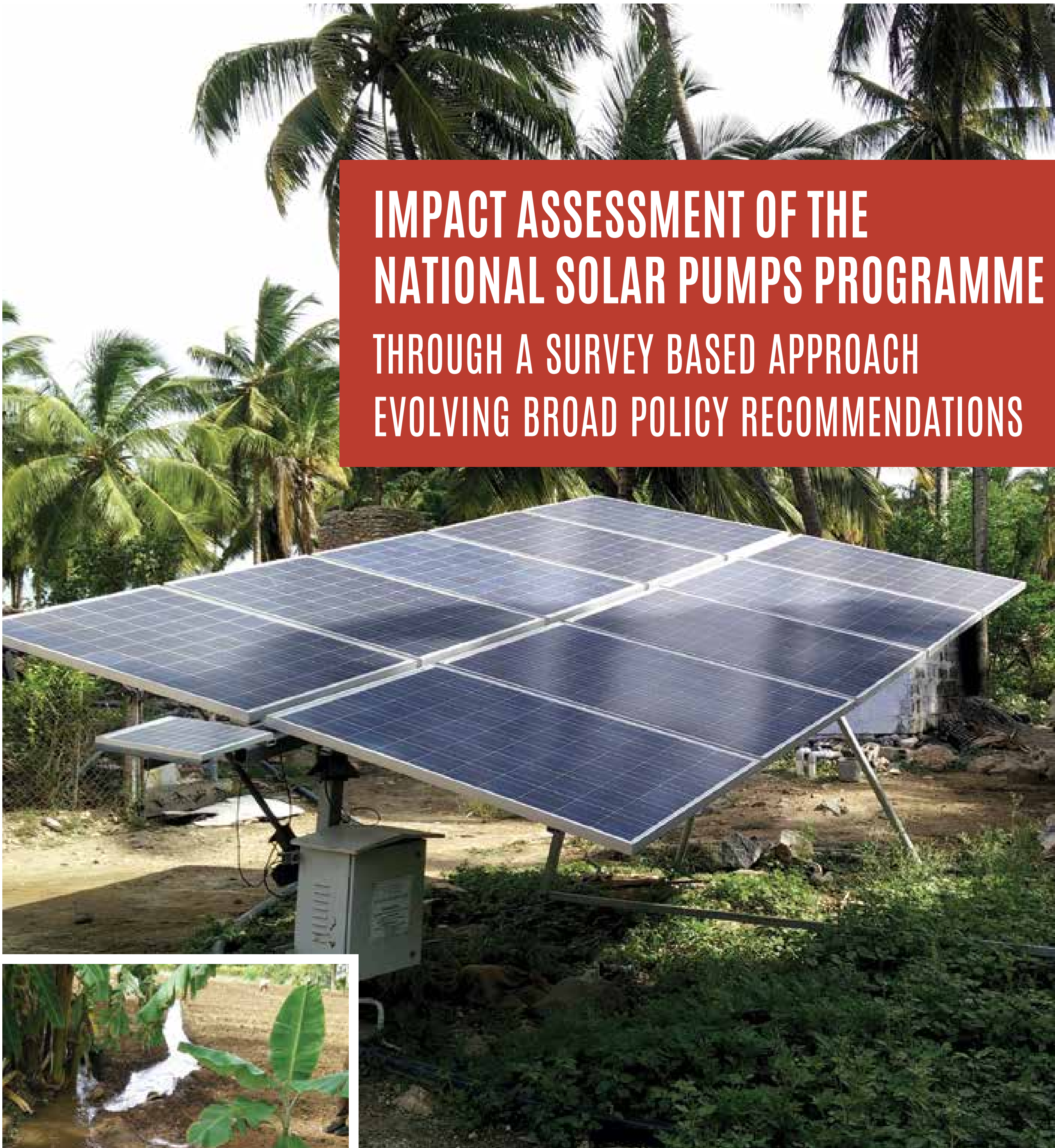

IMPACT ASSESSMENT OF THE NATIONAL SOLAR PUMPS PROGRAMME

THROUGH A SURVEY BASED APPROACH EVOLVING BROAD POLICY RECOMMENDATIONS

An initiative supported by

SHAKTI SUSTAINABLE ENERGY FOUNDATION

Schweizerische Eidgenossenschaft
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Prepared by

SAMBODHI KNOWLEDGE FOR CHANGE

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This report has been commissioned by Shakti Sustainable Energy Foundation. The report has been prepared by Dalberg Advisors, in collaboration with Sambodhi Research and Communications.

Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that support renewable energy, energy efficiency and sustainable urban transport.

Table of Contents

List of Abbreviations and Common Terms

Abbreviation/ term	Description
SWP	Solar Water Pumps
SHAKTI	Shakti Renewable Energy Foundation
MNRE	Ministry of New and Renewable Energy
JNNSM	Jawaharlal Nehru National Solar Mission
Stacking	Stacking refers to the complimentary use of two types of pumps, such as diesel and solar, electric and solar or electric and diesel pumps
Pure diesel farmers	Farmers using only diesel pumps
Pure electric farmers	Farmers using only electric pumps
No pump farmers	Farmers using no irrigation pumps
FGD	Focus group discussion
BREDA	Bihar Renewable Energy Development Agency
UPNEDA	Uttar Pradesh New and Renewable Energy Development Agency
TISS	Tata Institute of Social Sciences
CEEW	Council on Energy, Environment and Water
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit—a German development agency
PV	Photovoltaic
SNA	State Nodal Agency
NABARD	National Bank for Agriculture and Rural Development
PAYG	Pay-as-you-go—a financing model involving payments for use to service provider
HP	Horse Power
UID	Unique Identification Number
PMKSY	Pradhan Mantri Krishi Sinchai Yojana
DIP	District Irrigation Plans
DBT	Direct Benefit Transfer
NMMI	National Mission on Micro-Irrigation
KVK	Krishi Vikas Kendra
MFI	Micro Finance Institution
RRB	Regional Rural Bank
SHG	Self-help group
B2G	Business-to-government

Executive Summary

In 2014-15, the Government of India, MNRE announced a special budgetary allocation to implement a minimum of 100,000 solar water pumps per year, and a total of 1,000,000 pumps by 2020-21, through State Nodal Agencies (SNAs) and the National Bank for Agriculture and Rural Development (NABARD), under the National Solar Mission (NSM). As of 2014-15, only about 65,000 pumps had been commissioned nationally, with another minimum 25,000 targeted by end-2017.[1] As MNRE explores continuing and expanding the scheme, it seeks to understand its results and impact till date, and incorporate emerging lessons into plans. In support of MNRE's forward-looking efforts, Shakti Sustainable Energy Foundation (Shakti) commissioned a study on the results and broader socio-economic impact of solar water pumps installed under the JNNSM in four states—UP, Bihar, Rajasthan and Tamil Nadu.

Main findings and recommendations

At least 26,000 pumps have been sanctioned/ approved in the four study states up until 2014-15[2], though actual installation is lower. Rajasthan, Uttar Pradesh and Tamil Nadu have installed approximately ~50% of pumps sanctioned for their states, while Bihar has installed 6%. Across the states, total installation is 41.2% of sanctioned pumps, according to latest estimates in the public domain.[3] Pump selection is a major driver of the witnessed installation rates. States that have high installation rates, such as Rajasthan and Tamil Nadu, offer a variety of pump sizes to choose from, based on farmer needs, while Bihar, which has a lower installation rate, does not.

The study results indicate the potential for deep and scaled impact in the future, if certain changes are implemented. MNRE is well-aware of the some of the challenges that the scheme has faced in its rollout, and has incorporated several of the required changes – as also articulated in the recommendations below - in its policy update.[4] Our main recommendations include:

Technical recommendations: These seek to address challenges arising from the technical specifications of pumps tendered and installed in the 2013-2015 period, including pump size, current type (A.C. vs. D.C.), and proportion of pumps of chosen specifications that were procured. There is a need to optimize and

[1]The total targeted installations by end-2017 is 85,000.

[2]Our study was focused on impact of pumps that have been operational for at least 2 years, and hence 2014-2015 was the period of scheme relevant most relevant.

[3]State-wise status of solar pumps sanctioned during 2014-15, MNRE, April 2016

[4]Scheme for allocation of solar pumps informed to various State by MNRE, May/June 2017

decentralize technical parameters of the scheme based on target beneficiaries at the state level. Technical parameters must be optimized for critical environmental and agronomic conditions such as depth of the water table, available sources of water (surface or deep wells), and preference of AC vs. DC pumps. Allowing State Nodal Agencies and end-beneficiaries to select the appropriate SWP for conditions and needs will likely improve their performance and overall impact.

Policy and process recommendations: These seek to address challenges in the policy design and implementation process from the 2013-15 period, and seek to improve the way in which beneficiary selection criteria are developed and put in to practice, information is shared between the government, pump vendors, and farmers, and the pump installation, use and maintenance is monitored by relevant agencies. Specific recommendations include: (1) streamlining and re-orienting the existing MNRE policy to target beneficiaries and locations that would benefit most from the policy, through a needs-based adjustment of technical parameters; (2) integrating with allied policy infrastructure to improve beneficiary targeting using UID, multiply agricultural benefits with drip irrigation techniques, and build farmer capacity through technical assistance programs; (3) improving the policy implementation and enforcement process to make policy access for farmers and pump suppliers easier through a 'one-window' approach and better monitoring capacity; (4) deploying innovative financing mechanisms that incentivize private sector financing to make SWPs more affordable to target segments, through models such as credit-guarantees to MFIs, pump-leasing, and/or pump sharing agreements with cooperatives/SHGs, amongst others.

Socio-economic impact and challenges

Broader socio-economic impact has been limited, primarily due to the low levels of installation at the farm level, and varies according to state-level factors. At an aggregate level: *economic impact* across all four states has been reported in the form of an increase in energy savings due to partial substitution of electric and diesel pumps, but varies widely across states; *agricultural impact* in terms of change in irrigated area, crop productivity, and crop diversification has been negligible; *others impacts* include moderate decline in annual CO_2 emissions per farmer due to electric and diesel pump displacement, and the use of solar pumps for drinking water and electrification in some states.

There were three overarching challenges that were raised during the study that affected progress on installation and uptake across the four study states. These included (1) market conditions of low awareness amongst key stakeholders that has limited growth of demand and financing for SWPs, (2) technical issues of underpowered pumps for the region's needs, and (3) regulatory factors leading to long application procedures and suboptimal tendering criteria.

CHAPTER

1

Introduction

1.1. Context

Water availability affects agricultural yields and productivity, and inadequate supply impacts both national food security as well as farmer livelihoods. Only 45% of net sown area in India is irrigated, while the rest 55% relies on seasonal rains to provide moisture to crops[5], compared with 53% and 52% irrigated land in the neighbouring countries of Bangladesh and Pakistan[6]. In areas where farmers lack access to irrigation facilities, absence of water during the dry season limits crop choices during this period. Further, the diminishing predictability of monsoons and climate change is reducing effectiveness of planned planting and cropping, and an increase in freak-weather events like floods or droughts is leading to destruction of topsoil.

62% of farmers who do have irrigation rely on tube or bore wells, which require energy-intensive pumping to draw and distribute water on the field[7]. Of the 28 million irrigation pump sets in India, about 19 million are grid-based, while the remaining run on diesel[8]. In most cases in India, grid electricity for agriculture is highly subsidized, but this practice has also led to unsustainable consumption patterns and widespread use of inefficient pumps across the nation: electric pump sets consume electricity equivalent to 85 million tonnes of coal burned per annum. Apart from this, limited and unreliable supply of grid electricity has led to extensive dependence on diesel for water pumping[9], and diesel pump users use 3.1% of national diesel consumption, or 4 billion litres of diesel per annum. Reliance on diesel puts further pressure on the already stressed balance sheets of farmers, and releases large amounts of CO_2 emissions and pollutants in a country that can ill-afford either of those outcomes.

Solar photovoltaic (PV) powered water pumps are a clean and zero-emission solution to India's irrigation problem, and can play a key role in improving farmer livelihoods in India's agrarian states. Given the high distribution costs of grid-power to remote communities and rising oil prices,

[5]Central Water Commission, Govt. of India, 2016

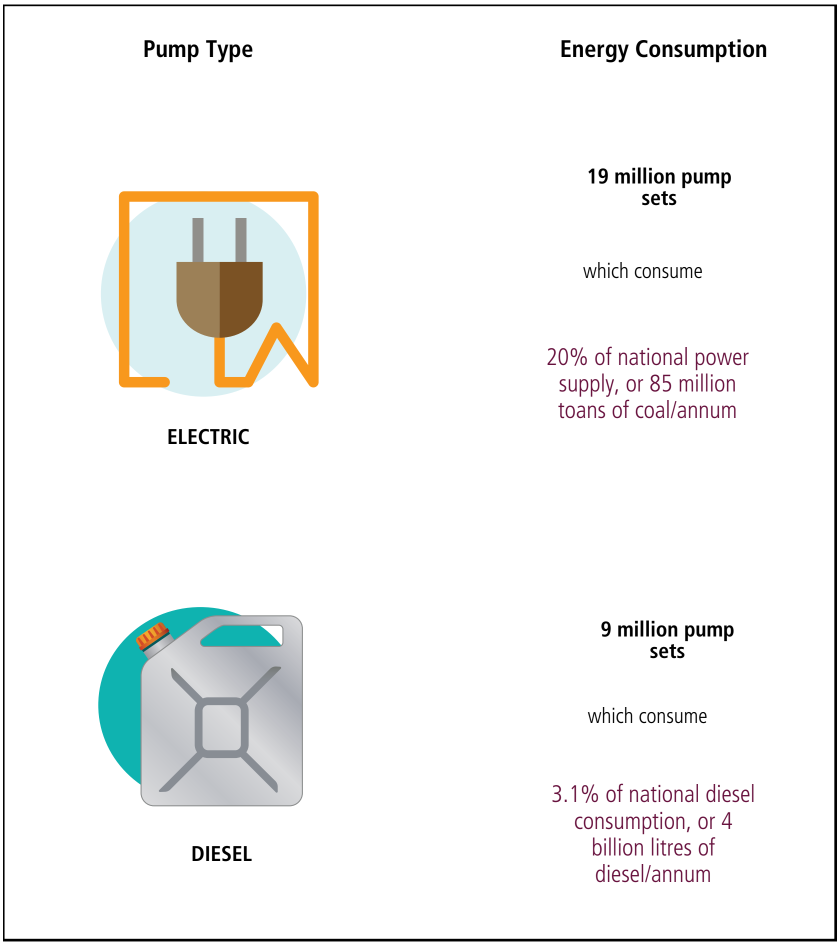
[6]FAO, 2006; FAO, 2011

[7]Water Resources Information System Directorate, Govt. of India, 2016

[8]: CEEW, Solar Pumps for Sustainable Irrigation, 2015; KPMG, Shakti Foundation; Feasibility analysis for solar water pumps in India, 2014

[9]IIT Powai, 2014

EXHIBIT 1. Prominent pump types in India and related energy consumption



solar pumps could have an advantage in meeting the needs of this market.[10] Moreover, solar pumps would help offset India's annual consumption of 4 billion litres of diesel consumption. Despite the potential of solar pumps, a key barrier to large-scale dissemination is their high upfront cost compared to conventional options. To achieve economies of scale and bring the prices down, there needs to be a nation-wide demand for solar pumps.[11]

In 2014-15, the Government of India, MNRE announced a special budgetary allocation to implement a minimum of 100,000 solar water pumps per year, and a total of 1,000,000 pumps by 2020-21, through State Nodal Agencies (SNAs) and the National Bank for Agriculture and Rural Development (NABARD), under the National Solar Mission (NSM). To date, about 65,000 pumps have been commissioned nationally, with another 25,000 targeted by end-2017.[12] A recent study by Climates cope estimates the number of installed SWPs at 43,098 at the end of FY16.[13]

After three years of implementation, MNRE seeks to clearly map and understand its results till date, specifically in terms of the number of pumps installed to date vis-à-vis targets, and incorporate emerging lessons into plans. The MNRE has already taken a pro-active role in updating the policy guidelines based on anecdotal knowledge it has gathered regarding the scheme's implementation and progress. Specifically, in June 2017,[14] the MNRE recommended that states target farmers who own diesel pumps, or own no pumps for irrigation, and required beneficiaries to be at least 300 meters away from the electricity grid. Further, 50% of the sanctioned pumps are advised to be expanded to a size of 3 HP, with subsidy slabs varying as per pump size (<1 HP- 30% subsidy, 1-3 HP- 25% subsidy, 3-5 HP- 20% subsidy). The MNRE has also suggested the reservation of 22.5% of solar pumps for farmers belonging to SC/ST categories, as well as the allotment of 10% of sanctioned capacity for pumps to be utilised to provide drinking water. In addition, states have been advised to prioritise farmers using micro-irrigation systems such as drip irrigation, and sprinklers. Pump purchases by SNAs are to be completed within four months of ministry approval, and states can petition for additional pump capacity after seeking MNRE approval. These efforts on the part of MNRE must be applauded. At the

[10] Jain, Amit. Is Solar a solution to Blackouts in India: A case study with agriculture diesel pumps sets?

