Relax land ownership requirements so small and tenant farmers can participate in the scheme
- Target women-led SHGs and promote women's ownership of solar pumps
- Identify and use alternative criteria like MGNREGS enrollment to ensure equity
- Link solar pump subsidies to efficient irrigation practices

Facilitate through engagement efforts:

- Design an Information, Education and Communication campaign with a special focus on small and marginal farmers
- Provide in-person technology demonstration through knowledge networks and farmer institutions
- Develop a "single window" application process to reduce administrative hurdles
- Leverage an existing network of digital facilitators for online application

Further guidance and resources

The CEEW Solar Pump Tool – https://portal.ceew.in/. If any state wishes to organize a demonstration or workshop for the tool, please reach out at info@ceew.in.

IWMI solar pumps sizing tool – Excel and app versions of the tool are available from IWMI.

For different models of solar pump deployment: CGIAR Research Program in Climate Change, Agriculture and Food Security (2020), *Compendium on Solar Powered Irrigation Systems in India:* https://ccafs.cgiar.org/resources/publications/compendium-solar-powered-irrigation-systems-india

5.0
Infrastructure Support

5.1 Why Does Infrastructure Matter for Solar Irrigation Sustainability?

One of the main concerns associated with solar irrigation is its impact on groundwater tables in water-stressed regions. Although PM-KUSUM guidelines restrict the deployment of pumps in districts with critical or overexploited groundwater tables, consultations with officials and policy experts suggest that this may still exclude some districts with rapidly depleting groundwater tables and unsustainable cropping practices.

The success of policies and strategies in mitigating these negative externalities often hinges on the right supporting infrastructure. For example, operationalizing convergence between micro-irrigation and solar irrigation schemes depends on farmers' access to affordable micro-irrigation technologies, such as drip and sprinkler systems. Additionally, the implementation of metering mechanisms that enable farmers to become prosumers by selling excess energy from grid-connected solar pumps rests on the reliability of the electricity grid and the installation of meters at the farm level.

The deployment of solar pumps to small and marginal farmers is also linked to infrastructure support provided under solar irrigation schemes. A survey in UP found that only 41% of marginal farmers owned a borewell, compared to 95% of large farmers (Jain & Shahidi, 2018). Interviews with state officials indicate that the eligibility criteria for PM-KUSUM in many states mandate that beneficiaries must have existing borewells, which may exclude small and marginal farmers from participating. This makes it imperative for states to make smart infrastructure choices across the value chain, comprising the solar pump, controller, electricity grid, and irrigation system.

5.2 How Can States Align Solar Irrigation With Efforts to Support Infrastructure?

Strategies to deploy the right infrastructure can be grouped into five themes:

1. Selection of the appropriate solar irrigation system
2. Increasing the water use efficiency from solar pumps
3. Infrastructure for optimal use of solar irrigation systems
4. Infrastructure to address grid reliability
5. Awareness generation and capacity building

The rest of this chapter explores these themes in detail, emphasizing where relevant strategies are particularly important for standalone or grid-connected pumps.

5.2.1 The Selection of the Appropriate Solar Irrigation System

As recommended in a review of state experiences by Shakti Sustainable Energy Foundation (2018), SIAs must consider a range of parameters when recommending the appropriate solar irrigation system.

- **The capacity of solar pumps** should be determined by the prevalent water table depth, cropping patterns, and the average size of landholdings in the district, avoiding both oversizing and undersizing pumps. SIAs can use the IWMI solar pump sizing tool and site visits to determine the appropriate pump size (see Section 4 for more details).
- **The choice between surface or submersible pump** should be determined by the water sources (channels, wells, tanks) available to the beneficiary. In regions with surface water sources, surface pumps should be preferred, and submersible pumps can be discouraged to preserve groundwater. SIAs should also consider additional district-specific factors, such as that submersible pumps may be less prone to theft in some regions but more prone to damage due to water salinity in others. Expert interviews also revealed that submersible pumps can have higher maintenance costs than surface pumps due to the additional labour expenses incurred while removing the pump from a borewell.
- **The choice of an alternating current (AC)/direct current (DC) pump** should be determined by its intended applications and the availability of maintenance services at the district level. DC pumps have a higher efficiency and discharge rate up to a 30-m waterhead, especially during cloudy weather or non-sunny days, and are more suitable for deployment if farm output is the key requirement (Dahiya et al., 2017). AC pumps have higher efficiency at a 50-m waterhead and a broader range of uses, can leverage existing service centres, and are estimated to be, on average, 10%–15% cheaper than DC pumps (Shakti Sustainable Energy Foundation, 2018). Recent tenders, however, have found a much lower price differential between DC and AC pumps.

Box 26. BLDC solar pumping scheme in Andhra Pradesh

The Andhra Pradesh Eastern Power Distribution Company Limited (APEPDCL) implemented the BLDC solar pumping pilot project in 2018. Under the project, 216 grid-connected pumps of a maximum 5 HP pump capacity in the Savaravilli feeder were replaced free of charge with grid-connected solar-powered BLDC pumps, with the objective of reducing the DISCOM's subsidies. According to APEPDCL's internal evaluation, the pumps successfully ran for 10–12 hours, increasing the daylight electricity hours available to farmers (APEPDCL, 2019). These findings have not been independently verified by the consortium.

The DISCOM also claimed they benefited from the use of BLDC pumps since the participating farmers were unable to draw power from the grid, thereby helping to reduce its losses and the need for network investments. As BLDC pumps are more efficient than AC pumps, smaller-sized pumps were chosen without affecting the water discharge rate. Consultations with state officials revealed that the use of the BLDC pump technology coupled with metering mechanisms enabled farmers to become prosumers, which acted as an incentive to restrict groundwater depletion.

5.2.2 Increasing the Water Use Efficiency From Solar Pumps

A recent review by the Bureau of Energy Efficiency (2019) found that interventions to improve irrigation water use efficiency, such as micro-irrigation, can deliver energy savings almost comparable to pump replacement while also addressing groundwater stress. This suggests that water-efficiency policies can be an excellent way to pursue both cost savings and sustainability for specific types of crops. SIAs are recommended to pursue three main strategies to increase the water use efficiency of solar pumps.

(1) Pairing solar pumps with micro-irrigation technologies

The Per Drop More Crop (Minor Irrigation) component of the PMKSY scheme is focused specifically on helping states subsidize micro-irrigation—such as drip or sprinkler irrigation—which is significantly more water-efficient than traditional methods. While Section 2 emphasizes the need for scheme convergence, this can require supporting measures because micro-irrigation can increase costs and is relatively more complex to make, set up, and run (IRENA, 2016a). States may need to explore the creation of service centres at the district or block level, and farmers will need technical guidance to properly operate the system—this has already proved essential in the case of solar pumps (see Box 27).

In principle, water-efficiency technologies ought to help reduce water consumption. In practice, the actual impacts of bundling this with standalone pumps have not yet been comprehensively studied and could vary considerably by context—for example, in Rajasthan, a study found that farmers continued to use up all of the water stored in their *diggis,* despite having solar pumps (Kishore, et al., 2014). It is recommended that states first run pilots to evaluate the impacts of micro-irrigation using soil sensors and water flow meters and consider further measures to ensure sustainable groundwater use, as impacts may vary by context and how well the technology is operated. Deploying micro-irrigation in districts with multiple fragmented plots can be challenging and should be considered during planning and design.

Box 27. The need for district-level after-sales service centres and trained human resources

An impact evaluation study of solar irrigation in Andhra Pradesh and Chhattisgarh found that the physical presence of pump companies, suppliers, and service centres in the vicinity of beneficiary farmers played a major role in driving the adoption of solar pumps, as farmers preferred to depend on pump suppliers with local service centres over external suppliers (Kishore, et al., 2014).

Under the guidelines of PM-KUSUM, installers must provide free maintenance for 5 years, after which they can charge fees. But the time for addressing complaints can be lengthy. A survey of solar pump users in four states found that around 20% of the pumps were non-operational, primarily due to breakdown and lack of servicing (KPMG & GIZ, 2021). Mandating the creation of support, therefore, such as district-level service centres, should be integrated into the bidding process for solar pumps. Where it is economically unviable for integrators to create service centres in all districts, schemes could consider targeting a smaller number of districts, particularly where this aligns with geographic targeting efforts, as highlighted in Section 4. A survey of solar pump users found that the after-sales experience was better when there was good communication between the SIA and beneficiaries (KPMG & GIZ, 2021). This highlights the importance of SIAs developing good communications, conducting field visits, and establishing grievance redressal mechanisms.

(2) Using surface water sources and water storage infrastructure

In districts with accessible surface water resources, states can combine solar irrigation with the Command Area Development and Water Management programme (CADWM), implemented under the Har Khet Ko Pani component of the PMKSY scheme. The CADWM aims to create infrastructure for distributing surface water from reservoirs and canals to farms and promote efficient water use by utilizing micro-irrigation technologies. Converging solar irrigation with CADWM can reduce pressure on groundwater in water-stressed districts and provide an alternative source of irrigation in districts with poor groundwater quality. A pilot community-based solar and micro-irrigation project was undertaken by the Command Area Development Authority (CADA) in Haryana with encouraging results (see Box 28).

In regions with limited water resources, rainwater harvesting structures like ponds and check dams can play a major role in recharging water sources (Agrawal & Jain , 2018). States can create these structures by converging solar irrigation with the Atal Bhujal Yojana scheme, whose primary aim is to recharge groundwater and create sufficient water storage for agricultural purposes. States can also link solar irrigation with the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), which will enable SIAs to leverage the scheme's considerable financial and human resources for creating temporary water storage structures at the village level.

Box 28. CADA project to support community-based solar-powered micro-irrigation in Haryana

CADA Haryana, along with Jain Irrigation Systems, conducted several field experiments in 2018 by installing community-based solar/grid and standalone solar-powered irrigation systems in the canal command area of two districts in Haryana (Sharma et al., 2020). The project team installed drip and sprinkler-based irrigation systems at canal outlets, sewage treatment plants, and overflowing ponds to understand the impact of these interventions on water and electricity utilization in these areas. An evaluation by the project team found that the use of advanced water-saving techniques contributed to groundwater savings of up to 50% and increased yield by 12%, demonstrating that such technologies could reduce electricity and water usage without compromising crop production. The study is particularly relevant for regions where canal water use efficiency is low and there is significant groundwater extraction through flood irrigation techniques.

(3) Exploring innovative solutions to curtail groundwater extraction

In regions with rapidly declining groundwater levels or highly water-intense cropping patterns, states may consider exploring innovative solutions such as deploying Internet of Things (IoT) technologies or providing direct incentives to curtail groundwater depletion. IoT-based devices can remotely turn off pumps that exceed benchmarked consumption patterns (see Box 29). Direct incentives operate by paying farmers to curtail water consumption below a specified limit by directly transferring subsidy benefits to bank accounts. This can also create many indirect benefits, such as promoting the diversification of cropping practices, increasing farmers' awareness of the groundwater situation, and facilitating the installation of water meters to improve monitoring (Box 30).

Such solutions, however, will create an additional financial burden on states and need to be budgeted as part of the initial scheme design. Further, they have only recently been explored. Their effective use and acceptance uptake among farmers will hinge upon pilot demonstrations, capacity building, awareness generation, and outreach activities. For example, pilots in Punjab found positive success with direct incentives (Box 30), but a similar experimental study in Gujarat found that its incentives did not have any impacts on water usage (Fishman et al., 2016).

Box 29. IoT-based technologies to remotely curtail groundwater extraction

In the last few years, there has been quite a bit of progress in designing IoT-enabled systems for productive use in agriculture. Researchers and experts have suggested that the deployment of IoT, or sensor-based soil moisture measurement devices complemented with a mobile app that facilitates the remote operation of pumps, could help control groundwater withdrawals from solar pumps. Real-time data monitoring and weather forecasting systems also have the potential to improve water management practices, while new technologies like artificial intelligence and big data analytics can play a constructive role. This is an emerging area of research and can be an option in areas with strong digital connectivity and high literacy.

Box 30. Paani Bachao Paisa Kamao pilot project in Punjab to promote water conservation

The Paani Bachao Paisa Kamao pilot project of the Punjab State Power Corporation Limited (PSPCL) was implemented in 2018 at six of Punjab's 5,900 rural agricultural feeders covering 14.16 lakh tubewells. This World Bank-supported project paid farmers an incentive for using less power and hence less water to irrigate their crops. The money was transferred directly to the beneficiary farmers' bank accounts using the Direct Benefits of Transfer of Electricity (DBTE) mechanism and is estimated to have contributed to a reduction of water and electricity consumption in the range of 6% to 25% (Foley, 2020). The project deployed a mobile application-based remote control of the pump, which included features like the scheduling of pumping hours. It also involved setting up demonstration farms to show how irrigation and agriculture practices can save water, offering capacity-building activities through training and farmer camps to increase awareness about the state's groundwater situation, and promoting crop diversification and water conservation practices.

5.2.3 Infrastructure for the Optimal Use of Solar Irrigation Systems

According to a Central Government notification, solar pumps are used for an estimated 100–150 days in a year (PIB, 2020c). However, a survey of solar pump users found that in four out of nine surveyed districts across multiple states, the utilization rate was less than 50 days in a year, partly due to declining water tables (KPMG & GIZ, 2021). States can bolster this utilization rate by deploying the following complementary infrastructure and services to help reduce groundwater extraction and enhance farmer incomes.