[11] KPMG Report on Feasibility analysis for solar agricultural water pumps in India (2014)

[12] The total targeted installations by end-2017 is 85,000.

[13] Climatescope, '1Q 2017 Off-grid and Mini-grid Market Outlook'

[14] As per the updated MNRE guidelines communicated to the states in a policy document on 2nd June 2017

same time, there is scope for further improvement of the scheme, based on a more comprehensive, data-backed understanding of the progress of the scheme.

1.2. Objectives

In support of MNRE's forward-looking efforts, Shakti Sustainable Energy Foundation (Shakti) commissioned Dalberg Advisors to undertake a study on the results and broader socio-economic impact of solar water pumps installed under the JNNSM in four states—UP, Bihar, Rajasthan and Tamil Nadu. The key measure of success for the scheme, and therefore a primary indicator for this study, is the actual deployment and installation of solar water pumps. Beyond this, the study also identifies and articulates the wider impact of the scheme across economic, agricultural, environmental, social and communal dimensions. The drivers of impact across these dimensions are expected to feed into scheme improvements and design elements going forward. These three objectives are described below:

- **Assess achievement of solarisation targets in states** to understand how the four states in our study have performed on installation of pumps as against the pumps sanctioned by the MNRE in 2014-2015. Gaining a solid understanding of the number of sanctioned pumps in these states, as well as the share that were eventually installed is a major data-point for MNRE, as has been the thrust of the SWP scheme.[15]
- **Assess the broader socio-economic impact of existing pump installations in the top four participating states**, to understand successes and barriers in the adoption and use of existing pumps installed under MNRE's scheme. The study compares the change created by solar pumps relative to alternative solutions, such as diesel pumps, including impact on farmer incomes, livelihoods, and quality of life. The study seeks to extract forward looking lessons from the user experience of pumps, and therefore focuses on pumps that have been in use for at least two years. As a result, the impact assessment looks at pumps installed in the 2013-2015 period, and no later. Changes in the solar pumping policy after 2015, hence, do not reflect in the results of the survey.
- **Provide recommendations on best practices to inform National and State policy and programmes**, in the areas of technology (e.g., pump type), delivery and performance, as well policy design and implementation processes such as developing selection criteria for beneficiaries, implementing and monitoring the policy, and various financing and business models to support uptake of solar pumps.

After three years of implementation, MNRE seeks to clearly map and understand its results till date, specifically in terms of the number of pumps installed to date vis-à-vis targets, and incorporate emerging lessons into plans.

This report incorporates feedback received from state level stakeholders during ongoing consultations, but further deliberations with SNAs could help adapt recommendations to state level political and administrative priorities that are expected to evolve over time.

Furthermore, it should also be noted that this report does not consider the impact of certain policies that have recently been, or are in the process of being implemented. One such policy is the Maharashtra State Power Generation Company's pilot program to set up separate solar feeders for the agriculture sector. This involves the establishment of solar plants through the public-private partnership route, with support from the MNRE, to provide power to farming households for agricultural purposes. This is stated to reduce the pressure on the state electricity grid, while providing farmers with reliable day-time power for agricultural activities. However, this policy to centralise the distribution of solar power could dampen the demand for expensive SWPs by farmers. While further study is needed to explore the impact of the policy on SWP adoption in the state, we plan to comment on the potential implications in the detailed report.

[15]Note that the scope of the study commissioned by Shakti included understanding and articulation of the broader socio-economic impact of SWPs and ensuing implications for future policies.

1.3. Report structure

This report has been conceptualized as an answer-first document, given that its main objective is to support the MNRE in making policy adaptations that can improve the performance of the solar water pump scheme. Therefore, the report describes recommendations and best practices first, before discussing the key impact assessment results and challenges from the four states in our study. Overall, the structure of our findings are as follows:

- Methodology: This section lists out the impact assessment framework, as well as the research design and activities conducted across the study states.
- Progress against overall targets and recommendations: Here we report the progress of the scheme in terms of pump installation numbers (of key interest to MNRE), and recommend changes to the technical and policy framework of the policy to enable implementation at scale.
- Socio-economic impact assessmet: This section examines the findings related to the broader socio-economic impact of SWPs, and the key challenges faced by the policy.
- State-level findings: Here we take a deep-dive into the social economic impact findings for each state, and outline our assessment of the key challenges and recommendations for SNAs. State-level recommendations are a subset of the overall recommendations, and several are common across states, given the similarity of findings in these geographies.

Chapter

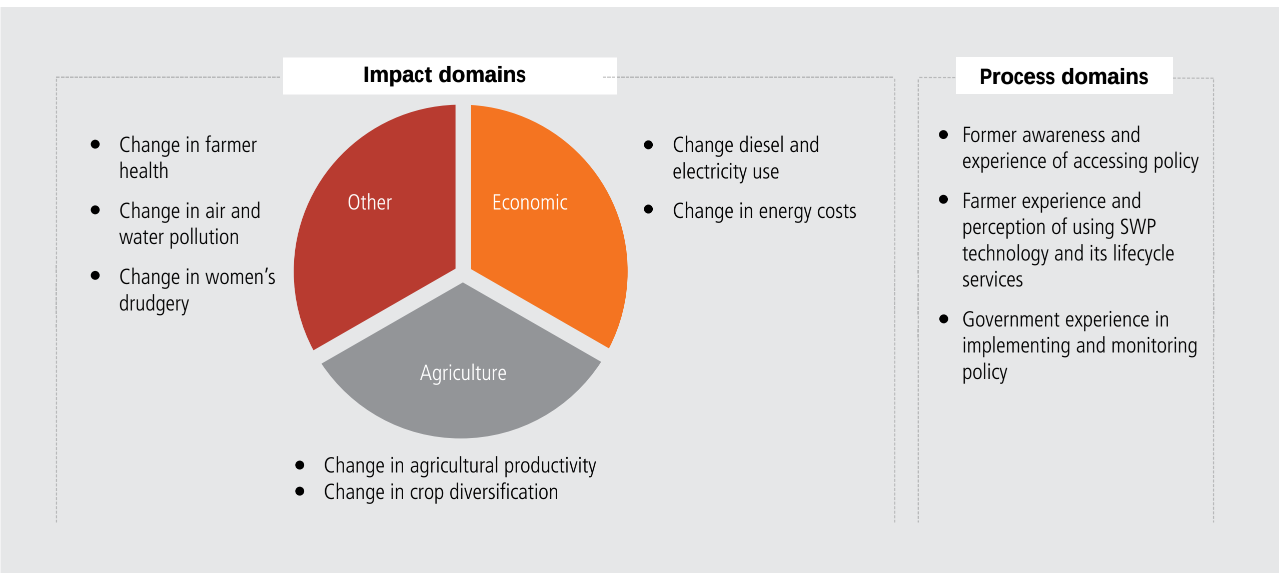
2

Methodology

2.1 Analytical Framework for the Socio-Economic Impact Assessment

The study seeks to understand the experience of farmers, vendors and government stakeholders interacting with MNRE's solar water pump policy, and assesses the level and nature of the broader socio-economic impact of the solar pump initiatives on beneficiaries. Firstly, the study classifies the socio-economic impact as a function of impacts across multiple thematic areas. The broad thematic areas are displayed below.

EXHIBIT 2: Analytical framework



The study focuses primarily on the economic and agricultural impact of SWPs on beneficiaries, while also incorporating additional social and community benefits. Further, the study emphasizes user experience, measured by process indicators such as ease of access, awareness, ease of use, and quality of after-sales service, as another critical component of the scheme.

2.2 Research design

To analyse impact across the socio-economic and process domains, the study has adopted a mixed-method cross-sectional descriptive research design (with project and comparison groups). To identify the trajectory of change, the design includes creation of a retrospective baseline for both study *(project and comparison)* groups. Based on recall by farmers, the retrospective baseline uses data for the year before pump installation in the state. The study has also incorporated a strong secondary research component along with the primary research. The secondary research was used to develop the framework that was adopted for the primary component of the research. The secondary research involved interactions with sector experts and systematic review of the different scheme related literature.

Desk review: This was a concurrent activity that involved review of existing literature on SWPs. This helped in the preparation of the research framework and helped triangulating findings from the primary research. We consulted literature focusing on solar pump policy, technical and feasibility analyses, and the policy background consisting of allied public schemes and infrastructure, published by government agencies, think-tanks, multilateral organisations, foundations and non-profits.

The policy documents we reviewed included a mix of publicly available orders and memorandums published by the MNRE, NABARD, and other allied agencies, as well as documents on commissioned and installed pumps, and beneficiary data lists shared with us by stakeholders in the MNRE and state nodal agencies. A large majority of policy documents we reviewed for this study were dated prior to 2015, due to the focus years of this study (2013-2015). Others included policy updates and orders sent to states more recently, and were used to track changes and updates to the policy.

Sector expert interactions: We held consultations with a broad range of stakeholders from across agricultural and energy access domains, to build a representative view of the challenges and opportunities for SWPs in India. Stakeholders we interviewed included administrators within the government, policy experts at think tanks, academics at leading agricultural or natural resources institutions, and private sector professionals from the solar pump industry. These expert interactions were mostly in-person semi-structured interviews, and were attended by at least two people, one from the Dalberg, and one from Sambodhi Research. Interviews were transcribed for future reference and analysis. The semi-structured format of interviews allowed us to test specific hypotheses on the impact of solar pumps on farm-level economics and agricultural outcomes, but also provided us flexibility to explore the individual's perspectives on policy performance, on technological challenges, and on future opportunities for scaling solar pump use in India.

Overall the secondary research helped in the preparation and designing of the indicator framework used in primary research. For an effective and rigorous primary research framework, the study followed a mixed-methods approach, using a combination of quantitative surveys and qualitative interviews, as well as focus groups.

2.2.1 Quantitative research

The quantitative component adopted a cross-sectional descriptive research design with **project and comparison groups**. This involved interaction with a sample of beneficiaries (farmers using solar pumps) and of farmer groups who use non-solar irrigation pumps like diesel pumps, electric pumps, as well as rain-fed agriculture. To ensure comparability of the groups, the comparison group was selected from the same village as the project group, and they exhibited broadly similar geographical, climatic, cropping and water table characteristics.

Sampling design: A total of ~250[16] sample of farmers for the project group and ~250 for the comparison groups were selected to provide state level estimates. The project farmers (or beneficiaries of

[16] Sample size estimated is powered to capture a change of 10% in the indicator: Proportion of households moving out of poverty

SWP) were selected from the beneficiary list provided by the State Nodal Agencies (SNAs). Each of the beneficiaries in the list were mapped to their village and district information. Then, the study selected those districts that demonstrated highest SWP user concentration to reflect impact of the intervention. Even amongst the chosen districts, those villages were selected that had the highest user concentration. All the project farmers (beneficiaries) present in the list from the village were interviewed for household surveys from the chosen village. The number of comparison farmers selected from the respective villages was the same as the number of project farmers. The comparison farmers were composed of non-solar users who exhibited similar geographical, climatic and water table characteristics. At the same time to ensure variability amongst comparison group in their pump types and depict impact across various sub-groups, different non-solar pump users were selected. These were composed of either pure diesel pump users, pure electric pump users, or a mix of electric and diesel pump users. The comparison farmers also consisted of farmers that did not use any pump for irrigation.

2.2.2 Qualitative research

The impact assessment framework involved a robust qualitative component that helped capture nuanced indicators such as barriers to adoption, pump performance, and access to maintenance and repair services. This component included community level interactions with pump users in the form of Focus Group Discussions (FGDs), and was further accompanied by interviews with distributors, empanelled suppliers and SNAs. There was a total of 8 FGDs held in each of the four states. Each FGD had an average of 6-8 participants that included a mix of both solar and non-solar users. These interactions helped in gauging the community perception of solar pumps and the effectiveness of the programme, understanding barriers to adoption, and revealing the on-the-ground challenges associated with the scheme. The findings from these were further validated and refined with inputs from other stakeholders such as individual farmers, SNAs, distributors and empanelled suppliers.

The impact assessment framework involved a robust qualitative component that helped capture nuanced indicators such as barriers to adoption, pump performance, and access to maintenance and repair services.

2.2.3 Quality assurance through continuous monitoring

The data collection activity was a real-time activity that was conducted on a daily basis for concurrent monitoring. The data was checked for quality, consistency and validity by the data team as well as the core project team, and continuous feedback was provided to the field team on the quality of the data.

2.2.4 State-specific research design

Below we detail the research activities carried out in each state, including beneficiary selection, the beneficiaries surveyed, and the focus group discussions (FGDs) held.

Bihar: Field research in Bihar was conducted across three districts: Gopalganj, Bettiah, and Sitamarhi, from June 4 to June 25, 2017. Survey sites were selected to optimize for beneficiary spread, concentration, and logistical ease. In Bihar, the highest concentration of pump owners was found in the northern districts of Gopalganj, West Champaran, and Sitamarhi. From amongst these districts, those villages that demonstrated maximum SWP coverage were selected to interview project and comparison farmers.

A research team of 40 surveyors interviewed a total of 280 respondents from the project group, and 284 from the comparison group for the household surveys. In addition, to test and validate the insights emerging out of household surveys, the research team conducted 8 FGDs with project and control group members. The project group was comprised mainly of pump users who use solar and diesel pumps in conjunction (63%), pure solar pump users (32%), and a few with solar and multiple diesel pumps (5%). The comparison group was composed almost entirely of diesel pump owners, with a few respondents (17%) who had no pumps.

Uttar Pradesh: In Uttar Pradesh, field research was conducted in two districts: Pilibhit and Basti from May 20 to June 12, 2017. Similar to Bihar, these survey sites demonstrated highest solar pump user penetration and therefore displayed highest potential to disclose impact if any. From amongst these chosen districts, those villages that had maximum SWP coverage were selected to interview project and comparison farmers.

Uttar Pradesh had the same research team of 40 surveyors and supervisors that interviewed a total of 253 respondents from the project group, and 257 from the comparison group for the household surveys. In addition, to triangulate the findings from the household surveys, the research team conducted 8 FGDs with project and comparison group members in 8 different villages. The project group was comprised mainly of pump users who use solar and diesel pumps in conjunction (57%), and a few pure solar users (9%) and solar & electric users (8%). The comparison group was largely composed of pure diesel pump owners (66%), with only a few respondents who had no pumps (11%).

Rajasthan: The same team of 40 researchers carried out field research in Rajasthan across three districts: Jaipur, Rajsamad, and Hanumangarh from May 9 to May 19, 2017. In line with the other states, these survey sites exhibited highest solar pump user penetration. From amongst these districts, those villages that demonstrated highest SWP user concentration were selected.

A total of 260 respondents were interviewed from the project group, and 272 from the comparison group for the household surveys. In addition, the research team conducted 8 FGDs with project and comparison group members. The project group was comprised mainly of pump users who use solar and electric pumps in conjunction (80%), a few pure solar users (10%), and solar & diesel users (7%). The comparison group was composed almost entirely of electric pump owners (82%), with a few respondents who had no pumps (9%).

Tamil Nadu: A separate field training was conducted for data collection in Tamil Nadu in their local language from June 6 to June 11, 2017. Thereafter, field research was conducted across three districts: Coimbatore, Theni, and Erode from June 12 to June 30, 2017, the three districts reflecting the highest solar pump penetration. Within these districts, those villages that had the highest SWP concentration were selected to optimize for beneficiary concentration as well as logistical ease.

CHAPTER

3

Progress Against Overall Targets and Recommendations

3.1 Progress against overall targets

At least 26,000 pumps have been commissioned in the four study states up until 2014-15;[17] actual installation is lower. The number of commissioned pumps does not exceed 10,000 in any state, ranging from 3,516 in Bihar to 9,902 in Rajasthan (as of 31st April 2016). Of these, Rajasthan, Uttar Pradesh and Tamil Nadu have installed approximately ~50% of sanctioned pumps, while Bihar has installed 6%. Across the states, total installation is 41.2% of sanctioned pumps, according to latest estimates in the public domain[18]. Recent reports suggest higher installation numbers, with 31,472 SWPs being installed in 2015-16 alone, to bring up the total estimated pumps to 43,098 at the end of FY16.[19]

Solar pumps largely compliment, not substitute, other pumps. Solar pumps have not been used to substitute diesel or electric pumps entirely, except for a few rare cases in each state (less than ~5% of SWP sample on average). Instead, farmers have mainly used the solar water pumps to supplement ("stack-on") existing diesel and electric pumps, and not to replace them.

Solar pumps largely compliment, not substitute, other pumps. Solar pumps have not been used to substitute diesel or electric pumps entirely, except for a few rare cases in each state

Pump selection is a major driver of the witnessed installation rates. States that have high installation rates, such as Rajasthan and Tamil Nadu, offer a variety of pump sizes to choose from, based on farmer needs, while Bihar, which has a lower installation rate, does not. Other drivers range from the low levels of awareness and access to the scheme for farmers, partly due to inadequate demand generation efforts on the part of state nodal agencies, and broadly, a mismatch in the socio-economic and agricultural profiles of intended beneficiaries, and actual beneficiaries. These challenges are discussed further in Section 5.

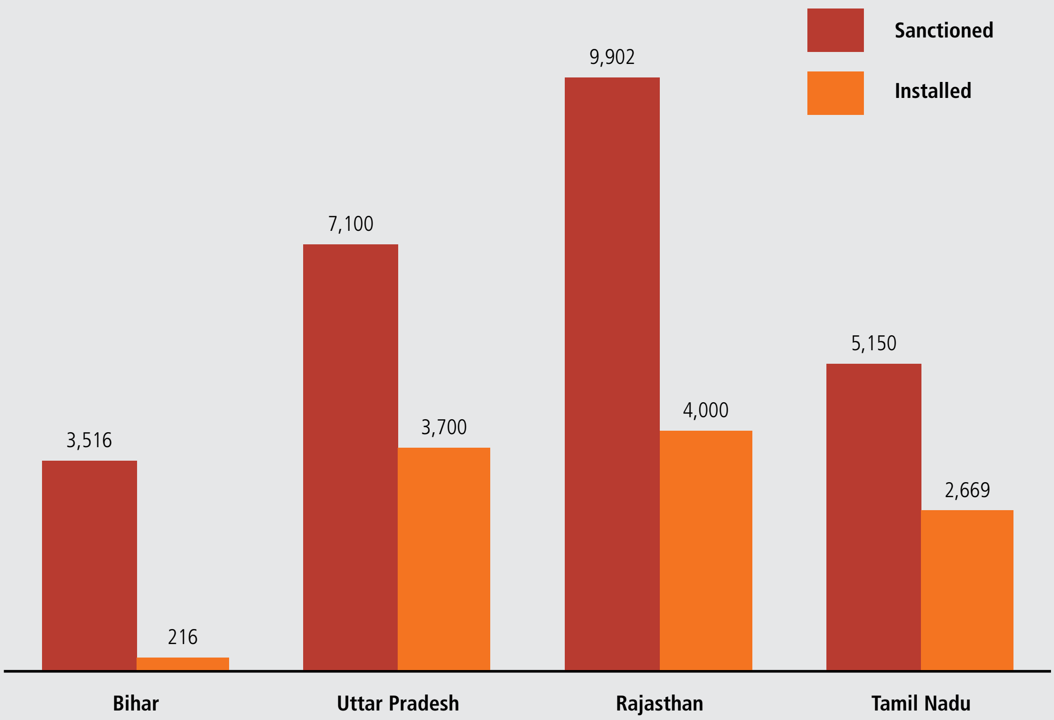
[17]Our study was focused on impact of pumps that have been operational for at least 2 years, and hence 2014-2015 was the period of scheme relevant most relevant.

[18]State-wise status of solar pumps sanctioned during 2014-15, MNRE, April 2016

[19]Climatescope, '1Q 2017 Off-grid and Mini-grid Market Outlook'

EXHIBIT 3: Installation rates and observations in states

Number of pumps



State-wise status of solar pumps sanctioned during 2014-15, MNRE, April 2016

3.2 Recommendations

The study results indicate the potential for deep and scaled impact in the future, if certain changes are implemented. As mentioned above, it should be noted that MNRE is well-aware of the challenges that the scheme faced in its rollout, and has also self-surfaced several of the recommendations articulated below in a policy update. We have developed two types of recommendations, which are described in the table below. The study's actual recommendations follow.

EXHIBIT 4: Overview of technical and policy recommendations

Type	Description
Technical	These recommendations seek to address challenges arising from the technical specifications of pumps tendered and installed in the 2013-2015 period, including pump size, current type (A.C. vs. D.C.), and proportion of pumps of chosen specifications that were procured. The recommendations were developed based on the impact reported by SWP owning farmers, as well as consultations with pump manufacturers and agricultural experts.
Policy and process	These recommendations seek to address challenges in the policy design and implementation process from the 2013-15 period, and seek to improve the way in which beneficiary selection criteria are developed and put in to practice, information is shared between the government, pump vendors, and farmers, and the pump installation, use and maintenance is monitored by relevant agencies. These are built based on lessons from data collection, from the reported policy experience of farmers in focus group discussions, and from consultations with state and central level government stakeholders.

[20]Allocation of solar pumps to the State of Tamil Nadu, MNRE, 2017

3.2.1 Technical recommendations

There is a need to optimize and decentralize technical parameters of the scheme based on target beneficiaries at the state level. Technical parameters must be optimized for critical environmental and agronomic conditions such as depth of the water table, available sources of water (surface or deep wells), and preference of AC vs. DC pumps. Encouraging State Nodal Agencies and end-beneficiaries to select the appropriate SWP for their conditions and needs will likely improve their performance and overall impact. For example, a 2 HP pump can be sufficient for most farmers in Bihar where water tables are at an average depth of 10 meters, but in Tamil Nadu, where water tables are at the 20m mark, higher-powered pumps of 5HP+ would be more appropriate. SNVs should consider supporting these decisions by mapping and segmenting target beneficiaries according to these pre-conditions and needs, and offering farmers such knowledge and information, potentially in the form of a menu of options. Accordingly, states can adjust the portfolio of pump types they procure through tenders. It should be noted that our study looks at pumps installed primarily in the 2014-2015 period, and that some states like Tamil Nadu and Rajasthan have since made revisions aligned with this recommendation. Some additional important considerations for policy makers when designing technical specifications are described below in the box.

Broadly, there are a few technological developments in the pump market that should be tracked by the MNRE to update pump specifications as time progresses. A large majority of first generation solar water pump systems used centrifugal pumps driven by AC/DC motors, which had hydraulic efficiencies of 25-35%[21]. A second generation of pumps which use positive displacement pumps, progressive cavity pumps or diaphragm pumps have higher hydraulic efficiencies of up to 70%, and should be prioritized as they can give higher water output per unit of energy.[22] Add-ons such as controllers to monitor pump speed and storage tank levels, and maximum power point tracking (MPPT) can be made mandatory, as they help optimize water pumping and improve performance of the pump. Finally, system integrators and site inspectors can help determine the monthly, seasonal and annual values for the Optimum PV array tilt angle for each location. Pumps using the optimum tilt angle can help increase the power output from PV panels in a system.

EXHIBIT 5: Technical considerations for SWPs for policy makers

Size of pumps should be determined by the prevalent water table depth at block level in a state, the average size of landholding in the region, and the cost of pumps. Policy makers should consider offering a menu of pump options to farmers based on these local factors.

Surface/submersible should be determined by the source of water (channels, wells, tanks, etc.) in the region, and the lifecycle and performance of each type of pump. For example, if water tables are under 10m (that cut-off point for surface pumps) for a majority of farmers in a region or state, submersible pumps should be a clear priority. In addition, submersible pumps are more immune to theft and robbery due to their inaccessibility.

AC/DC pumps should be determined by their intended applications, their relative price, availability of maintenance services, their quality and performance. DC pumps have a higher discharge rate and are suitable if farm output is a major need. AC pumps, however, have a broader range of uses, and their panels can be used for household electrification without the need of an expensive inverter. AC pumps can also leverage existing service networks of electric pumps, and are on average, 10-15% cheaper.

[21]Hydraulic efficiency refers to how well a pump converts a source of power into hydraulic energy (flow, pressure of water)

[22]Review of solar PV water pumping system technology for irrigation and community drinking water supplies, Renewable and Sustainable Energy Reviews, 2015

We have developed high-level recommendations for each state along these dimensions, based on the prevailing agro-climactic and agricultural conditions. These are described below:

EXHIBIT 6: High-level technical recommendations in each of the four study states

	Size	Surface/Submersible	AC/DC
Bihar	The current size of 2 HP is adequate for water levels and land sizes	Currently used surface pumps are ideal as per state water levels	Maintain DC if focus is on farm output; shift to AC in case household use is prioritised
UP	Expansion of pump sizes from 2 HP to include 3 and 5 HP, to account for water levels and land size	Add submersible pumps to the present option of surface pumps, for farmers with low water levels	Maintain DC if focus is on farm output; shift to AC to encourage observed household electrification
Rajasthan	Add 7.5, 10 HP pumps to the current range of 3-5 HP pumps for 40% of farmers with low water levels	Maintain existing submersible pumps	Shift from DC to AC to take advantage of existing service networks and encourage the observed use for drinking water
Tamil Nadu	Add pumps bigger than 5 HP for farmers with larger landholdings	Both types can be used by a significant proportion of farmers	Expand availability of AC pumps to take advantage of well-developed service network of AC electric pumps

In addition to improving the technical specifications of the pumps, the government can consider improving the technical capacity of farmers and local institutions to use and maintain pumps, to help the extract the best performance from pumps. Technical expertise relating to a solar pump can be of two types. First, the capability to operate the pump effectively, which would require a farmer be able to identify times of the day with solar irradiation is strongest, to move panels to track the sun (in case the PV panels are manual tracking type) as per the sun's movements when required, and to install appropriate add-on technologies such as water tanks and irrigation systems that can improve the use of water drawn by the pumps. Second is the ability for farmers and local institutions (gram panchayats, local utility and hardware stores) to repair and maintain solar water pump systems to ensure optimal operations through its lifecycle. Proper maintenance of solar pumps can help keep its water yields consistent, and extend the lifecycle of the product. Regular cleaning of panels with the right materials, checking wires, cleaning pipes and replacing inverters (every 8-10 years) can help ensure the high investment in a solar pump pays back a farmer over its entire guaranteed life time (25 years).

The government can help in building farmer and local institutional capacity by mobilizing its service network, and provide technical expertise. Krishi Vigyan Kendras (KVKs), gram panchayats, and local agricultural universities are examples of government institutions allied with agriculture that can offer their human resources to support training programs for farmers, given that they're already involved in doing so for a host of other agricultural interventions. State agricultural universities and agricultural block offices have existing repositories of information on agricultural technologies, and adding solar pumps to their knowledge packs should not be difficult.

3.2.2 Policy recommendations

Like our recommendations on technical parameters, our suggestion on policy changes intend to make the existing policy and rollout more relevant (e.g. intended beneficiaries are also the most likely to benefit and derive impact from the scheme), efficient (i.e. the process of availing the SWPs through the scheme is simple and accessible to end beneficiaries), and effective.

Streamline and re-orient the existing MNRE policy to be customized and adaptive to beneficiary needs. Improvements to the current policy will include targeting/ prioritizing end-beneficiaries and locations that would benefit most from the policy. This may be effectively done by (1) incorporating an end-beneficiary-centric philosophy and approach, and (2) allowing for greater flexibility on technical parameters of SWPs, mapped closely to the needs of beneficiaries.

EXHIBIT 7: Criteria and considerations for improved beneficiary targeting

	Recommendations	Rationale
Existing pump type	• Shift focus to diesel farmers who have high operational expenses • Target farmers with no pumps to maximise agricultural impact	• Currently, the majority of SWPs are owned by electric pump farmers (44%) • Electric pumps have a distinct advantage over SWPs due to a higher discharge rate and heavily subsidized operational costs
Electrification status	• Focus on states with less than 7-8 hours of daily electricity and long delays in installing electric connections	• In states with high electricity availability, SWPs economics are unfavorable and will likely result in low adoption
Land size	• Adjust proportion of pumps procured in each power category to the average land sizes amongst beneficiary base in each state	• Land sizes for SWP farmers vary from 2-7 hectares and require different pump sizes, instead of the current one-size-fits-all policy
No. of plots	• Explore group or community ownership models, for farmers with adjacent lands to share water	• The average SWP farmers owns 2.7 plots of land, and this fragmentation limits the use of immobile SWPs
Crop type	• Focus on farmers with water-intensive crops such as vegetables and sugarcane • Integrate drip irrigation to improve efficiency of additional water use	• The discharge rate is too low for crops like rice, which needs constant flooding • Additional water use is likely being used for flood irrigation, limiting productivity improvements

Based on the data from the study, the optimal target beneficiary either owns a diesel pump or does not own any pump, is away from the electricity grid, is open to techniques such as drip irrigation, and cultivates water-intensive crops. These farmers have already begun to be targeted by the MNRE as stated in a recent policy update, which states have now been asked to adopt.

To ensure improved targeting of beneficiaries on paper is realized in practice, there are certain systems and checks that need to be put in place. First, application forms for solar pumps should include self-reporting of essential characteristics such as distance from grid, and number and types of existing pumps owned, in addition to the current set of questions. More importantly, the mechanism to verify self-reported data of pump applications must be strengthened. The use of GIS mapping and geo-tagging can be a low-cost, highly-accurate method to authenticate the location of farms, their distance from the nearest electricity facilities, and other data points required to assess the applicability of solar pumping solution.

A two-step authentication method can be used here: first, farmers can self-report data on forms, and provide geographical identification using geo-tagged SMSs sent through their phones from their farms. Second, after a round of screening, local block officers can inspect sites in person, photograph essential characteristics, and geo-tag each qualifying applicant farm on a GIS map. Additional layers of data can then be applied to the maps, including sources of water, depth of water tables, crop types, micro-climate data, which can help ascertain how types of solar pumps should vary according to farmer profiles across a region. Creating a GIS-map based database of applicants and eventually pump installations will help with monitoring, and provide granular inputs and data for ongoing changes and tweaks to the scheme and its implementation. The linkage of Aadhar information with geo-tagged photos of farms can help reduce cases of fraud in farmer applications, and assist in tracking complaint redressal and scheduling inspections.

EXHIBIT 8: Profile of a successful SWP user in Rajasthan interviewed during field study

Name: Devi Lal Saini
Age: 46
Location: Jaipur rural, Rajasthan

"Solar pump is well suited for drip irrigation as against electric pumps as solar pump ensures continuous supply of water drip by drip at least for the entire times electricity is not available so continuous drip by drip water supply to my crops become difficult"

"For me solar is a primary pump, I have started using electric pump only when solar is not working"

Background:

Devi Lal Saini is a solar pump farmer from Rajasthan, who owns 4 bigha (0.404 hectares) of land and grows cauliflower, ladyfinger and chilies throughout the year. Before solar pump, he used electric pump for only 6 5-6 hours every 3rd to 4th day but that did not fulfil his water requirement. Now he solely grows his crops using solar pump with the drip irrigation system and uses electric pump whenever necessary.

Criteria met:
- ✓ Marginal farmer
- ✓ Suffers intermittent electricity supply
- ✓ Rarely uses electric pump as backup
- ✓ Grows water-intensive horticultural crops
- ✓ Integrated pumps with drip-irrigation system

Use of Solar Pump

1. Agriculture: Uses solar pump along with the drip irrigation network to grow crops like cauliflower, ladyfinger and chilies. His needs are met with the solar connection and uses the electric pump only in situation where solar is not able to meet his needs.
2. Household: Solar pump and panel are present on the field. He does not use it for household electrification. However, sometimes when on the field, he uses it for drinking purpose

Reported benefits:

"After solar pump, I don't have to depend upon electric connection, I save on my monthly electricity cost. The most important benefit I get is my vegetables are able to get continuous water through solar and drip network. With electric pumps, sometimes they would dry when electricity was not available."

EXHIBIT 9: Case study of shared solar pump scheme in Zimbabwe and its impacts[23]

What: Oxfam's Ruti Dam Irrigation Scheme has utilised solar pumps to increase crop yields and incomes for smallholder farmers who previously owned no pumps and produced at the subsistence level.

Who: The program covers 270 smallholders farming across 60 hectares of land.

How: Two SWPs are used to boost water to a reservoir, from which the water is transferred to the adjacent fields using a gravity irrigation system—that transfers water from the higher reservoir to drip lines on lower-lying fields using gravity.

Outcome: Farmers have been able to achieve higher yields, and rotate crops to achieve multiple harvests in a year. With the ensuing increase in income of 47-286%, farmers have been able to quit labour activities on other farms, and have even begun to create employment for others on their own land. A farmer explained this transformation as following, *"Long ago we used to have to go 93km searching for food on large scale farms…Now we don't need to go anywhere, we are empowered and what is more, we are giving other people jobs so job creation has been achieved."*

Harmonize with other relevant policies and leverage existing policy infrastructure: This involves leveraging the existing policy ecosystem to improve beneficiary targeting using UID, maximizing agricultural benefits with drip irrigation techniques, and building farmer capacity through technical assistance programs. Certain existing schemes that could be considered for integration and/ or streamlining include the National Mission on Micro-irrigation (NMMI), Krishi Vikas Kendras (KVKs), and allied investment and irrigation policies under PMKSY. For example, the NMMI utilizes District Irrigation Plans (DIPs) to identify gaps in current irrigation schemes, and relies on an Aadhaar based

[23]Transforming lives in Zimbabwe, Oxfam, 2015

beneficiary verification system to make direct benefit transfers (DBT) of subsidies to farmers. The Solar water pump scheme planning could be integrated with the DIPs and planning process for NMMI, and use the same Aadhaar based DBT mechanism for pump recipients. The table below summarizes our recommendations on how and why it could integrate with existing government initiatives, and potentially amplify its impact.

Integrating solar water pumping solutions with irrigation systems can help achieve the dual objective of preventing over extraction of ground water, and improve the farm-level outcomes of solar pumps. Drip irrigation offers field application efficiency in the range of 90%, whereas sprinkler and surface irrigation have efficiencies of around 75% and 60% respectively.[24] Higher efficiency of pumps, if utilized with other beneficial agronomic techniques, increase crop yields with less water. In addition, drip irrigation also helps lower the water pressure required at field entrance to 20-25 psi, compared to overhead systems (50-80 psi). This reduces the power needed for pumping.