(1) Devices to enable production applications, such as USPCs

USPCs have a built-in mechanism to divert energy from standalone solar pumps to run electric equipment, such as cold storage devices. Like IoT technologies and direct incentives, this is another exploratory area that has seen interesting pilots in some states (see Box 31) but remains an early-stage innovation. States interested in USPCs should first consider how solar systems are used in pilots and consult directly with farmers to assess the potential residual energy that can be generated. Following this, pilot programs can be considered for USPCs to determine if and how they can support secondary use of power. Regulatory barriers may also need to be addressed, such as when vendors or system integrators do not provide warranty services when a solar system is used for non-irrigation activities.

MNRE has released technical specifications and extended PM-KUSUM's subsidy mechanisms for solar pumps with USPCs. Survey research, however, suggests that USPC devices do not enable the concurrent usage of multiple devices due to an unbalanced load, so they need to be used carefully (KPMG & GIZ, 2021). States can address this challenge by prioritizing the distribution of DRE-optimized equipment over inefficient and low-cost appliances. Waray et al. (2018) have identified 20 appliances, including cold storage and sewing and milling machines, that can be efficiently run using DRE. Policy experts and state officials have also suggested that the success of USPCs is linked to their integration into wider rural livelihood promotion activities being pursued by state agriculture and rural development agencies. These linkages can help farmers access financial and technical support for micro solar cold storage and food processing. They also suggested that residual energy from a single pump is unlikely to be sufficient to operate cold storage or food processing, so additional power evacuation infrastructure may be needed to collect residual energy from multiple solar pumps.

Box 31. Project to encourage the productive use of under-utilized solar pumps in West Bengal

Under a GIZ-supported pilot project, three operational solar pumps with a utilization rate of fewer than 30 days per year were customized for productive load in West Bengal. Prior to the intervention, the energy use of the pumps was between 1% and 13% of their net potential, undermining their financial viability (Durga et al., 2020). Stitching machines, animal fodder, and water purification plants were then added to the three solar pumps, complemented with technical and financial support. The project was jointly financed by GIZ and an equity contribution from farmer clubs. At two project sites, the use of the solar pumps more than doubled. This pilot highlights the importance of linking up to rural livelihood promotion and addressing infrastructure needs.

(2) Regular cleaning of solar panels and maintenance of solar pumps

Regular cleaning and maintenance support can help prevent power output loss and extend the life of the solar irrigation system. As per a recent experimental study, the accumulation of a uniform layer of 5 g of dust led to a 20% reduction in the power output of solar PV modules (Hussain et al., 2017). A survey of solar pump users across four states found that 20% of pumps were non-operational (KPMG & GIZ, 2021). It also found that only 35% of surveyed solar pumps were properly maintained, while 7% had never been cleaned (KPMG & GIZ, 2021).

These numbers underscore the importance of imparting basic operations and maintenance training to farmers at the time of installation. States can help in building the capacity of the farmer and local institutions by leveraging KVKs, Gram Panchayats, and local agricultural universities, as these institutions are already engaged in agricultural interventions. State agricultural universities and agricultural block offices have existing repositories of information on agricultural technologies and can include solar pumps as part of their repositories.

The proper maintenance of solar pumps can help maintain the system's water yields and extend its life cycle. Additionally, the regular cleaning of solar panels and pipes, checking wires, and replacing inverters (every 8–10 years) can help to ensure that farmers earn back their high upfront investment in solar pumps over the duration of its estimated life cycle (25 years) (Shakti Sustainable Energy Foundation, 2018).

5.2.4 Infrastructure to Address Grid Reliability

Grid-connected solar pumps can fulfill multiple objectives of solar irrigation. This includes boosting farmers' income with metering for prosumers, improving the reliability of power and irrigation supply, reducing DISCOM electricity subsidies, and curbing excessive groundwater use (World Bank, 2020). However, there are multiple barriers to using them successfully, including grid unreliability in rural regions, the absence of trained human resources, and the reluctance of farmers to shift from subsidized electricity to capital-intensive solar pumps. Strategies to address some of these challenges include:

1. Deploying smart meters to capture agricultural electricity consumption
2. Addressing the free-rider challenge
3. Integrating solar pumps with feeders
4. Institutional capacity building.

5.2.4.1 DEPLOYING SMART METERS TO CAPTURE AGRICULTURAL ELECTRICITY CONSUMPTION

In many states, a large share of agriculture connections is not metered. This is estimated to range from around 35% in states like Maharashtra, Gujarat, and Madhya Pradesh, to 90% in Punjab (Maharashtra Electricity Regulatory Commission, 2020). The absence of metering not only affects DISCOMs' financial health and ability to forecast demand but also impedes the deployment of grid-connected pumps.

In some states, installing meters can be challenging due to the political economy of subsidized agricultural power. However, metering that allows farmers to become prosumers offers an opportunity to link incentives to smart meters. Under the SKY scheme, Gujarat Urja Vikas Nigam Limited (GUVNL) installed a bidirectional energy meter consisting of a solar generation meter, consumption meter, and net meter (Patel & Patel, 2019). Financially stressed DISCOMs can also look to collaborate with Energy Efficiency Services Limited (EESL) for support in deploying smart meters (Box 32).

SIAs are recommended to establish clear guidelines for procuring meters for grid-connected solar pump schemes, including identifying the responsible agency and a cost-effective procurement process.

Box 32. EESL's Smart Meter National Program for DISCOMs

In a joint venture under the Ministry of Power, EESL launched the National Smart Meters Program to replace 250 million traditional electric meters. The program has multiple objectives, including, among others, reducing DISCOMs' commercial losses, enhancing their revenues, and supporting power sector reforms. Under the program, more than 12 lakh smart meters have been installed in UP, New Delhi, Haryana, and Bihar. EESL estimates that they have led to an around 20% average increase in DISCOM revenue (EESL, 2021).

EESL's funding model for the program follows a build–own–operate–transfer (BOOT) approach, which requires no upfront capital investment from the DISCOM. Instead, EESL recovers the capital investment over time from the DISCOM through the monetization of savings from enhanced billing accuracy, avoided meter reading costs, and other efficiencies from the smart meters.

5.2.4.2 ADDRESSING THE FREE-RIDER CHALLENGE

Interviewed DISCOM officials reported that grid-connected solar pumps require the agricultural feeder to be kept on throughout the daytime for 12 hours to support metering mechanisms for prosumers. This could lead to a free-rider challenge where non-participating farmers increase pumping hours, exacerbating the DISCOM subsidy burden and increasing pressure on groundwater. SIAs therefore may need to convince a majority of farmers in a selected feeder to switch to solar pumps.