EXHIBIT 10: Integration of existing government initiative into the SWP scheme

What?	How?	Why?
Improve targeting and financial access by linking with Aadhar accounts	Push for an Aadhar-based application and verification system for beneficiaries to reduce double-counting and improve beneficiary tracking for the program lifecycle Instead of making Aadhar mandatory for every applicant, SNAs can prioritize Aadhar account holders for micro-loans from banks, thereby promoting Aadhar-backed farmers	Currently, tracking farmer application, installed pumps, and status of installed pumps is difficult due to long paper trails and difficult in identity verification Aadhar linked application processes can help digitize tracking, and help process loans to those with Aadhar bank accounts
Improve impact potential by integrating with govt. policies on allied agricultural technologies	Focus on policy convergence at the state level – ensure farmers get access to information on multiple allied policies during time of application, and are able to apply for them in through one window Incentivize co-application to other irrigation policies primarily, PM Krishi Sinchai Yojana and National Mission on Micro-irrigation	Benefits of standalone solar pumps have been minimal – integrating with agricultural productivity schemes can help diversify and multiple areas of impact Integration with policies that support drip irrigation systems can improve agricultural returns per additional drop of water
Increase relevance by including SWPs in technical assistance programs in agriculture	Improve utilization of solar pumps and additional water through technical assistance programs to farmers Leverage existing information networks – agricultural universities, Krishi Vikas Kendras, and field service officers to provide ongoing assistance to farmers	New farm technology requires upgrading farmer capabilities and changing behaviors Using existing knowledge infrastructure of the government can provide more frequent inputs on the farm and improve farmer capacity to utilize solar pumps effectively

[24]SunEdison: The global market for solar irrigation is almost limitless, Forbes, 2014

The solar pumping scheme will also confront other electrification and solarization schemes currently under development in states. While this study did not look at the broader landscape of policies under development at the state level, a few themes mentioned in our expert consultations should be carefully examined by policy makers at the MNRE. States such as Maharashtra are already considering alternatives to the individually-owned SWP model currently in use. In May 2017, the Chief Minister Devendra Fadnavis announced the state government's decision to set up small and micro solar power plants to distribute solar energy to rural Maharashtra using dedicated feeders. The impetus for this decision appears to come from the poor performance of the solar pumping scheme in the state, with Fadnavis reporting that "…solar pumps did not work…but separate feeders will run on solar power and ensure 12 hours of power supply during the day."[25] Pilot projects for solar power generation are being implemented in Solapur and Latur on a PPP basis, selling power at INR 3/unit. If scaled, the scheme may diminish the rationale for subsidising individual solar water pumps for farmers. Niti Ayog plans to replicate the policy in other states. A Niti Ayog policy document from 2015 specifies solar feeders as being 40-50% more cost-effective than SWPs, with minimal upfront subsidy cost required[26].

Integrating solar water pumping solutions with irrigation systems can help achieve the dual objective of preventing over extraction of ground water, and improve the farm-level outcomes of solar pumps.

Similarly, the 'Deen Dayal Upadhyaya Gram Jyoti Yojana' launched Prime Minister in 2015 seeks to improve electricity supply in rural areas by focusing on feeder separation of rural households and agriculture[27], and strengthening of sub-transmission and distribution infrastructure. If this scheme gains momentum among a large enough number of states, it would change the sub-regions of priority in each state, which must remain focused on off-grid areas. State nodal agencies of the SWP scheme must coordinate closely with their electricity departments to understand rural electrification plans in their state, and reorient their policy targets accordingly.

Improve the policy implementation and enforcement process: This would primarily involve establishing a 'one-window' approach, and building better monitoring capacity in state implementing agencies. The one-window platform would ideally be housed online, and cater to the needs and requirements of suppliers and vendors, as well as target end-beneficiaries. Suppliers would access the eligibility criteria for pumps as well as the necessary technical assistance and support to get "empanelled" and participate in the tender. Farmers would be able to access details about pump types on offer, their suitability criteria, enlisted vendors, their service networks, etc. Previously, the "one-window" approach has been deployed in industry by the union government, in the form of the e-Biz B2G portal, a central online platform for addressing all regulatory approvals/ checks during a business's life cycle. Better state-level monitoring capacity can involve remote tracking of pump installation and use (using GPS enabled chips, for example), and a designated helpline number and task force for farmer complaints (as has been done in Tamil Nadu, for example).

[25] Maharashtra Chief Minister Devendra Fadnavis announces solar feeders to power agro pumps, Hindustan Times, 2017

[26] Indian state of Maharashtra announces 2gw of solar projects, Niti Ayog, 2017

[27] PM launches new scheme for power reforms in rural areas, The Hindu, 2015

EXHIBIT 11: A snapshot of the e-Biz B2G portal

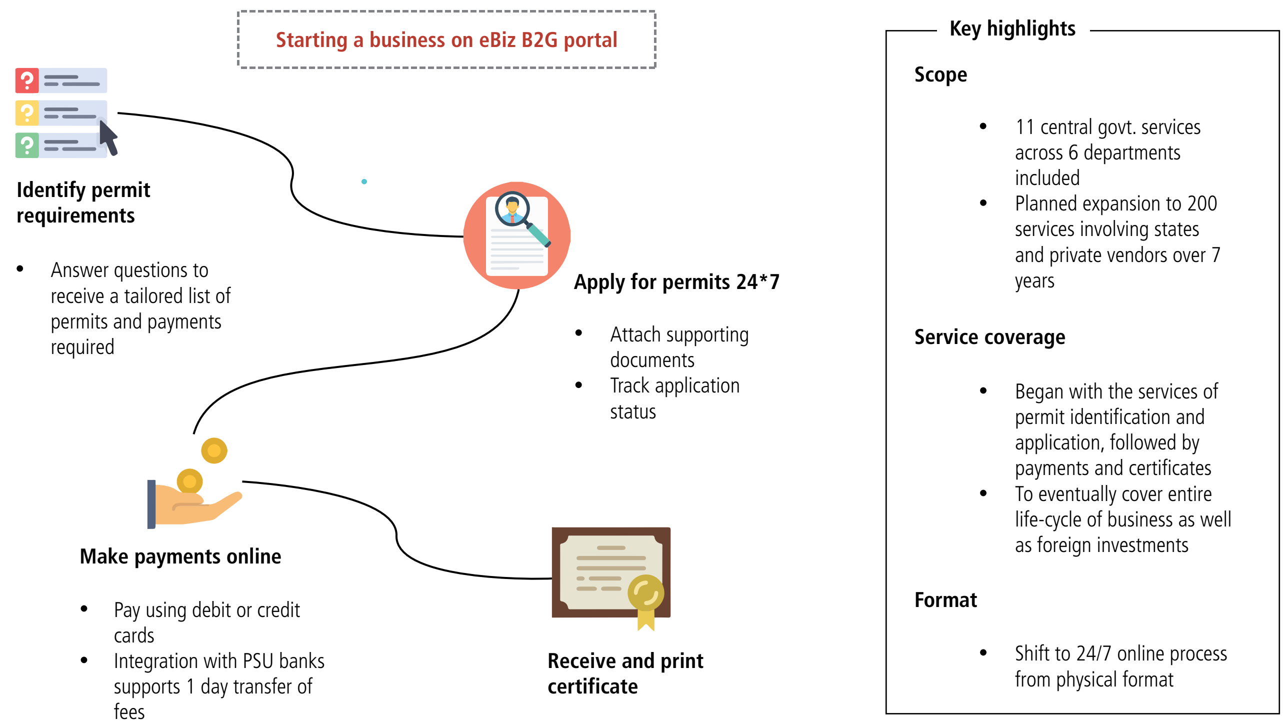


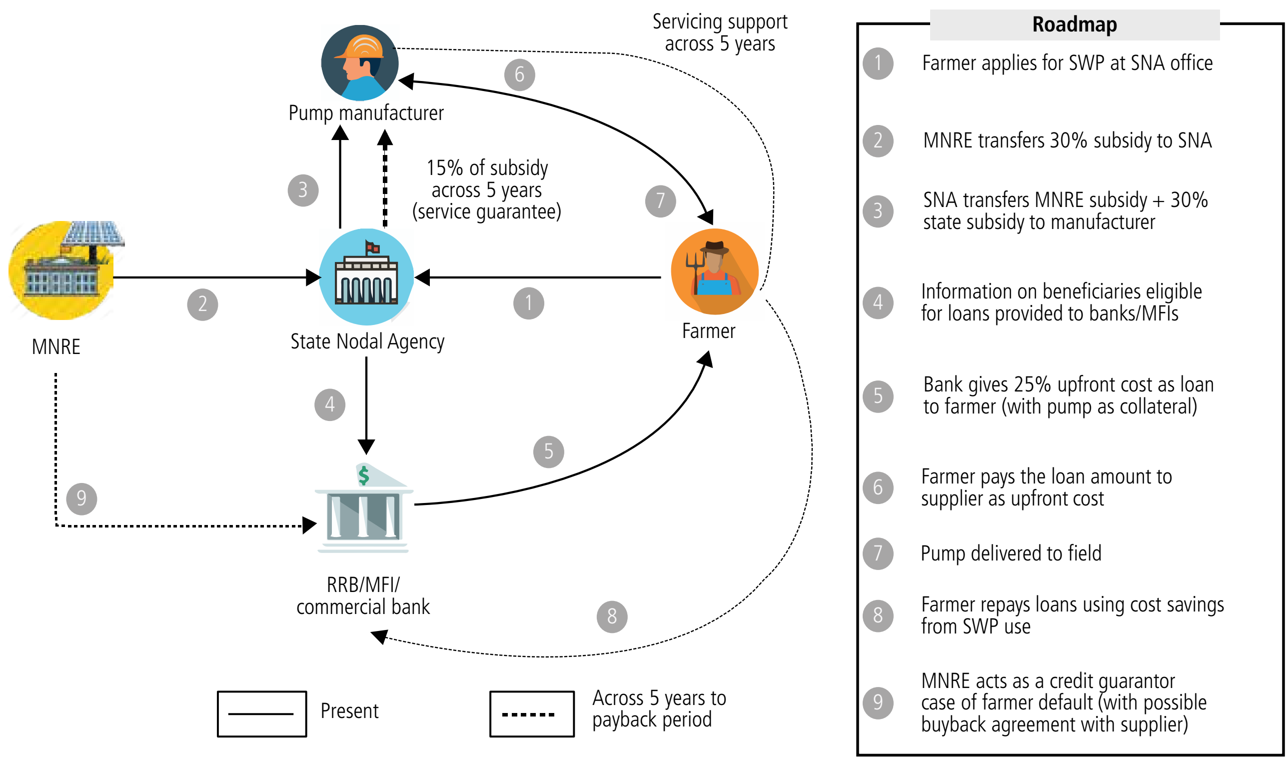
EXHIBIT 12: Best practices in developing a "one-window" approach for policy access

Farmers	1. Information on specifications, costs, savings 2. Applying/tracking progress 3. Resources for installation, use 4. Online complaint redressal system, service tracker, supplier rating system	• This would help disseminate information in a clear and accurate manner • It will improve access by ensuring transparency in the application process • Supplier rating system will improve after-sales service and pump quality	UPNEDA has established a toll-free complaint redressal hotline with a UID for each beneficiary; suppliers have to address complaints within 72 hours, and complaint resolution is monitored to ensure adherence to timeline
SWP manu-facturers	1. Information on tendering requirements, processes 2. Submit tender application, track progress 3. Database of installation and Service requests	• This ensures a transparent tendering process with well-specified quality standards • It gives suppliers the opportunity to identify competitors' progress and build up a reputation	Tamil Nadu has shifted from an L1 bidding process to a price discovery process, in which the SNA benchmarks and clearly specifies costs per HP, to ensure quality standards are maintained by manufacturers
Policy makers	1. Central database of beneficiaries to be shared across stakeholders 2. Online approval and application/monitoring 3. Monitoring of pump quality/ service	• The system fosters easy information sharing with various state and national policymakers • It also allows state to identify, analyse and rectify process issues at the macro-level	The National Deworming Day (NDD) steering committee instituted by the Ministry of Health has equal representation from state departments, and meets bi-annually to review policy

Explore innovative financing mechanisms that incentivize greater engagement from the private sector: This would include a possible credit-guarantee offered to MFIs and rural banks by the MNRE to catalyse lending, a pump-leasing model, and inclusion of cooperatives/SHGs as beneficiaries with possible pump sharing agreements, amongst other financing models that can be explored state-by-state. Salient features of the proposed financing models are described below.

Credit guarantees: Credit guarantees represent a promise of full and timely debt service payment up to a predetermined amount of the default. Typically, the sum that is paid out under the guarantee covers creditors irrespective of the cause of default.[28] This is done to allay the concerns of investors and bankers on the riskiness of their potential investments, thereby incentivizing capital to flow in. In this case, MNRE would act as the guarantor, and cover losses to financial institutions due to farmer defaults. MNRE could also consider a "supplier buyback" option, which would reduce the cost of the credit guarantee.

EXHIBIT 13: High-level architecture of proposed credit guarantee for SWPs[29]



Community lending: Community and or self-help group lending models, where loans are provided to small groups of end-beneficiaries, much like micro-finance loans, have also shown promise in other sectors and programs. Not only do these models reduce the burden of assessing risk of default (since the whole group is typically expected to be penalized in case of default), but also the intensity and frequency of transactions (and therefore transaction costs) are reduced. The SWP scheme could incorporate community-based lending models by distributing the pumps and associated subsidies to farmer cooperatives, SHGs, other village-level groups, who would then be charged with distribution and on-lending to farmers.

Pay-as-you-go models: Pay-as-you-go models, as the name suggests, reduces the high up-front cost burden for users of products and services. The pay-as-you-model has been effectively piloted and deployed for solar home systems and associated appliances, especially in East Africa, where they have led to the distribution of close to 1.5-1.8 million devices over the last 2 years. Pay-as-you-go could be incorporated into the existing scheme either directly, with SWP providers extending credit to their customers (in this case, enterprise financing would be key), through cooperatives/ SHGs, and/ or directly through existing government channels. In this situation, the government could either (1) provide credit guarantees to SWP vendors or manufacturers to enable access to finance for their pay-as-you-go business

[28]www.ifc.org

[29]Note: (1) Loan to be offered to marginal and small farmers (2) Payback period to be determined according to interest rate, land size, income, etc. (3) Align repayments with agricultural timelines (4) Assumption of an average 45% state subsidy; Source: Dalberg and Sambodhi analysis

models, and/or (2) set up and steer a platform for SWP vendors, technical component manufacturers, innovators and financiers to collaborate and form strategic partnerships.

EXHIBIT 14: International case studies of innovating financing mechanisms for SWPs[30,31]

Providing financing options to solar farmers in Nepal

Who: When offered a menu of financing options, farmers in Nepal opted for a model that financed the upfront cost through loans or a pay-as-you-go model. The International Centre for Integrated Mountain Development (ICIMOD) conducted a randomized control trial (RCT) of financing options for 1 HP solar pumps in the Teri region of Nepal.

What: The financing models on option to the farmers were (1) 60% grant, with rest being up front cost paid be farmers (similar to MNRE model) (2) Grant-loan model, adding a loan of 20% to the existing 60% grant to reduce the upfront cost barrier for farmers (similar to NABARD model), and (3) A pay-as-you-go (PAYG) system combined with a grant, where a local entrepreneur was offered a 60% grant to purchase the SWP, and could then rent out pumps to farmers on a PAYG basis.

Results: The results of the study found that of the 65 SWP applicants, 30 (46%) preferred the grant-loan model, while PAYG came in second with 22 (34%) farmers, and only 12 (20%) farmers preferred to pay the high upfront cost in the only grant model. The study also found no statistically-significant difference in the socio-economic characteristics (assets, land ownership, and irrigation indicators) of the groups preferring different financing models, indicating the possibility of utilizing grant-loan and PAYG models even for larger farmers for whom cost is not a barrier to access.

Helping women farmers attain sustainable incomes in Benin

Who: The Solar Electric Light Fund (SELF) has set up three 'Solar Gardens' in Benin, each of which consists of an SWP driven drip irrigation system that services a cooperative of 35-45 women.

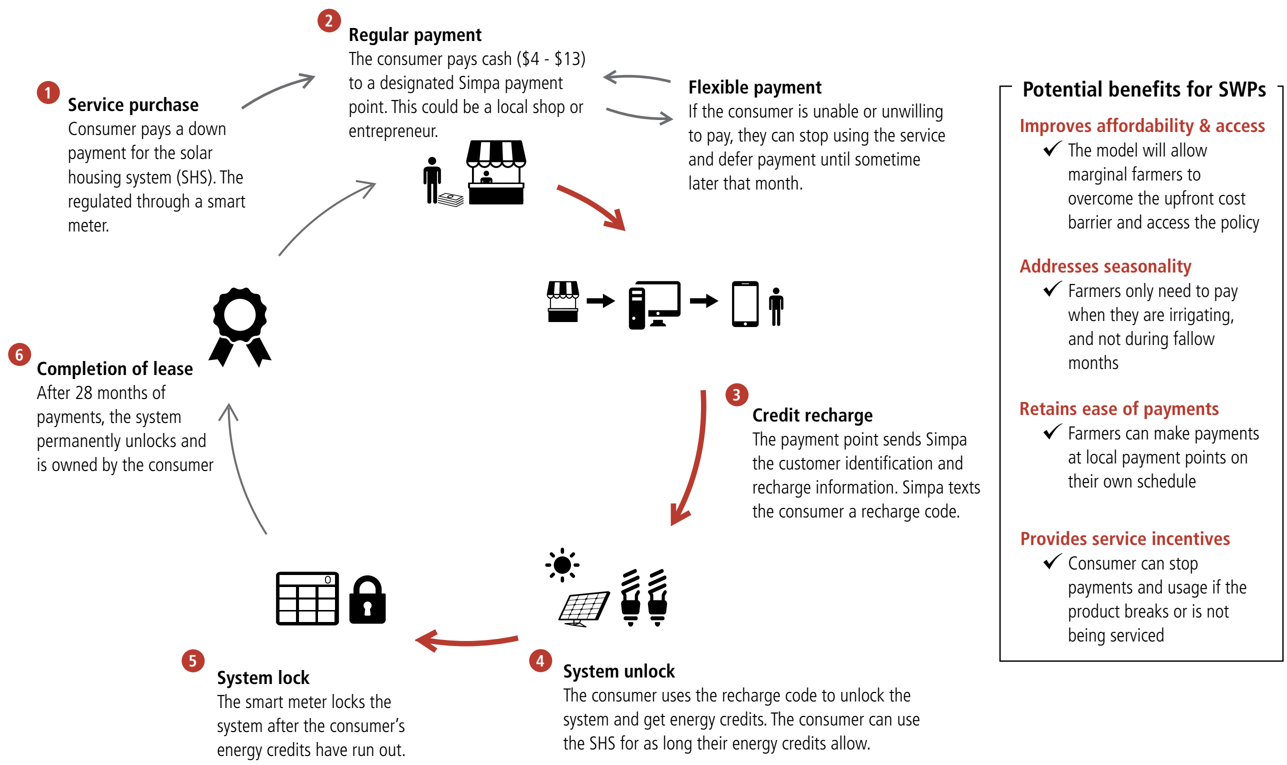
What: Each member pays a small weekly fee to amortize the cost of the system, and in turn is entitled to plant crops in a separate irrigated plot.

Results: The irrigation system has helped women reduce time spent on irrigation activities by up to four hours, and has supported reliable cropping outcomes, and hence consistent income flows. In the dry season of 2013-14, the Solar Gardens yielded produce worth USD 40,000—funds that have allowed women to make independent household choices regarding education, healthcare and child rearing. The president of one of the women cooperatives said, "My life has changed dramatically since we started the SMG program, because I'm now earning an income, and I'm better able to help my husband. We are feeding our family, and we have extra income to educate our children and get them medical care."

[30]Sustainable Financial Solutions for the Adoption of Solar Powered Irrigation Pumps in Nepal's Terai District, CGIAR, 2017

[31]Annual report, Solar Electric Light Fund, 2015;

EXHIBIT 15: Illustration of a pay-as-you-model



The exhibit below summarises the key trade-offs associates with these models.

EXHIBIT 16: Advantages and disadvantages of proposed financing models

	Advantages	Disadvantages
Loan financing with credit guarantee	• Targeted loans allow marginal farmers to access policy • Loans allow farmers to access expensive, high-powered pumps • Farmers pay less due to a reduced bank interest spread (as default risk is removed)	• Default risk lies with MNRE (shared with suppliers in case of buyback agreement) leading to an additional financial burden
Cooperative/ SHG model	• Removes the barrier of upfront cost for pump ownership • The pump sharing variant allows farmers to rent pumps as per needs–eliminating fallow periods	• Cooperatives, especially those of marginal farmers, might still face affordability problems • Pump allocation can be hijacked by powerful farmers
Pay-as-you-go (PAYG)	• Specially suited for marginal farmers due to piecemeal nature of payments • Strongest service incentives—farmers only pay if they can use pump • Limited subsidy support (for capital costs)	**Difficult to get supplier buy-in:** • High investment costs borne by supplier service providers • Default risk lies with supplier, along with repossession costs • Seasonal/ unoperational risk falls on supplier, as pumps cannot be shifted easily Beneficiary perception is problematic, as funds are transferred to firms rather than farmers

Chapter

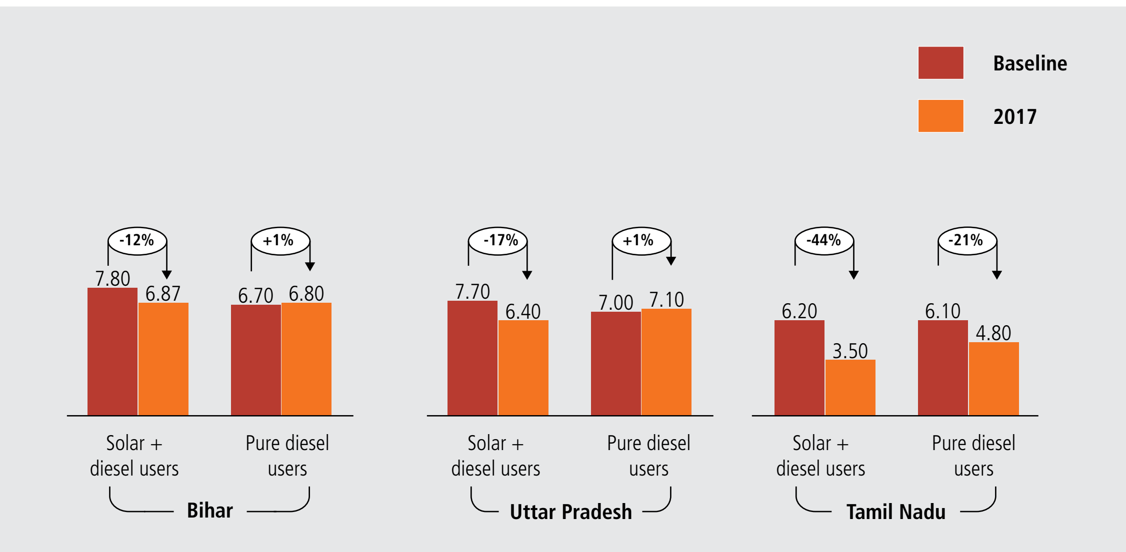
4

Socio-Economic Impact Assessment

Broader socio-economic impact has been limited, primarily due to the low levels of installation at the farm level, and varies according to state-level factors. Impact at the farmer- or household-level has been significant for specific segments, suggesting that the scheme has high potential.

Economic impact: Across all four states, farmers using SWPs have reported an increase in energy savings due to partial substitution of electric and diesel pumps. The size of this economic impact varies widely across states based on the existing landscape of pumps and, critically, the cost of agricultural electricity in the state.

EXHIBIT 17: Change in daily usage of diesel and electric pumps due to 'stacking' of SWPs

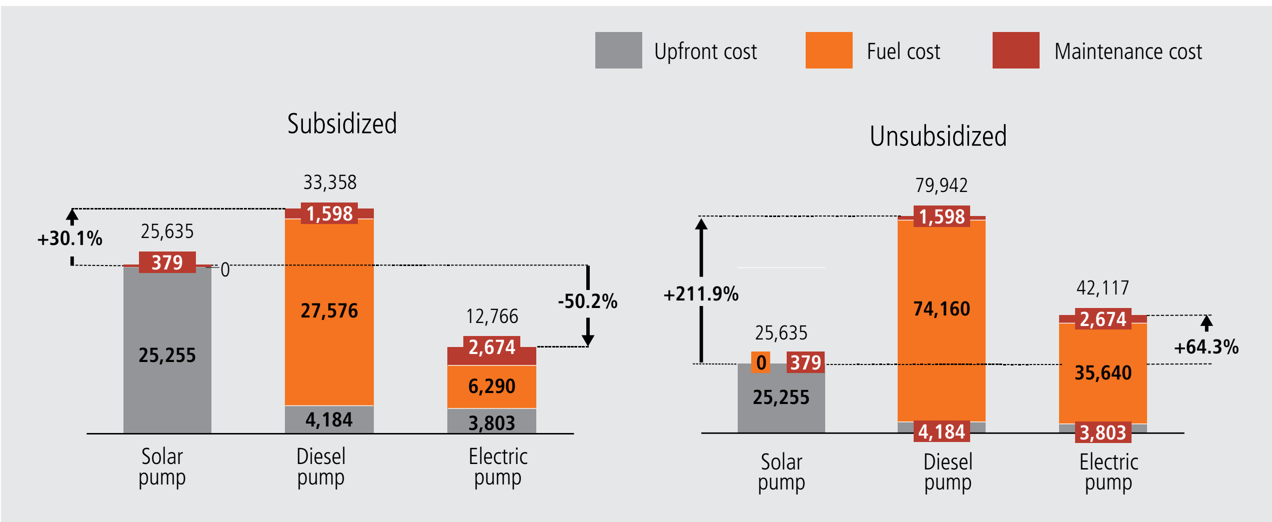


The figure above shows the effect of SWP 'stacking' on the daily usage patterns across three states (Rajasthan mostly has electric pump users) relative to the control group i.e. "pure diesel users". In Bihar and Uttar Pradesh, where a majority of SWP pump owners stack usage on top of diesel pumps, solar pumps have displaced ~1 hour per day (from 7.8 hours to 6.87 hours in Bihar, and from 7.7 to 6.4 hours in Uttar Pradesh), and ~1 day a month of diesel pump use. This has generated significant annual savings of ~INR 13,500 for the average farmer, which is about three-four times the average monthly income for farmers in these states. It should be noted that in the same period, the control group of diesel users in these states maintained or increased their diesel pump usage. In Rajasthan and Tamil Nadu, where most farmers use solar pumps with electric pumps, economic benefits were less definite.

The cost of electricity is a key driver of the economic impact on the end-beneficiary. In UP, Rajasthan, and Tamil Nadu, electricity is heavily subsidized, and most farmers have unmetered connections, with low, fixed monthly tariffs for their electric pumps. Due to the subsidy, solar pumps cost twice as much as electric pumps over five years, and are thus not economically viable replacements. According to one farmer in Tamil Nadu, *"We use electric pumps because of the free electricity and the low cost of [electric] pumps. I can buy up to three electric pumps of the same HP at the price I pay for one solar pump."* If the electricity subsidies were to be removed, SWPs would cost ~40% less across five years and provide a compelling economic rationale for electric pump farmers to switch.

EXHIBIT 18: Average five-year cost for each pump[33]

In INR/HP, 2010-17



Agricultural impact: Agricultural impact in terms of change in irrigated area, crop productivity, and crop diversification has been negligible. Three major reasons contribute to this outcome.

First, the typical solar pump provided by the scheme is lower-powered relative to the average diesel and electricity pumps (~2HP vs. 5-10HP) in use. This tends to favour the 'stacked' usage patterns observed across all states, as opposed to full replacements. Demand from farmers in states with low water tables (e.g. Rajasthan) was especially curtailed. This was clearly pointed out by a FGD respondent in Rajasthan who said, *"[The] solar pump has not helped me increase my production. With my electric pump, I am able to irrigate my entire land area as it gives out more water. This is also because the power of the solar pump is about 3HP as against a 10HP electric pump."*

Second, at an aggregate level, given that most farmers using SWPs are existing pump users (either diesel or electric), the increase in water availability due to SWPs has not been sufficient to cause significant changes in crop-level outcomes. SWPs give 15-25% lower water output (litres/ minute) than conventional pumps accounting for pump size.[33] While subsidised SWPs offer more water output per unit cost than subsidised diesel pumps, the extensive power subsidies mean that electric pumps can provide ~150% more water output per unit cost than SWPs, in addition to the technological discharge rate advantage.

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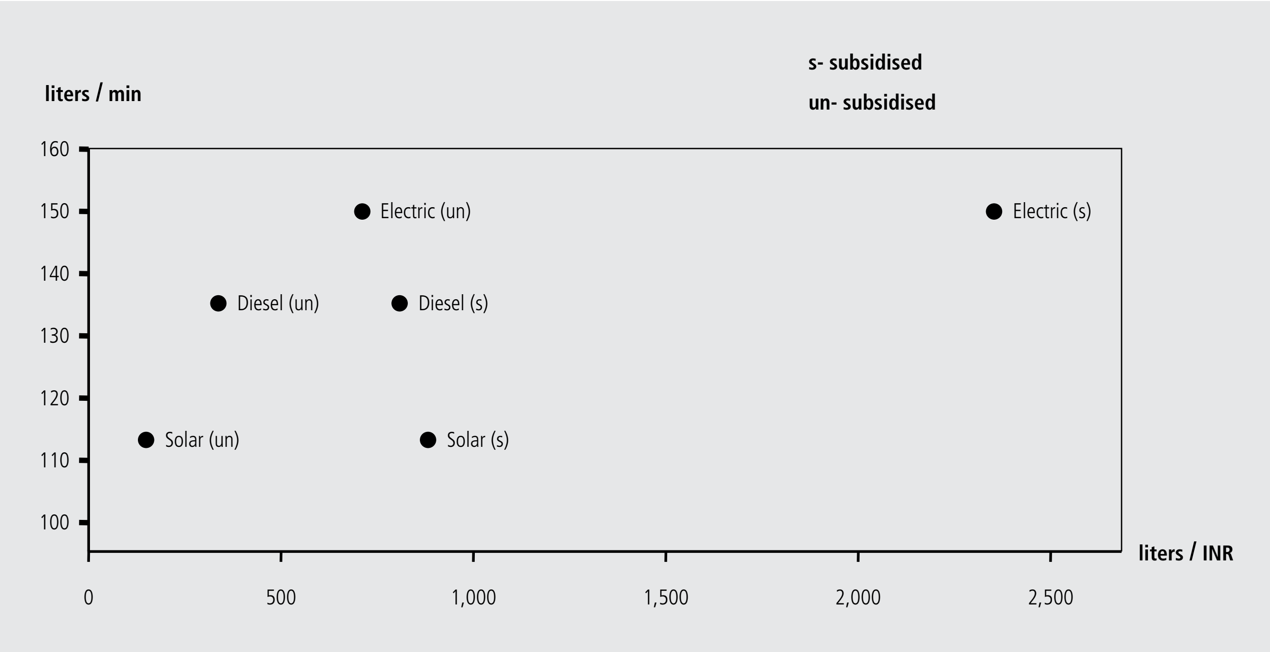
[32](a) Subsidised cost is calculated by using self-reported data by farmers in Bihar, UP, Rajasthan and Tamil Nadu (b) Unsubsidised cost is calculated through desk research and averaging across different states (c) Price of diesel= INR 60 (Bihar & UP) (d) Cost of a unit of electricity= Rs 6 (Rajasthan)

[33]Farmer consultations, focus group discussions, consultations with pump manufacturers in India.