Consultation with officials in Gujarat found that the initial draft of the SKY scheme required all farmers on a feeder to agree to participate. However, this proved unrealistic since some feeders covered multiple villages. Officials then decided to implement the scheme in feeders with at least 70% farmer participation. Ultimately, it was implemented in some feeders with even 50% coverage, aided by watchdog transformers with smart meters, to monitor energy usage of non-participating farmers and enable DISCOMs to remotely disconnect consumers who were overdrawing electricity (Box 33).

Box 33. The use of watchdog transformers in the SKY scheme in Gujarat

Under the SKY scheme, GUVNL installed watchdog transformers with a smart meter (remote relay) at every generation and consumption point on the feeder (Patel & Patel, 2019). They were installed to check if any power was lost (apart from line losses) due to over-extraction or theft from non-SKY farmers. They were equipped with an IoT-based programmable smart device that measured all electrical parameters from the pumps. The device limited the 3-phase power supply to non-participating consumers for 8 hours and recorded the energy used (Patel & Patel, 2019). This data and an ability to remotely connect and disconnect users were integrated into the scheme's Solar Energy Data Management (SEDM) platform to allow regulators to disconnect non-SKY farmers who were overdrawing electricity from the grid.

5.2.4.3 INTEGRATING GRID-CONNECTED SOLAR PUMPS WITH FEEDERS

Selecting the appropriate feeder for grid-connected solar pumps depends on a range of factors, including the level of feeder separation for agricultural consumers, maximum pump capacity in different feeders, the number of agricultural consumers, and the distance from the nearest substation. Interviews with officials in some states, including Haryana and Jharkhand, revealed that they were concerned about the possibility of the tripping of 11 kilovolt lines and low-tension feeders after solar pump integration. To avoid such problems, SIAs and DISCOMs can draw lessons from rooftop solar (Box 34). A modelling analysis by The Energy and Resources Institute (TERI) (2020) recommended various options for DISCOMs when integrating rooftop solar, including:

1. Smart solar inverters with Volt-VAr control can reduce the curtailment of active power while reliably maintaining the grid.
2. On-load tap changer (OLTC) devices are commonly used to regulate downstream voltage, with better results than Volt-VAr if the control point is properly defined but with higher costs.
3. Battery energy storage systems can help in energy-loss and peak load management but are not effective in voltage control.

Before implementing these technologies, it is recommended that DISCOMs conduct a thorough assessment of costs and benefits. The need for grid reinforcement can be delayed or even prevented by updating interconnection standards, procedures, and distribution planning methodologies to better reflect the characteristics of distributed solar.

Box 34. TERI study on addressing grid integration concerns from distributed solar energy

A study on rooftop solar projects in West Bengal and Delhi found that the quality of grid integration is dependent on the system's location (TERI, 2020). At times when the load on the feeder is low, the high voltage magnitude may affect the lifespan of overhead insulators and damage consumer equipment. DRE can also cause problems for sub-station components and safety instruments in the distribution transformer. Therefore, careful planning of peak power procurement, location of integration, and network load management need to be undertaken by DISCOMs before implementing on-grid solar pumps to ensure that it does not hamper grid stability.

5.2.4.4 INSTITUTIONAL CAPACITY BUILDING

Interviews with state officials highlighted the need for capacity-building measures to support DISCOMs' district and block-level staff in implementing grid-connected solar irrigation. The operation and maintenance of these systems require specialized skills and knowledge. Gujarat Energy Research and Management Institute (GERMI) officials reported that the SKY scheme's success in Gujarat was driven by the quality of GUVNL's (the state DISCOM) human resources, particularly the training imparted to their engineers and reliance on baseline studies.

States can help build DISCOM staff capacity through the Suryamitra Skill Development Program run by the National Institute of Solar Energy (2021). Trained human resources at the district and block levels can help reduce the redressal and response time for solar plant and feeder maintenance. Training of government officials and frontline staff needs to be included in state planning with measures for adequate funding and regular training to improve institutional capacity. States can also leverage KVKs, Gram Panchayats, and local agricultural universities to support farmer training programs on the efficient use of grid-connected solar pumps and groundwater management.

Box 35. Institutional challenges faced under the Surya Raitha scheme in Karnataka

According to Durga et al. (2020), the Surya Raitha scheme's design primarily focused on the technical and financial aspects of grid-connected solar pumps and overlooked the institutional factors. The implementing agency created a farmer aggregate institution without adequate consultations with participating farmers, which undermined the institution's influence over farmer groups.

The study found that a lack of awareness and trust deficit meant that farmers were reluctant to contribute their stipulated share under the scheme, leading to the DISCOM availing a loan on their behalf. The absence of farmers' financial contribution and passive participation in the scheme restricted their technical understanding of the system, such as the ability to read meters. This limited their awareness of the electricity generated, utilized, or sold to the DISCOM under the scheme. Interviews with state officials highlighted the importance of having a local NGO or farmer organization assist in grid-connected solar irrigation projects to address farmer apprehensions.

5.3 Key Recommendations

Enhance water use efficiency by:

- Bundling pumps with micro-irrigation technologies, like drip and sprinkler irrigation
- Leveraging surface water sources and creating water storage infrastructure
- Promoting regular cleaning and maintenance of pumps to prevent leakage and breakdown

Enable metering for prosumers by:

- Deploying smart meters
- Designing the right metering mechanisms
- Selecting the appropriate feeders and boosting grid reliability
- Building institutional capacity to increase farmer participation
- Addressing the free-rider challenge by deploying watchdog transformers

Explore innovative solutions to curb excessive groundwater withdrawals through approach pilots, monitoring, and evaluation, such as:

- Enabling productive use of excess power from solar pumps to promote efficient energy and water use, such as through universal controllers for standalone pumps
- Financial incentives to discourage extraction of groundwater, as is used in Punjab
- IoT-based technologies to remotely curtail groundwater extraction from pumps

Infrastructure Support

Further guidance and resources

World Bank (2020), *Grow Solar, Save Water, Double Farmer Income: An Innovative Approach to Addressing Water-Energy-Agriculture Nexus in Rajasthan.* https://openknowledge.worldbank.org/handle/10986/33375

TERI (2020), *Technical Impacts of Increasing Rooftop Solar PV Penetration in Electricity Distribution Systems in India: A Case Study for Delhi and West Bengal* https://www.teriin.org/sites/default/files/2020-11/2016RT08.pdf

Shakti Sustainable Energy Foundation (2018), *Impact Assessment of the National Solar Pumps Program* https://shaktifoundation.in/report/impact-assessment-of-the-national-solar-pumps-programme/

For different models of solar pump deployment: CGIAR Research Program in Climate Change, Agriculture and Food Security (2020), *Compendium on Solar Powered Irrigation Systems in India:* https://ccafs.cgiar.org/resources/publications/compendium-solar-powered-irrigation-systems-india

6.0
Monitoring and Evaluation

6.1 Why Does Monitoring and Evaluation Matter for Solar Irrigation?

Solar irrigation has economic, social, and environmental objectives. Achieving all of this is complicated. There are many possible implementation challenges that can emerge, such as administrative bottlenecks, subsidy disbursement delays, and after-sales issues. Given the complex relationship between water, energy, and food, it is also possible to see unexpected outcomes.