EXHIBIT 19: Output per unit time and output per unit cost for subsidized and unsubsidized pumps[34]

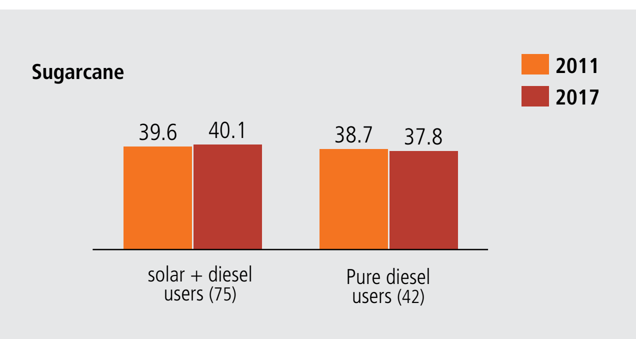
In liters/ min, liters/INR. For 1 HP pumps with 15m head size. 2010-17



Despite these challenges, SWPs have shown promising signs of agricultural impact in terms of increased yield on a small sub-set of water-intensive crops such as sugarcane and maize. These effects are not statistically significant due to small sample sizes, but highlight the potential of a better-targeted scheme to improve specific agricultural outcomes. Exhibit 20 shows an increase in productivity in sugarcane production of 0.5 tons/ hectare in Bihar where SWPs have displaced diesel usage. More anecdotally, a farmer in Bihar indicated during a focus group discussion, *"Where I used to give water only 1-2 times using diesel pump to save costs, I am able to irrigate the same crop 7-8 times using solar pump. This has helped me increase the production of crops."*

EXHIBIT 20: Effect of SWP usage on productivity of sugarcane in Bihar[35]

In tonnes/hectare, n=117



Third, the peak efficiency of solar pumps is not optimally-aligned with preferred irrigation time of farmers, meaning that when farmers need water most, solar pumps are unable to provide adequate irrigation. In Bihar, 65% of respondents cited '6 am-11 am' as their preferred irrigation time, and about 40% said that they could not always depend on SWPs during this period. Of these respondents, 71% reported 'lack of sunlight' as being the major inhibiting factor. Similar views were also noted in Rajasthan, where an FGD respondent

[34](a) Subsidised cost is calculated by using self-reported data by farmers in Bihar, UP, Rajasthan and Tamil Nadu (b) Unsubsidised cost is calculated through desk research and averaging across different states (c) Price of diesel= INR 60 (Bihar & UP) (d) Cost of a unit of electricity= INR 6 (Rajasthan) (e) Output is calculated from multiple interviews with pump manufacturers

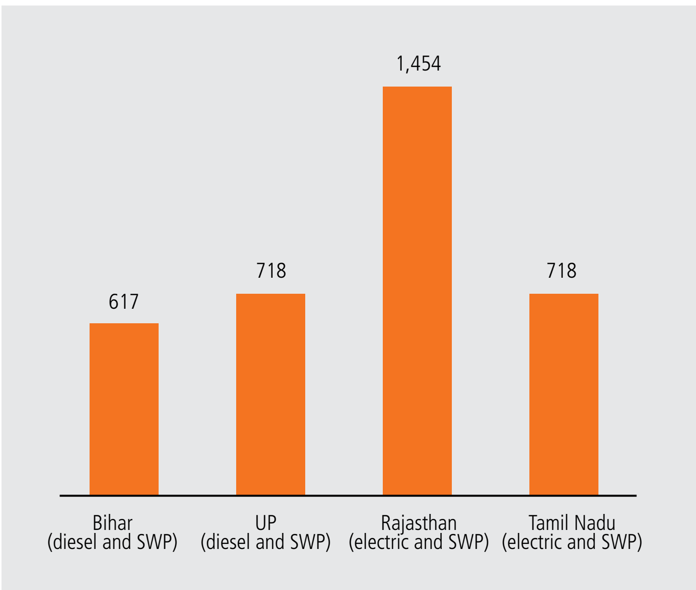
[35]Socio-economic impact assessment household surveys in Bihar, Dalberg and Sambodhi Research, 2017

mentioned, *"Solar pump works the best when there is maximum sunlight. Its effectiveness goes down with reduced sunlight or cloudy weather."*

Environmental impact: The reduction in diesel pump and electric pump usage has led to a moderate decline in annual CO_2 emissions per farmer. Respondents in Bihar and UP reported 0.6-0.7 tons in annual CO_2 savings for stacked users relative to diesel users. In Rajasthan, stacked users saved 1.4-1.5 tons of CO_2 annually because SWPs have displaced usage of higher-powered electric pumps (10 HP) than the diesel pumps (5 HP) in UP and Bihar. In comparison, the average passenger vehicle yields about 3-4 tons of CO_2 annually. Our results indicate that SWPs aggregate impact on the environment could be substantial, if adoption rates were enhanced. For example, when unit-level CO_2 savings for Rajasthan's farmers are applied to all farmers in the state, the potential savings could add up 5,800 tons of CO_2 per year.

EXHIBIT 21: Reduction in annual CO_2 emissions across states brought about by SWP use

In kgs CO_2 per year



Social/ community-level impact: At the household and community level, a small proportion of farmers (~10-20% of SWP sample across states) use solar pumps to pump drinking water, and combine the panels with inverters to provide additional electrification for the household. SWP use for drinking water is particularly striking in Rajasthan—43% of respondents utilized solar pumps for this purpose, and many of them recycled the drinking water for irrigation through canals.

While state-specific factors contributed to differing levels of impact across the states, there were three broad, overarching challenges that were raised during the study. We have discussed these challenges earlier in the report, within the context of the findings as well as the recommendations, but they bear calling out. These challenges to the uptake and impact potential of SWPs in India revolve around (1) underlying market conditions, (2) technical issues, and (3) regulatory factors.

1. Market conditions: While the awareness and understanding of SWPs is increasing, it remains a relatively recent technology amongst farming communities and surrounding eco-systems (including rural banks). This means that there is a lack of knowledge and capacity, amongst both farmers and bank managers, about SWP use and potential benefits, thereby limiting demand and the financing required to scale adoption. This sentiment was echoed by an agricultural expert who said, "A farmer doesn't have any reliable source of information about irrigation or pumps. Some can rely on educated children who can connect it to the agricultural officer or unit. Most farmers don't understand how good is the dealer, what mechanism do I use. That critical connectivity is missing."

There is also a beneficiary mismatch, with large farmers owning most pumps instead of the targeted smallholders (e.g., in Bihar, ~50% of pump owners were medium sized farmers). This reduces the scale of both economic impact, as large farmers frequently use solar pumps to complement, instead of substitute, existing conventional pumps. The major driver of this mismatch is the high up-front cost (~INR 30-60,000) of the pumps, which is four-eight times the average monthly income a farmer in these states, and inhibits many marginal and small farmers from purchasing a pump, even with high state/ national subsidies in place. Further, the lack of aftersales and maintenance networks and support in villages poses a major challenge to adoption.

2. *Technical issues:* As noted earlier in the report, a majority of the SWPs deployed under the scheme between 2014-2015 are underpowered (2-3 HP), being inadequate for irrigation in terms of both water table levels (Rajasthan), and landholding sizes (Tamil Nadu). The incorporation of other technologies (e.g. drip irrigation, battery packs, inverters etc.) that could enhance the performance and output of SWPs needs to be fully explored, and monitored in states where it has been made mandatory but not fully implemented, such as Rajasthan.

3. *Regulatory factors:* The long application process for SWPs is a comparative disadvantage as compared to conventional pumps. For example, farmers in FGDs indicated that paperwork for the SWPs is long and tedious, often requiring multiple visits to the block office which results in loss of productive time. Most states take 2 months to process pump applications, compared to an immediate purchase of diesel pumps. Anecdotal evidence suggests an increase in processing time to a year. Second, there is a mismatch between the policy orientation towards small pump sizes targeted to marginal and small farmers, and the actual adopters, who are larger farmers requiring bigger pumps, thus limiting the impact of these underpowered SWPs. Pump disbursement plans to do not consider the set of geographical, climactic, and hydrological conditions – solar intensity, water table depths, micro-climates – that determine pump applicability, yielding varied and tempered results at state level. Finally, a lack of financial linkages for marginal farmers who are typically income-constrained has further limited their ability to access and use the solar pumps. Finally, the policy does not currently target beneficiaries based on agro-climactic conditions, which limits both the benefits to the farmer, as well as the impact.

CHAPTER

5

State Level Findings

5.1 Bihar

Context:

Key characteristics of the state:
Farmer population: ~16,000,000
Chosen districts: Gopalganj, Sitamarhi, Bettiah
Average farmer income: Rs 3,558
Landholding: Medium (average size is 1-3 hectares), highly fragmented (average no. of plots is 2.5-3.5)
Major crops: Rice, wheat, sugarcane
Water situation: 99% of farmers have water levels within 10 meters

Policy highlights:
Nodal agency: BREDA
Subsidy cover: 90%
Type of pumps: 2 HP
Target beneficiary: Marginal and small farmers

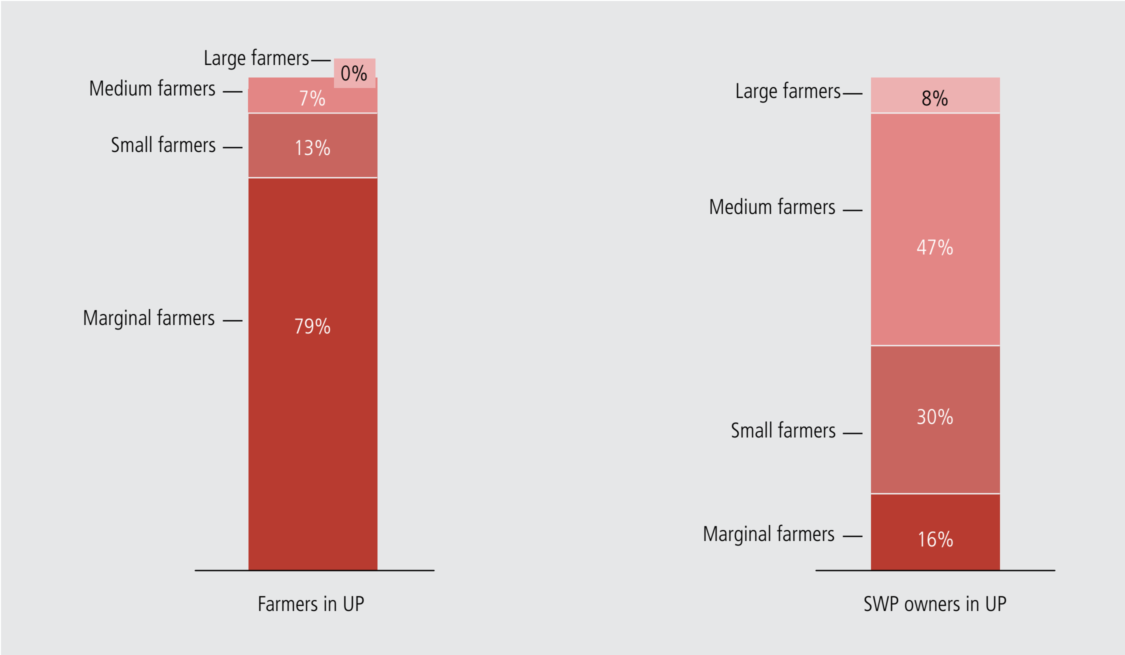
Irrigation in Bihar is crucially dependent on the monsoon. While 57% of the gross cultivated area is irrigated, a third of that is through canal water, the availability of which is largely dependent on rainfall. Further, with only 20% of the rural households using electricity as their primary lighting source, farmers are unable to use electric pumps, and are completely dependent on diesel pumps for irrigation. As diesel prices have risen by ~40% over the last few years, many farmers are searching for an alternative to the increasingly expensive fuel. SWPs are seemingly the perfect solution to a largely unelectrified, cost-conscious farmer population's irrigation needs, as they have no operational expenses and provide a reliable supply of water.

The solar water pump policy in Bihar is administered by BREDA (Bihar Renewable Energy Development Agency) that provides a 60% subsidy in addition to the 30% MNRE subsidy, for a total subsidy level of 90%, for 2 HP DC pumps.

At the highest level, 3516 solar pumps have been sanctioned in Bihar, and 216 have been installed (as of April 2016), with the 90% subsidy provided. Bihar's Saur Kranti Sichai Yojana, which aims to bring irrigation to farmers in the state, is designed to target small and marginal farmers. However, marginal farmers have been unable to access the SWP policy, with semi-medium and medium sized farmers being the largest recipients of the subsidy scheme. Despite constituting 91% of all farmers in Bihar, only 16% of SWP owners are marginal farmers.

FIGURE 1: Proportion of Farmers and SWP owners across land categories[36]

In %, Bihar, N=23.325 million, n=254



Adoption at scale is being held back by the high upfront cost of pumps, which at INR ~30,000 post subsidy, is still almost double the cost of an average diesel pump (INR ~16,000), and more than eight times the average monthly income of a farmer (Rs. 3,558). Given that the MNRE BREDA scheme does not facilitate linkages to loan products, farmers who can shell out this upfront cost are likely to be better off than the average farmer in Bihar. A farmer had this to say about the lack of financing linkages in an FGD, *"We pay the entire solar pump amount in the form of demand draft of Rs. 29,700 in full. We pay this money using our own savings, earnings from harvest or by informally borrowing from our friends or relatives."* Unless an average farmer can pay out the cost of the pump in instalments, funded partly through diesel savings from SWPs, it is difficult to choose solar over diesel when making a purchase decision.

Recommendations:

Our findings suggest that the design and implementation of the scheme can be improved. Keeping state-specific factors in mind, we recommend the following:

Technical recommendations:

- *Pump size:* The 2 HP pumps are adequate for state characteristics, as they can be used by the 99% of farmers having water table levels below 10 meters and average landholdings of less than 1 hectare.
- *AC vs DC:* We recommend a shift to AC pumps to reduce upfront costs and encourage household use. AC pumps are 10-15% cheaper and can be used for household applications directly, without the expensive inverter that DC pumps require. The quality issues that might arise from using locally-manufactured AC pumps instead of the imported DC pumps, can be addressed by using a price discovery supplier selection process—where the SNA conducts market research and benchmarks costs per HP—instead of the lowest bid (L1) process.

[36] Marginal- <1ha, Small- 1-2 ha, Medium- 2-10 ha, Large- >10 ha

Policy recommendations:

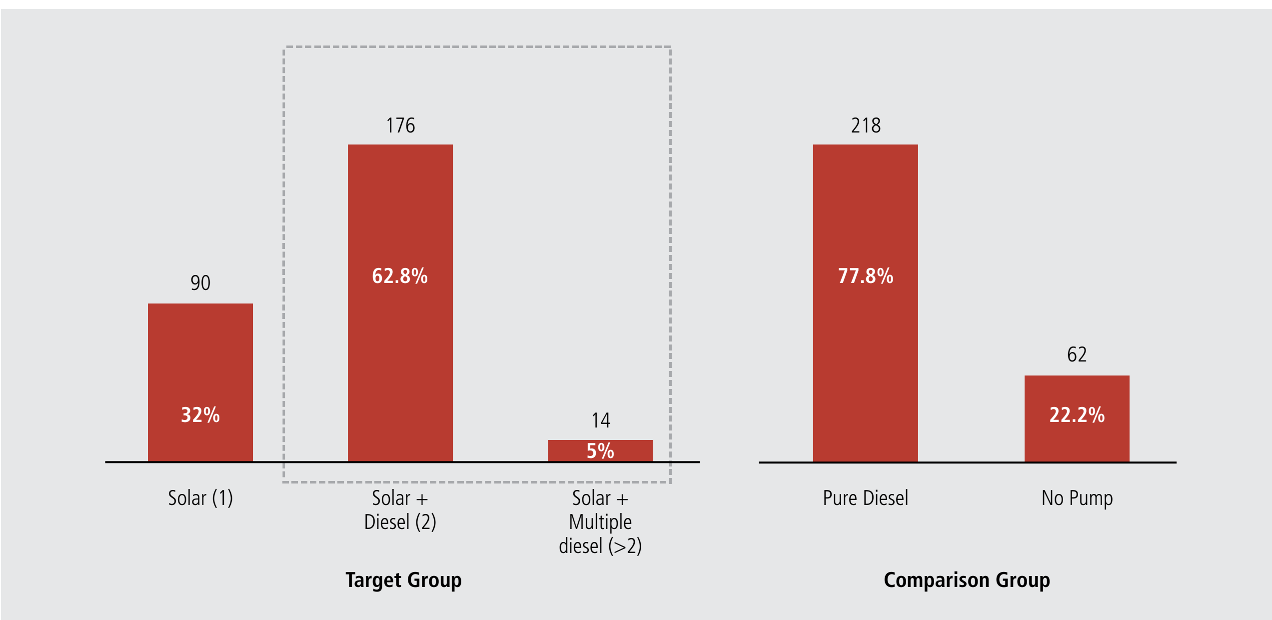
- We suggest *targeting* marginal farmers who own diesel pumps or do not own any pumps. Diesel pump operating costs have increased by 40% in the study period, and the cost-conscious marginal farmers displayed the maximum diesel pump use substitution—thrice as much as that by medium farmers. Further, no pump farmers can derive the maximum agricultural benefits from SWP use due to their lower baseline.
- We also recommend the *integration* of policy with allied schemes. Integrating the drip irrigation technique under the National mission on Micro-Irrigation can amplify farm impact. The state can also utilise the Aadhar UID scheme, combined with a one-window system for tracking applications, approvals, tendering, and complaint resolution, to improve access, transparency, supplier accountability, and policy feedback.
- Further, it is crucial for the state to establish *financing* linkages to address the upfront cost barrier, especially for the cost-conscious marginal farmers. One way to do so is by incentivizing private lending from RRBs and MFIs by using a credit guarantee mechanism that covers farmer defaults. Community ownership models involving SHGs and Joint Liability Groups can be explored, as they can also address land fragmentation by enabling water sharing. Additionally, the state can encourage the establishment of pay-as-you-go systems that are especially suited to smallholders.
- The state should also adopt *best practices*, such as remote monitoring and data retrieval from pumps, beneficiary prioritisation through subsidy slabs, and a price discovery tendering process, where the SNA conducts market research and benchmarks costs per HP, that have been implemented in the other three states.

Findings and challenges:

There are some emerging signs of broader socio-economic impact facilitated by SWPs, including cost saving for farmers, a moderate reduction in carbon emissions, and productivity gains for some types of crops.

FIGURE 2: Pumps owned by farmers

In %, Bihar, 2017, n_1=280, n_2=280

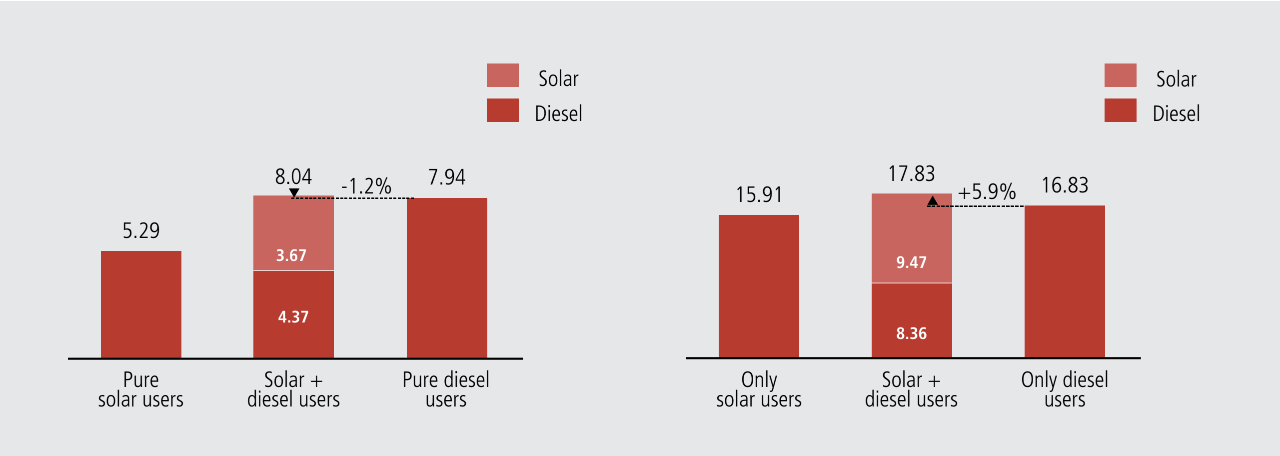


Economic: The main economic benefit of SWPs is cost savings due to partial substitution of diesel pump use by users stacking SWPs onto diesel pumps.

Solar pumps are currently not viewed as stand-alone solutions that can replace diesel pumps, but as add-ons to existing pump technologies. 68% of solar pump owners stack their pumps on top of diesel pumps, and only 4.5% of all solar users reported replacing diesel pumps. However, the similar daily and monthly irrigation pumping usage–8 hours a day and ~17 days a month–by both stacked and pure diesel farmers suggests that SWPs are substituting diesel pump use to an extent.

FIGURE 3: Average daily and monthly irrigation pump use (land-size adjusted)

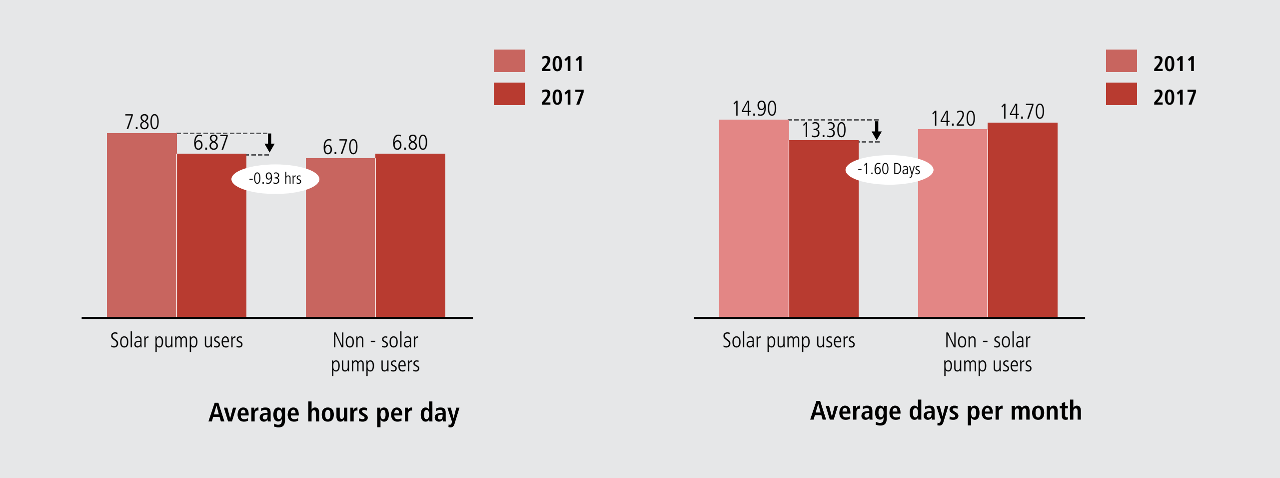
In hours per hectare, in days per hectare, UP, n=497



On average, stacked users reduced their average use of diesel pumps by ~1 hour per day, and ~1.5 days per month, as compared to the baseline use. This has resulted in average annual diesel savings of 230.5 litres and INR 13,400 per person.

FIGURE 4: Average daily and monthly use of diesel pumps

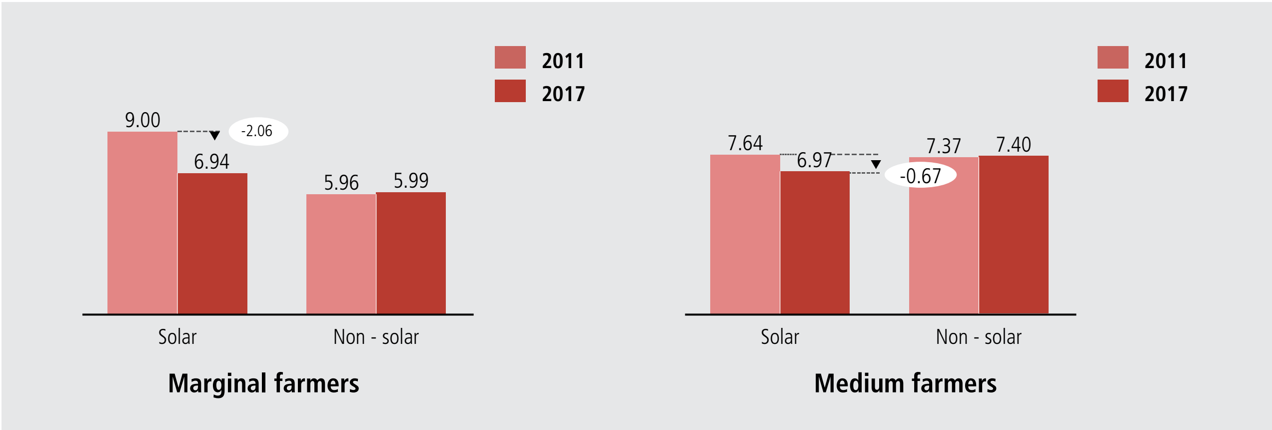
In hours, in days, Bihar, n=394



Marginal farmers in the state displayed the highest diesel pump displacement, reducing their pumping hours by three times as much as the reduction displayed by medium farmers. By targeting smallholders effectively, the state can unlock significant economic benefits for its farmers through the SWP policy.

FIGURE 5: Average daily use of diesel pumps

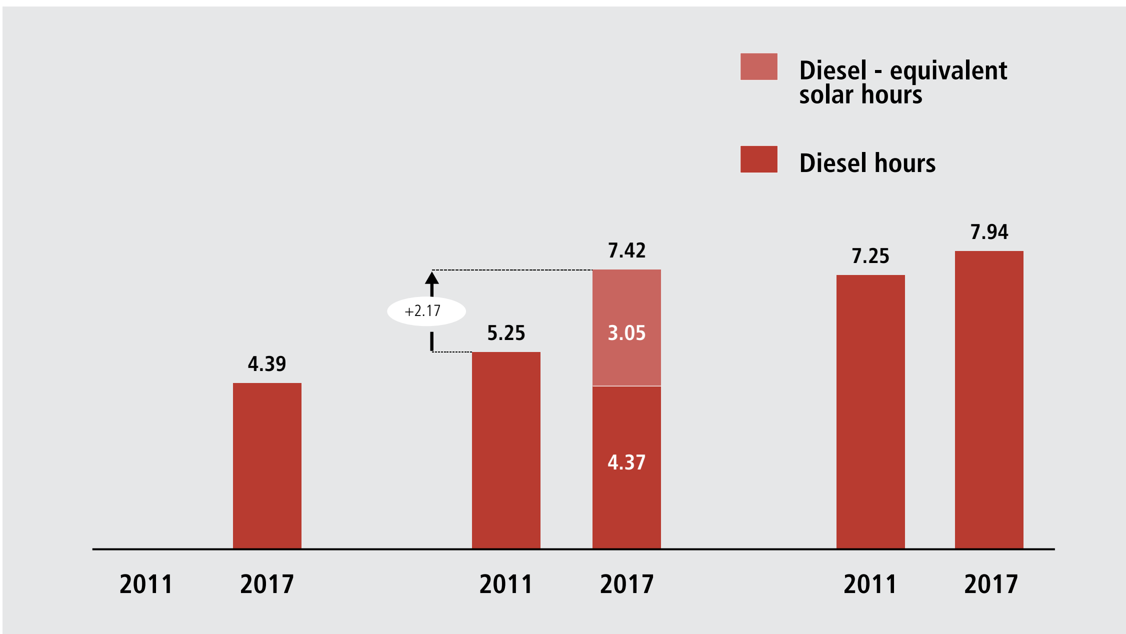
In hours, Bihar, n1=111, n2=144



Agriculture: *Additional irrigation by stacked users has led to no significant change in net irrigated area, productivity increase for some water-intensive crops, and no additional diversification gains over control group farmers.*

FIGURE 6: Change in average daily use of pumps (diesel-equivalent[37], land-size adjusted)

In hours per hectare, Bihar, n=560



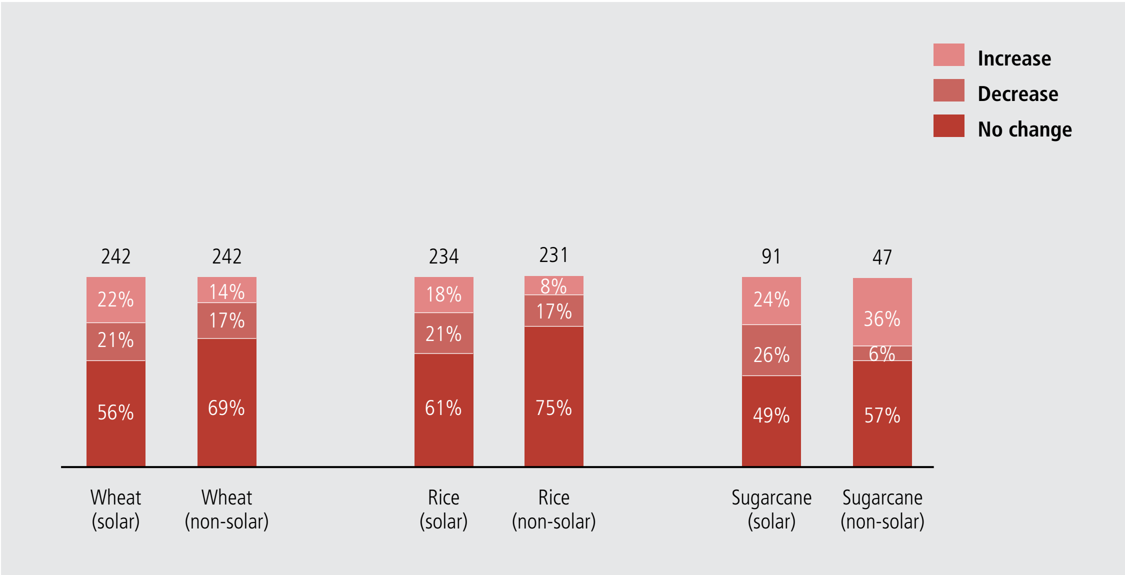
Stacked SWP users are pumping for ~2 additional diesel-equivalent[2] hours per day on a given hectare of land, as compared to their baseline use. The additional water output could lead to an increase in irrigated area, crop productivity, or diversification into water-intensive vegetables.

However, a majority of target and control group users reported no change in net cultivated and irrigated area, for the three major crops–rice, wheat, and sugarcane–that constitute 90-94% of total cultivated area.

[37]Hours of solar pumping converted to equivalent diesel hours based on the different discharge rates

FIGURE 7: Change in irrigated land area for major crops

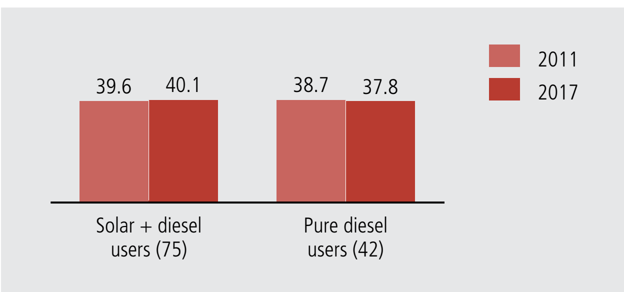
% of respondents observing change, Bihar, n=480



Crop productivity for those having solar pumps remain unchanged from the baseline, except in the case of sugarcane, a highly water-intensive crop. This suggests that water is not the productivity limiting factor for other major crops, such as rice and wheat.

FIGURE 8: Change in productivity for sugarcane

In tonnes per hectare, Bihar, n=117



Also, diversification gains reported by farmers, primarily into vegetables such as tomato, brinjal, okra, pumpkin, and peas, were similar (~30%) across all pump categories. Diversification is possibly driven by external factors in the state. According to an energy consultant in Bihar, *"External factors affecting the village can influence production of a new crop. Also, one farmer can start producing a crop if he sees other farmer growing that crop and has water available to start the same."*

The limited agricultural impact is primarily due to fragmented landholdings in the state limiting the irrigation potential of immobile SWPs, and the lower discharge rate of SWPs vis-à-vis diesel pumps. SWP farmers have ~3.4 plots of land on average, with one farmer noting that, *"Solar pump can become a primary pump if I am able to use it on a moving system on all plots of land. At this point, diesel pump is the primary pump as it…can be moved from plot to plot." Additionally, the discharge rate of solar pumps is 16% less than that of diesel pumps. 24% of SWP farmers felt solar pumps do not provide them with sufficient water to irrigate their land. A farmer mentioned the following in an FGD, "…the farmer continues to rely on diesel pump on the same plot of land…the discharge rate of solar pump is 20% less as compared to diesel. Solar takes 8 hours to irrigate one bigha of land."*

Other impact:

- *Environmental: The partial substitution of diesel pumps by SWPs has led to a decline in CO_2 emissions per farmer.* The 1 hour decline in average daily use of diesel pumps has led to a reduction of ~618 kg of annual CO_2 emissions per farmer. While these figures represent a moderate reduction, when benchmarked to the 4-5 tonnes of annual CO_2 emissions produced by a passenger car, by improving adoption and use incentives, the state can achieve significant environmental benefits.

- Household use: Only a small fraction of households used SWPs off the farm. Due to farms being distant from houses in Bihar, only ~5% of household reported using solar panels and water drawn from SWPs for other purposes, primarily for mobile charging and provision of drinking water.
- Gender: SWPs were unable to reduce women's drudgery as there was no significant change in water collection times. Potential future impact is also limited, as according to anecdotal evidence, women do not play a substantial role in irrigation activities in the state, with a farmer saying, "Women in the household are not engaged in irrigation. Irrigation is only handled by men. That is why solar pump does not impact irrigation activities of women."

Main challenges:

1. *Lack of financing mechanisms for high upfront costs.* Despite the 90% subsidy, the upfront cost of Rs 30,000 is eight times the monthly income of an average farmer in Bihar, and has to be paid entirely from savings. This is preventing marginal farmers from being able to access the policy.
2. *Limited irrigation potential of immobile SWPs due to fragmented landholdings.* SWP farmers have ~3.4 plots of land on average, and 24% of them felt solar pumps don't provide them with sufficient water to irrigate their land.
3. *A weak after-sales service network for SWPs as compared to diesel pumps, and a long application process.* Most solar pumps must be taken to the installer for repair, and take more than a week for repairs, while diesel pumps can be repaired by a local mechanic within a day. The process of acquiring solar pumps takes 10-11 weeks in the state, and anecdotal evidence suggesting even longer timelines, with a farmer saying *"The approval sometimes takes a lot of time. It took 6-8 months to get the approval as the pump was not available."*

5.2 Uttar Pradesh

Context:

Key characteristics of the state:
Farmer Population: ~23,325,000
Chosen districts: Pilibhit, Basti
Average farmer income: Rs 4,923
Landholding: Medium (average size is 0.6-1.7 hectares)
Major crops: Rice, wheat, sugarcane
Water situation: 77% of farmers have water levels within 10 meters, 23% have wells deeper than 10 meters

Policy highlights:
Nodal agency: UPNEDA, Department of Agriculture
Subsidy cover: 75%
Type of pumps: 2 HP
Target beneficiary: Marginal and small farmers

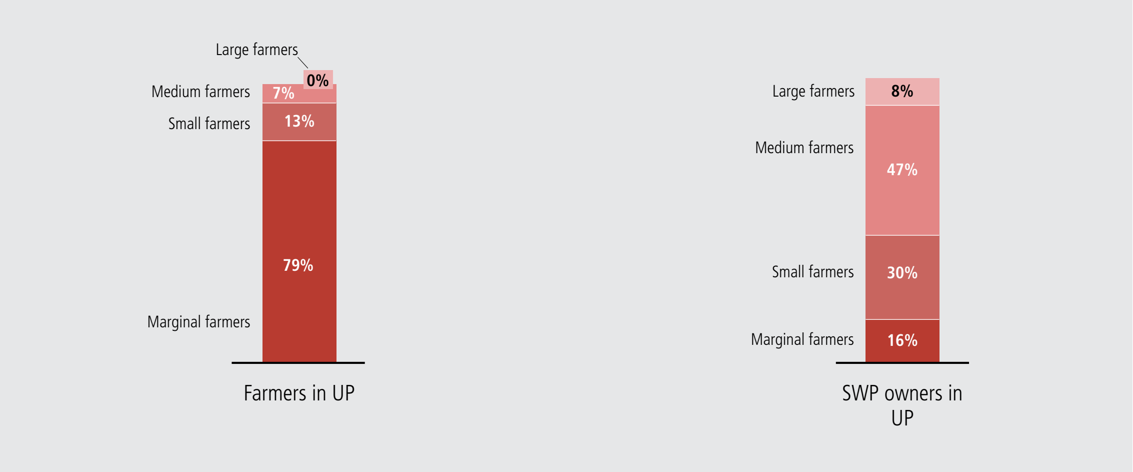
UP is a well-irrigated state, with ~80% of net sown area being covered by irrigation. The power availability in the state is increasing, and stands at 1.75 kW/hectare. However, the state has identified the need for a further increase in power availability to 2 kW/hectare by 2020 to ensure timely farm operations.[38] The SWP policy in UP can help reduce the rising pressure on the developing power grids, and position solar pumps as a viable alternative for farmers looking to replace expensive diesel pumps.