In this context, robust M&E is essential: data and analysis on implementation and impacts can help SIAs optimize schemes for maximum benefits. Much of the basics of M&E will be addressed by the SEDM platform being developed by MNRE for PM-KUSUM—but social and sustainability indicators may still require some additional efforts.

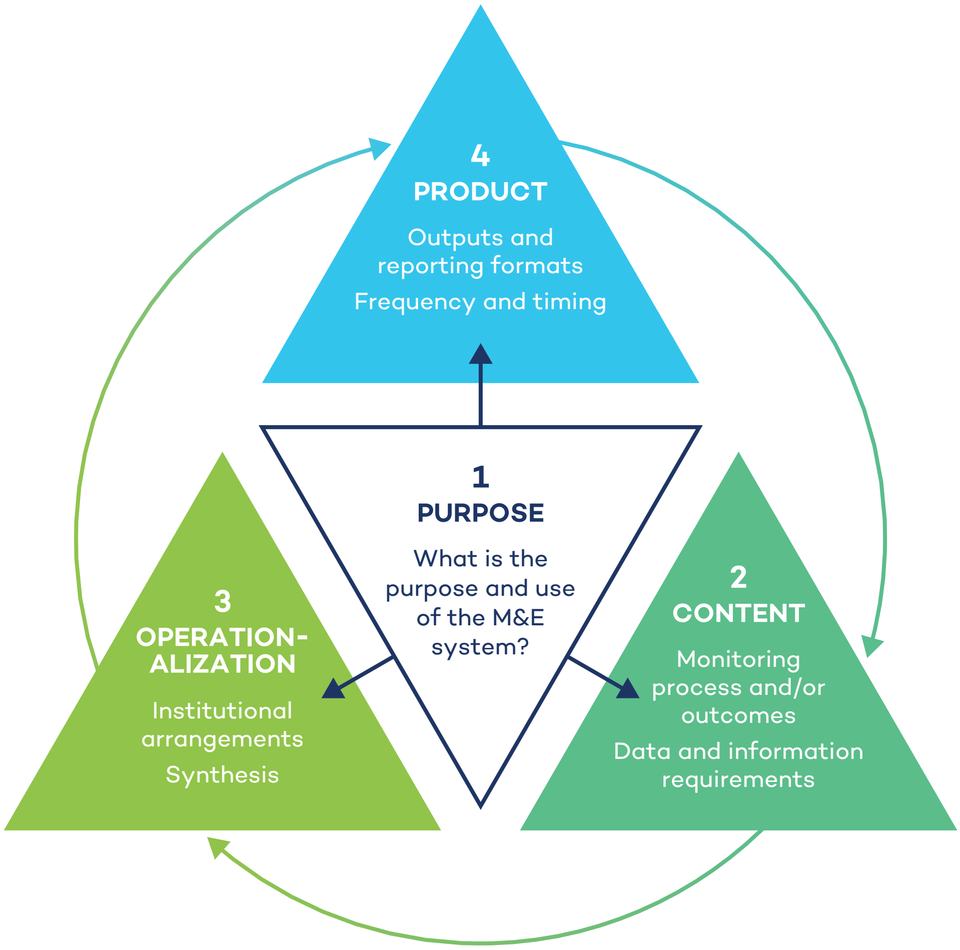
6.2 What Characteristics Should Be Considered for M&E?

Four key characteristics should be clear for M&E, as illustrated in Figure 12:

- **Purpose:** This can include adaptive management (tracking progress and, as necessary, taking corrective measures), accountability (reporting back to leadership, beneficiaries, and taxpayers), and learning (to inform future policies).
- **Content:** This can focus on implementation (progress in rolling out a scheme), outcomes (impacts of the scheme), or both.
- **Operationalization:** This establishes who does what. This typically includes a body responsible for coordination and analysis and a range of stakeholders responsible for data collection.
- **Product:** The methods, formats, and frequency of data collection and analytical reporting.

Naturally, there are trade-offs in determining the scope of any M&E system. A more comprehensive system may offer more useful outputs—but it would also involve higher administration costs.

Figure 12. Key components to consider for M&E



Source: Adapted from Price-Kelly et al., 2015.

6.3 What Will Be Captured by the SEDM Platform?

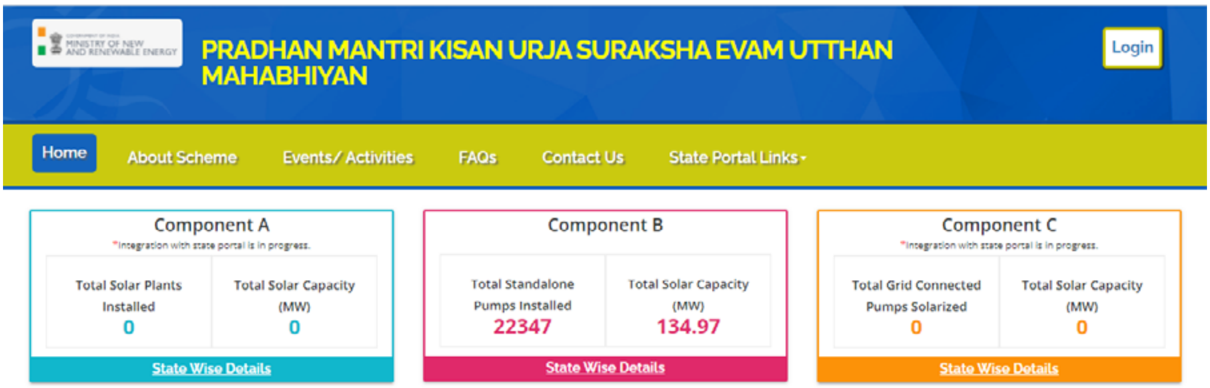
Under the PM-KUSUM scheme, MNRE has committed to developing a SEDM platform. This will consolidate data from each pump's RMS with data on scheme administration, such as progress with applications, subsidy disbursal, and management of complaints (Power Sector Reform Programme, 2021). The SEDM system is now operational in Gujarat, is being developed in Haryana, and will be scaled up to another 13 states (Power Sector Reform Programme, 2021).

The SEDM platform:

- Is multi-purpose. It will capture around 150 parameters pertaining to monitoring of consumers, assets, scheme progress, and system performance that can be used for adaptive management and accountability of existing policies and learning for future policies.

- Includes content on implementation and outcomes. The data are fully comprehensive on scheme operation. For outcomes, there is strong coverage of baseline data about farmers (crop details, irrigation methods, and existing pumps), pump operations, and complaints. Management information systems reports are generated, summarizing aspects of scheme progress.
- It is operated by the SIA, with data inputs from various stakeholders responsible for different parts of scheme implementation, such as vendors, DISCOMs, and groundwater departments. It links to a national-level SEDM that consolidates and analyzes data from all states.
- The product is the online web portal that has a summary of general information for all users and allows specific user groups, like SIAs, manufacturers, suppliers, and even consumers, to log in and view dashboards tailored to their specific needs and customizable data ranges.

Figure 13. National SEDM platform



Source: https://pmkusum.mnre.gov.in/landing.html

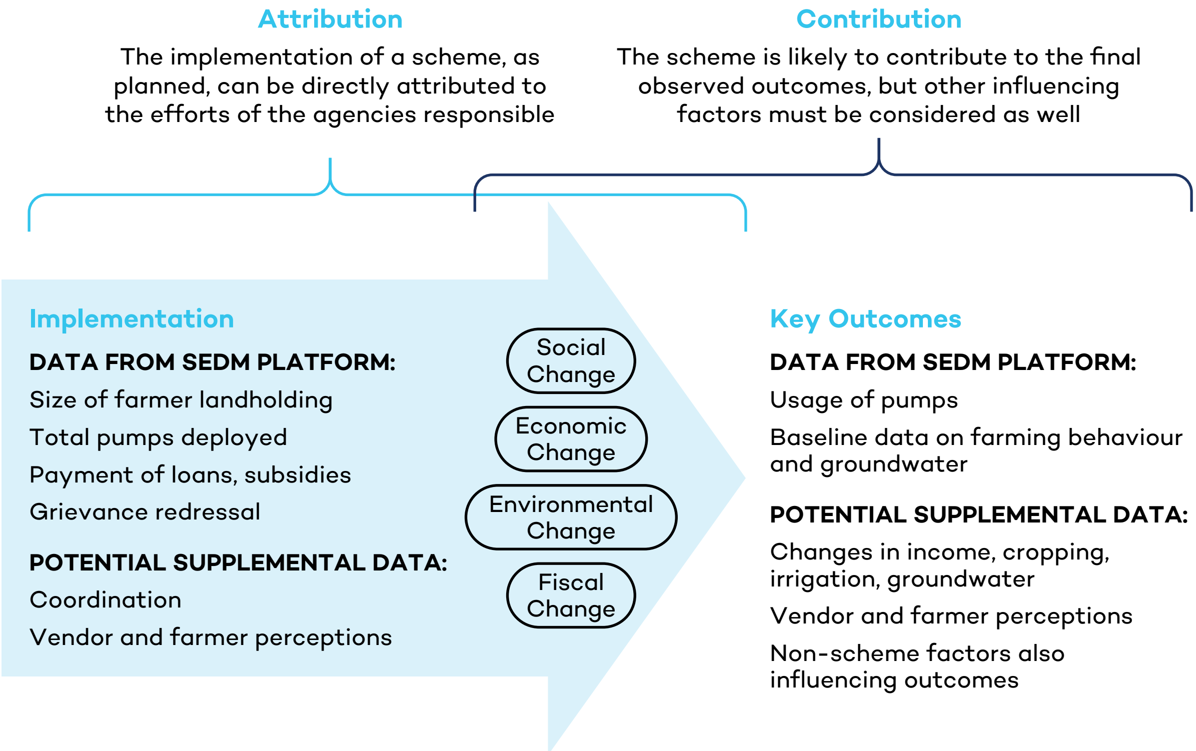
In addition to using the SEDM platform, we recommend SIAs conduct a recurring dedicated analysis of the social and environmental impacts as another "product" of its M&E systems. This chapter sets out some of the ways that the SEDM platform can be operationalized to this end. It also elaborates on how supplemental data collection efforts and analysis can help M&E be as robust as possible—such as around farmer perceptions, groundwater reserves, and non-scheme factors that also influence outcomes.

An overview of the most important data for analysis is illustrated in Figure 14, broken down by whether it is derived from scheme implementation or observed outcomes.

6.4 What Data Can Be Used to Monitor and Evaluate Social Outcomes?

To achieve social objectives, we recommend articulating a series of questions that can be answered by data from the SEDM and supplementary sources, as summarized in Table 2. Supplementary data can be commissioned and analyzed in collaboration with research organizations (see Box 36).

Figure 14. Tracking implementation and outcomes



Source: Authors

Box 36. How to collect supplementary data: Telephone surveys on social impacts

The data collection required for SEDM platforms is already quite demanding. Is it realistic, then, for states to collect supplementary data? In practice, these data are important for fully exploring scheme impacts, and much can be collected through one single activity: a survey of vendors and farmer beneficiaries. This can be conducted cost-effectively by telephone on an annual basis (or once in two years) using contact numbers in the SEDM or face-to-face surveys, which are more costly but usually result in richer data. They can be commissioned from external expert groups like agriculture universities, KVKs, or think tanks, who have the skills to ensure data quality. Such groups may also be able to propose piloting novel monitoring approaches, such as satellite data to track crop area planted, crop types, and evapotranspiration.

Table 2. Illustrative questions and data for monitoring and evaluating social outcomes

Question	Data
Is the scheme effectively accessible for small and marginal farmers? Is there gender-balanced targeting?	This can be assessed using SEDM data on: • Small and marginal farmers and women as a % of total beneficiaries • % of successful applications from small and marginal farmers and women
	With supplementary data, it could also consider: • The % of successful and unsuccessful applicants from key socio-economic groups, including landholding size, gender, and caste • Factors enhancing or constraining women's participation
Has scheme implementation prevented any undue cost burdens on beneficiaries?	This can be assessed using SEDM data on: • Timeliness of subsidy payments, net metering payments • Timeliness of loan applications, payments, grievance redressal
	With supplementary data, it could also consider: • Vendor and farmer perceptions on scheme roll-out and its cost burden, including satisfaction with pumps and maintenance, instances of theft
Is the scheme effectively coordinated with complementary policies?	With supplementary data, it could consider: • Representation of stakeholders responsible for farmer well-being in committees, task forces, and cells at state, district, and block levels • Explicit linkages created between the scheme and other forms of assistance, such as infrastructure or farming techniques
Has the scheme created income and welfare benefits for beneficiaries?	This can be assessed using SEDM data on: • Baseline data on crops, existing pumps, and energy use • RMS data on solar pump usage: hours of use, volume of water pumped • Sales from net metering
	With supplementary data, it could also consider: • Farmer perceptions on income impacts (including women farmers) • Change in income and welfare from changes in crop type and cropping patterns, sale of water, and other productive uses of energy • Qualitative review of non-scheme factors, such as the COVID-19 crisis

6.5 What Data Can Be Used to Monitor and Evaluate Impacts on Groundwater?

In its present form, the SEDM gathers little data on groundwater except for the source of water during site surveys and discharge rates from pumps. RMS devices do not typically display the quantity of water discharged by pumps, so states should make this mandatory. As a result, supplementary data are important to help assess water impacts. Another option is to integrate data on groundwater depletion from the Central Ground Water Board (CGWB) or state groundwater departments into the SEDM every 3 years. Table 3 summarizes key questions and data that can be used to answer them.

Table 3. Illustrative questions and data for monitoring and evaluating groundwater impacts

Question	Data
Is the scheme in areas with water stress?	This can be assessed using SEDM data on: • The % of pumps in different areas of the state by water stress
Is the scheme effectively coordinated with complementary policies?	With supplementary data, it could consider: • Representation of stakeholders responsible for water resources in committees, task forces, and cells at state, district, and block levels • Explicit linkages created between the scheme and other forms of assistance, such as infrastructure or farming techniques
How has the scheme affected water use and underlying groundwater resources?	This can be assessed using SEDM: • Baseline data from site surveys on crop details, existing pumps, and the source of power for the existing pump • RMS data on solar pump usage: hours of use, volume of water pumped • Income from net metering
	With supplementary data, it could also consider: • Changes in water needs from changing productivity and yields • Changes in water needs from changes in crop type and cropping patterns • Changes in irrigation methods since the scheme began, e.g., flood vs. micro-irrigation • Volume of water drawn for direct use vs. sale to others • Changes in groundwater level and recharge around scheme beneficiaries • Actual impacts of policies intended to promote water efficiency (e.g., micro-irrigation, net metering, USPC devices, etc.) • Qualitative review of non-scheme impacts also affects outcomes, such as rainfall and changing withdrawal rates from other users

Box 37. How to collect supplementary data: Tracking groundwater impacts

Many data points on water are linked to system performance and changes in farmer behaviour and can be gathered from the RMS and surveys, as mentioned under social impacts. However, this is not sufficient to ultimately assess the state of the physical water resource. Supplementary efforts must therefore also capture data on groundwater levels and recharge rates. To be cost effective, such assessments are best clustered around site visits for farmer surveys and focused on existing groundwater board observation wells. It is important that such information is collected by an authority with strong technical skills in assessing groundwater, such as a state groundwater department. It should also account for other pressures to ensure that impacts are not solely attributed to solar pumps but consider the wider WEF context of the specific area.

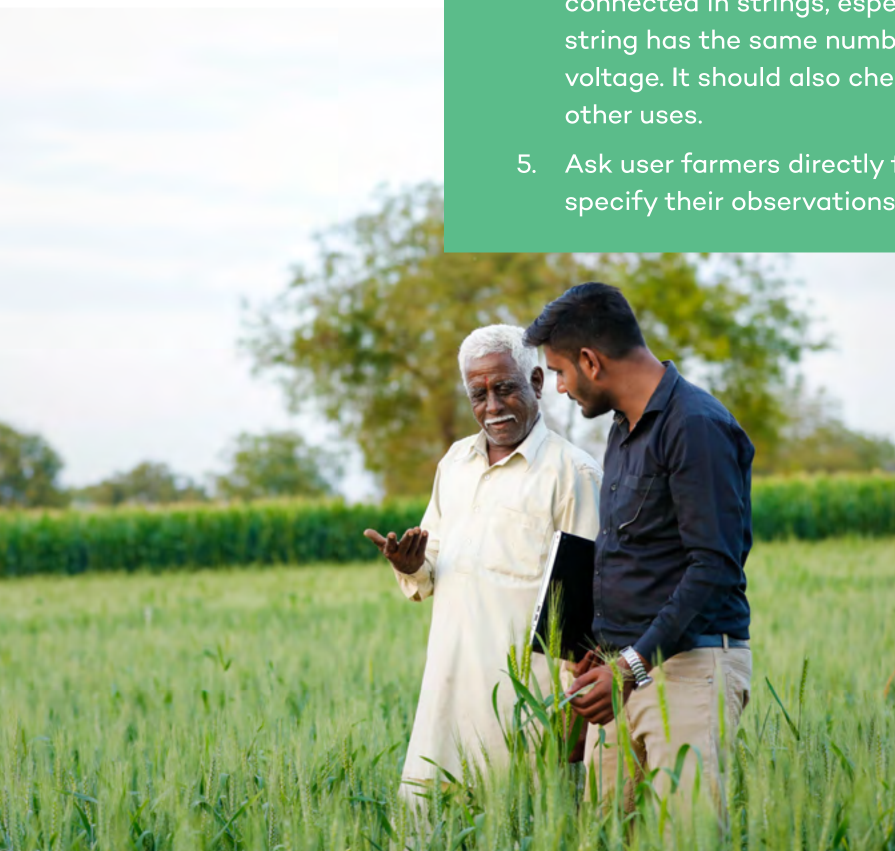
6.6 How Can Data Checks Support the Accuracy of M&E?

An SEDM platform is only as strong as its data. In the case of RMS data from solar pumps, this means specific guidelines and regulations to standardize data structure and conducting field tests at regular intervals, alongside supplementary data collection, following principles in Box 38. Experiences from previous M&E systems suggest that quality control processes are also critical, including automated checks integrated into the monitoring system, as elaborated upon in Box 39.

Box 38. Observations for field testing of solar pumps

A field-testing team should ideally consist of a Bureau of Energy Efficiency (BEE)-certified energy auditor and representatives from the state REDA, MNRE, and the manufacturer or equipment supplier. Dos and don'ts include:

1. A representative sample of different pump capacities should be field tested. Field testing should also investigate solar pumps whose RMS data involves significant outliers.
2. Field testing should ensure that suppliers of tested pumps are maintaining RMS data on their servers. Errors in the range of 5%–10% can be expected. The RMS directly monitors parameters like voltage and current, whereas all other parameters—such as power, radiation, flow of water, and depth—are derived. Derived parameters have more chances of error.
3. It is better to physically inspect the pumps. Performance can be tested with a pyranometer (for radiation), a multimeter (for voltage and current), a bucket with a stopwatch (for water discharge and flow rate), and a pressure gauge (water depth, static head and dynamic head). For more details, see BEE's guidelines in Energy Performance Assessment of Water Pumps (BEE, n.d.).
4. Testing should be scheduled on sunny days over different seasons to ensure performance is accurately captured. Tests should verify that MNRE-specified solar tracking structures are used and that modules are fully exposed and properly connected in strings, especially in parallel units, where each string has the same number of modules to ensure constant voltage. It should also check if systems are connected for other uses.
5. Ask user farmers directly for feedback, and ask them to specify their observations.



Box 39. Quality controls for manual data entry: Lessons from RMS metadata in Chhattisgarh

In a recent review of RMS data from solar pumps in Chhattisgarh, Rahman & Jain (2021b) found significant problems with data quality and infrastructure. While much of this should improve with SEDM platforms, there are still important lessons, particularly around manual data entry. In one Chhattisgarh portal, around 80% of geotag information was either missing entirely or pointed to the manufacturers' headquarters. Other metadata, such as pump owner address, were also frequently incorrectly entered. When creating SEDM platforms, states should not under-invest in creating quality control checks, such as automated alerts around missing data or values outside a typical range, alongside clear protocols for action to take when quality problems are identified.

6.7 How Can M&E Involve Stakeholders at Different Levels?

SEDM platforms already envisage providing information to different stakeholders who can log in to see dashboards specific to their individual needs. There are also additional ways that stakeholders can be engaged in M&E, building trust and creating opportunities for direct stakeholder feedback.

- **Farmers, FPOs, and vendors:** In order to use the SEDM platform or related mobile apps, farmers and vendors need to be trained in basic knowledge of the system and its operation. This may require a "Dos and Don'ts" manual in a vernacular language. In the event of a problem or during an in-depth evaluation of data, farmers and vendors could be asked to provide detailed inputs by joining site visits or through in-depth interviews. Farmer organizations and vendors should also be engaged in evaluation discussions at district and state levels.
- **Operators:** Vendors and operators may also require capacity building. They are an important point of contact for investigating scheme challenges and should participate in evaluation discussions.
- **Block/district level:** State officials should be familiar with the SEDM platform and encouraged to conduct regular field visits to confirm the accuracy of RMS data and metadata in the SEDM platforms. Interactions with vendors and farmers can also help to highlight any discrepancies in data collected or other grievances.

- **State level:** The SIA should analyze SEDM data and compile key findings in a short, written briefing on a quarterly or biannual basis, following a standard template. Findings could be shared in multistakeholder discussion forums to give voice to concerns and identify common solutions. Where third-party evaluators assist the SIA by collecting supplementary data, these independent agencies can potentially provide capacity-building activities to help it implement M&E.
- **National level:** The national-level SEDM platform can similarly take stock of state-wise progress. MNRE can create a discussion space for state stakeholders to share experiences and highlight measures taken for course correction, resource allocation, and personnel training, among others. Making data open source can help to enable independent analysis and recommendations.

Figure 15. Flow chart on engagement in different levels of M&E for solar irrigation

Monitoring level	Role in data monitoring	Strategies for additional engagement
Farmer	Basic observations of system operation; inputs to surveys	SEDM capacity building; site visits, interview; engagement in discussions
Vendor	O&M, SEDM inputs on policy administration grievances	Capacity building on SEDM; interviews; engagement in discussions
Block/District	SEDM inputs on policy administration from DISCOMs, financial institutions	Site visits
State	SEDM inputs on policy administration; reporting down and up	Short written briefings, multistakeholder discussion forums
National	Integrating data and experiences between states	National stock-taking, multistakeholder discussion forums

Note: O&M = operations and maintenance.
Source: Authors.

6.8 Product Planning for the Management of Online Data Portals

Data portals have been used in a number of schemes (see Box 40)—but not without challenges. For SEDM platforms to work well, states will still need to build capacity for implementation, such as the server capacity for storing and processing large volumes of data or training users. At the time of publishing this guidebook, most states do not yet have operational SEDM platforms and only 15 have committed to developing them. All states with solar irrigation schemes are recommended to create such systems, integrated with national SEDM reporting. For all states that do not yet have a platform, it is recommended to at least annually assess social and groundwater impacts through independent evaluations, building on this chapter's recommendations on supplementary data collection. Dedicated evaluations may be needed even after a platform is established— for example, targeted studies investigating any key issues that emerge (see Box 41) or assessing impacts of pilots on micro-irrigation or USPCs.

The SEDM system can also flexibly support additional parameters and undergo continuous quality improvement, meaning SIAs can adapt it to their needs. For example, it currently uses a mobile application that communicates directly with consumers, such as alerting them to faults or damage. This could be extended to provide initial solutions to problems through direct messages.

Box 40. Online data monitoring platforms in Chhattisgarh, Haryana, and Gujarat

Data portals like the SEDM platform have been used in the past in multiple states. In interviews, the CREDA reported that they use an online portal to track the SSY scheme, including the number of applications, installation reports, the performance of systems, and release of payments. Similarly, consultations with the Haryana Renewable Energy Development Agency (HAREDA) revealed that RMS data is accessible through a geographic information system (GIS) app. Gujarat's SKY scheme pioneered the use of SEDM for monitoring the technical, operational, and managerial parameters of scheme feeders (Upadhyay et al., 2019). The Watch Dog Device, an innovation by the Gujarat Power Research Development Cell, enabled IoT-based remote monitoring and energy auditing of power for SKY and non-SKY users, preventing pilferage or theft (Patel & Patel, 2019). There are also lessons to be learned from past initiatives. In a recent review, Rahman and Jain (2021b) found serious data problems with portals in Chhattisgarh, emphasizing the need for clear, specific guidelines and regulations for suppliers; robust quality control; and measures to pursue when guidelines are not followed.

Box 41. Targeted evaluations of key emerging issues

M&E systems often identify problems that require further investigation: for example, a large incidence of loan defaults in a certain region, poor performance on gender equality, or frequent theft. In such instances, it may be necessary to commission a targeted study to better understand the problem. Institutions such as agriculture universities, KVKs, and think tanks can assist in taking on thematic investigations of this nature. For example, with respect to gender, a targeted study could investigate the underlying factors affecting gender inclusion, such as women's awareness of the scheme and experiences getting loans.

6.9 Key Recommendations

Monitor and evalute social outcomes, including:

- Is the scheme well targeted at low-income and marginal farmers?
- Is the scheme avoiding the creation of undue cost burdens?
- Is the scheme well coordinated with other social policies?
- Has the scheme created income benefits for farmers?

Monitor and evaluate impacts on water resources, including:

- Is the scheme focused on low-risk areas for water stress?
- Is the scheme effectively coordinated with other water policies?
- How has the scheme influenced water use and groundwater reserves?

Use data from:

- SEDM platforms, backed up by field testing
- Supplementary surveys with farmers
- Supplementary assessments of water conditions
- Reviews of non-scheme factors that also affect outcomes

Engage stakeholders in M&E through:

- Capacity building for farmers and vendors on using the SEDM
- Site visits to explore challenges
- Quarterly or biannual analysis of social and water impacts

Monitoring and evaluation

Further guidance and resources

The Gujarat State Level Solar Energy Data Management Platform: https://pmkusum.guvnl.com/landing.html

EESL has, in the past, undertaken a project for replacing old and inefficient solar pumps with efficient variants. Monitoring is done on an online dashboard with data on energy savings, peak load demand reduction, water drawn, carbon dioxide reduction, and cost savings: http://agdsm.in/

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Published by the International Institute for Sustainable Development

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