The SWP scheme in UP is jointly implemented by the Department of Agriculture, which deals with the beneficiaries, and the UP New & Renewable Energy Development Agency (UPNEDA), which is responsible for supplier selection and monitoring. The scheme currently provided a 75% overall subsidy for 2 HP solar pumps, with the pump size being selected to target smallholders.

UP has the second highest no. of sanctioned pumps in the country. Of the 7,100 pumps that have been sanctioned, 3,700 have been installed (as of April 2016)—the >50% installation rate is much higher than the national average. However, marginal farmers in UP have been unable to access the policy, and make up only ~16% of SWP farmers, while accounting for ~79% of the total farmers in UP. It is the medium farmers, who own 2-10 hectares of land, that form 47% of SWP owners, despite representing only 7% of all farmers in UP.

FIGURE 9: Proportion of Farmers and SWP owners across land categories[39]

In %, UP, N =23.325 million, n= 254



[38]Agricultural mechanization guide for UP, Ministry of Agriculture, GoI

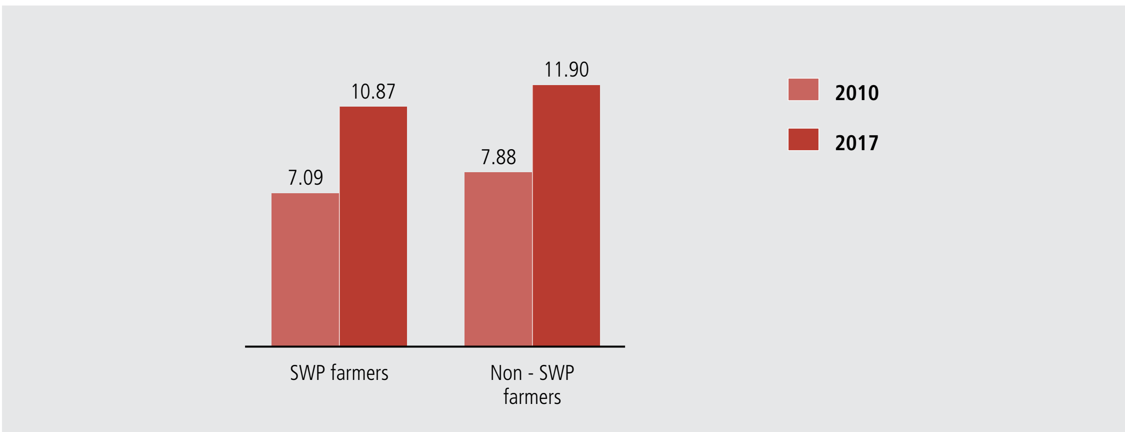
[39]Marginal- <1ha, Small- 1-2 ha, Medium- 2-10 ha, Large- >10 ha

UP has also introduced innovative practices such as a UID based complaint redressal system for greater supplier accountability, remote monitoring of pumps for real-time data retrieval, and e-corrective mechanisms for minor SWP problems.

High upfront cost per HP as compared to conventional pumps, and the rising availability of low-cost electricity are the limiting factors to be overcome to scale the SWP policy. The upfront cost of SWPs per HP is six times the monthly income of an average farmer in UP, and eight times the cost of a diesel or electric pump with similar power. Our sample reported a 50% increase in electricity availability in the state in the past few years, with most farmers are paying a low monthly cost for unmetered connections, thereby eliminating the cost-saving rationale for using SWPs. According to a farmer in an FGD, *"Before the availability of electricity was very poor. Now since the past 2-3 months, electricity is available normally for 18 hours. Because of this, those who use electric pump, they irrigate their land with just electric pump".*

FIGURE 11: Daily availability of electricity

In hours, UP, n=162



Recommendations:

Our findings suggest that the design and implementation of the scheme can be improved. Keeping state-specific factors in mind, we recommend the following:

Technical recommendations:

- *Pump size:* We suggest an expansion of pump sizes from the current 2 HP pumps to include 3-5 HP ones. 2-3 HP pumps are sufficient for the 77% of farmers in the state having water table levels within 10 meters, but the 23% farmers with lower levels require 5 HP pumps. Further, the average land size range in the state is 0.6-1.7 hectares, and farmers owning more than 0.8 hectares need pumps larger than 2 HP for adequate irrigation.
- *AC vs. DC:* We recommend a shift to AC pumps to take advantage of the developing service networks for AC electric pumps and encourage household use. The increasing availability of electricity in the state is allowing electric pump use to increase, and the fostering the development of associated AC service networks. Again, the quality issues that might arise from using locally-manufactured AC pumps instead of the imported DC pumps, can be addressed by using a price discovery supplier selection process—where the SNA conducts market research and benchmarks costs per HP—instead of the lowest bid (L1) process.

[40]Costs are self-reported by farmers in the state

Policy recommendations:

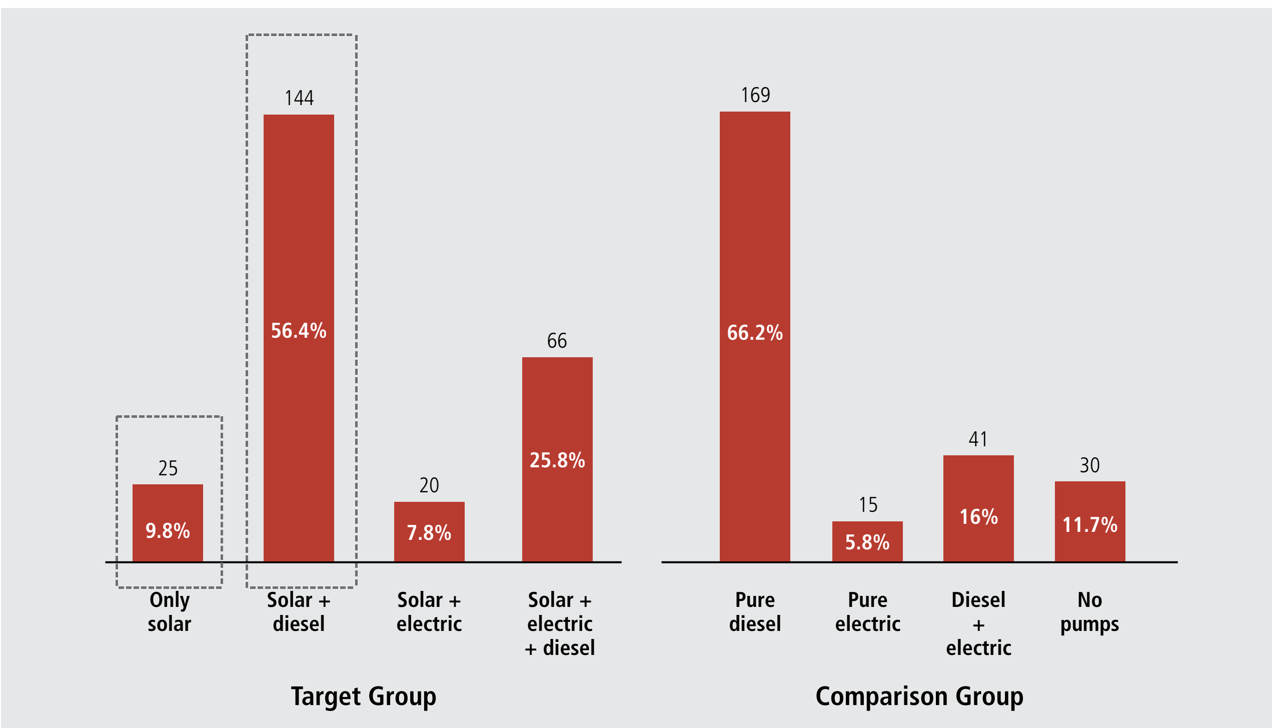
- We suggest *targeting* small diesel and no pump farmers with limited electric access to achieve maximum benefits per unit cost. Farmers combining SWPs with diesel pumps have displayed partial substitution of diesel pumps (1.3 hours per day), with marginal farmers reducing diesel use the most (1.97 hours). Pure solar farmers, who previously owned no pumps, have displayed high diversification gains, possibly due to a low baseline. On the other hand, the rising availability of cheap electricity has limited the economic impact of SWPs for electric farmers.
- *Integration* of the UID system, already implemented in the compliant redressal process, with the national Aadhar scheme, can further streamline the servicing process. Combining UIDs with a one-window system for pump applications, tendering, and servicing can fully integrate the policy process for all state stakeholders, thereby improving access, supplier accountability, servicing and transparency. Also, integrating the SWP policy with the Agriculture DSM (Demand Side Management) scheme can help improve efficiency of solar pump sets, build farmer capacity and encourage household use.
- To remove the upfront cost *financing* barrier for marginal farmers, especially as pump size is increased, we recommend incentivizing private lending from RRBs and MFIs using a credit guarantee mechanism that covers farmer default to a certain extent, exploring community financing models such as Joint Liability Groups and SHGs, and encouraging the establishment of pay-as-you-go systems by private vendors.
- Finally, the state should look to adopt best practices for the policy, such as prioritisation of unelectrified farmers using differing subsidy slabs, which has already been implemented in Rajasthan and Tamil Nadu, and a price discovery tendering process—where the SNA conducts market research and benchmarks costs per HP instead of accepting the lowest bid (L1) —from Tamil Nadu.

Findings and challenges:

There are similar emerging signs of broader socio-economic impact facilitated by SWPs in UP, including cost saving for farmers, a moderate reduction in carbon emissions, and increased household access to electrification and drinking water.

FIGURE 12: Pumps owned by farmers

In %, UP, 2017, n_1=255, n_2=255

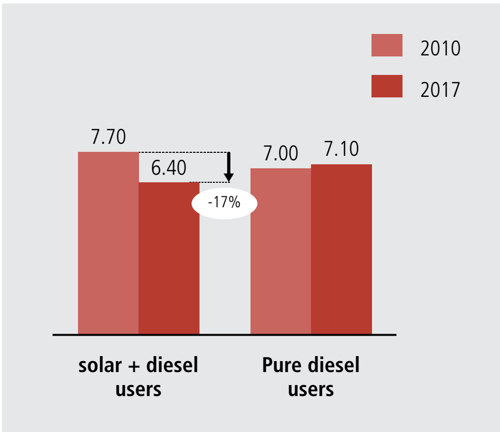


Economic: *The major economic impact of SWPs has been the cost savings due to the substitution of diesel pump use amongst farmers who stacked SWPs with diesel pumps (~56% of SWP owners).*

Stacking behaviour is also common in UP, with large farmers using SWPs to complement conventional pump use. ~56% of SWP farmers own both solar and diesel pumps, and possess 2.7 hectares of land as compared to 1.5 hectares owned by pure diesel farmers. Stacked users have substituted 1.3 hours of diesel pump use with SWPs. This has allowed stacking users to reduce their annual diesel consumption by 268 litres, and thereby save ~Rs 15,000 in the process.

FIGURE 13: Average daily use of diesel pumps

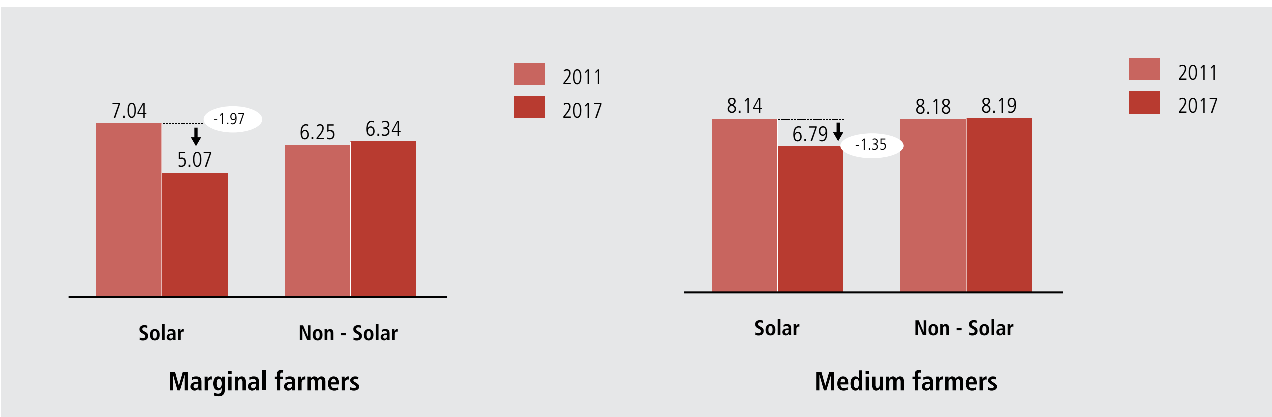
In hours, UP, n = 419



Marginal and small farmers have displayed the highest displacement of diesel use—targeting them more effectively can ramp up the economic impact. Marginal SWP farmers reduced daily diesel pump use by 2 hours, or 50% more than the 1 hour reduction exhibited by medium farmers in the state. Also, all of the 9 farmers who gave up diesel pumps in the sample belong to the marginal category.

FIGURE 14: Average daily use of diesel pumps

In hours, 2011-17, UP, n1=100, n2=95

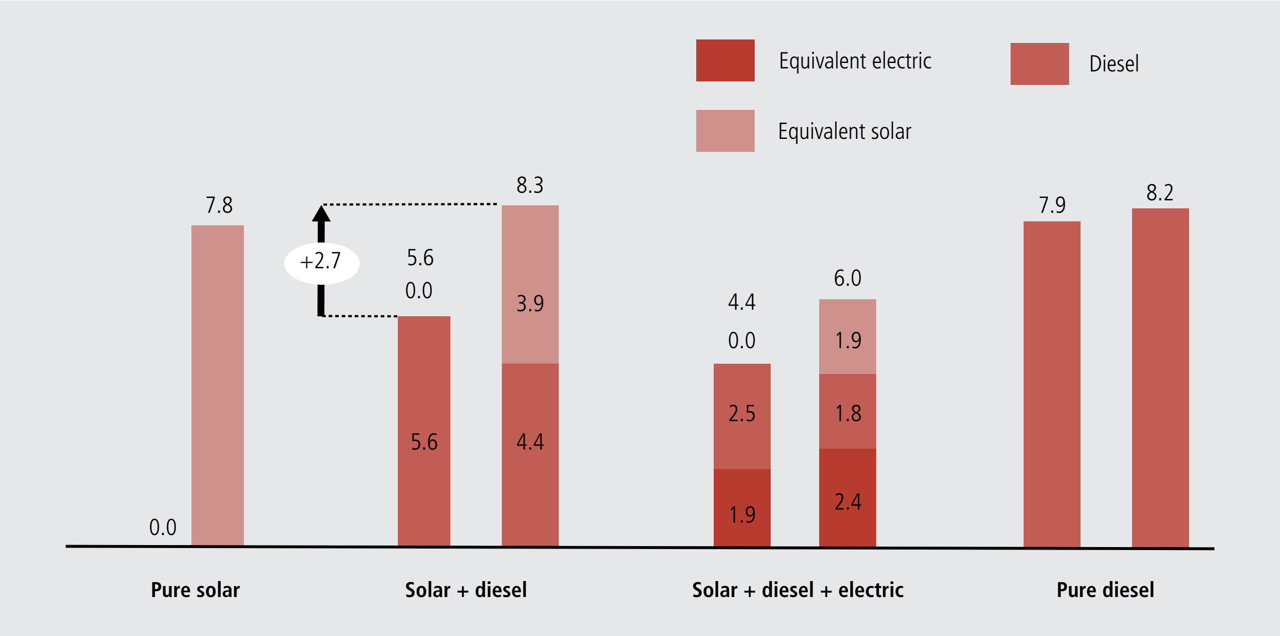


Further, in the case of the much larger farmers stacking electric pump on top of the other two pumps, despite the increased electricity availability in the state, SWPs have tempered the increase in the use of higher-discharge rate electric pumps for a small sample of 21 farmers, saving 875 units of electricity per farmer annually. Impact is limited because of the fixed-cost nature or electricity, as a farmer noted, *"The decline in electric pump is less as compared to others is because we have to pay the electric bill whether we use the pump or not, we do not have a metred connection".*

Agricultural: *The additional irrigation by stacked users has not led to a significant change in irrigated area or crop productivity for the major crops, with diversification gains being confined to the set of lower-baseline pure solar users.*

FIGURE 15: Change in average daily use of pumps (diesel-equivalent[5], land size-adjusted)

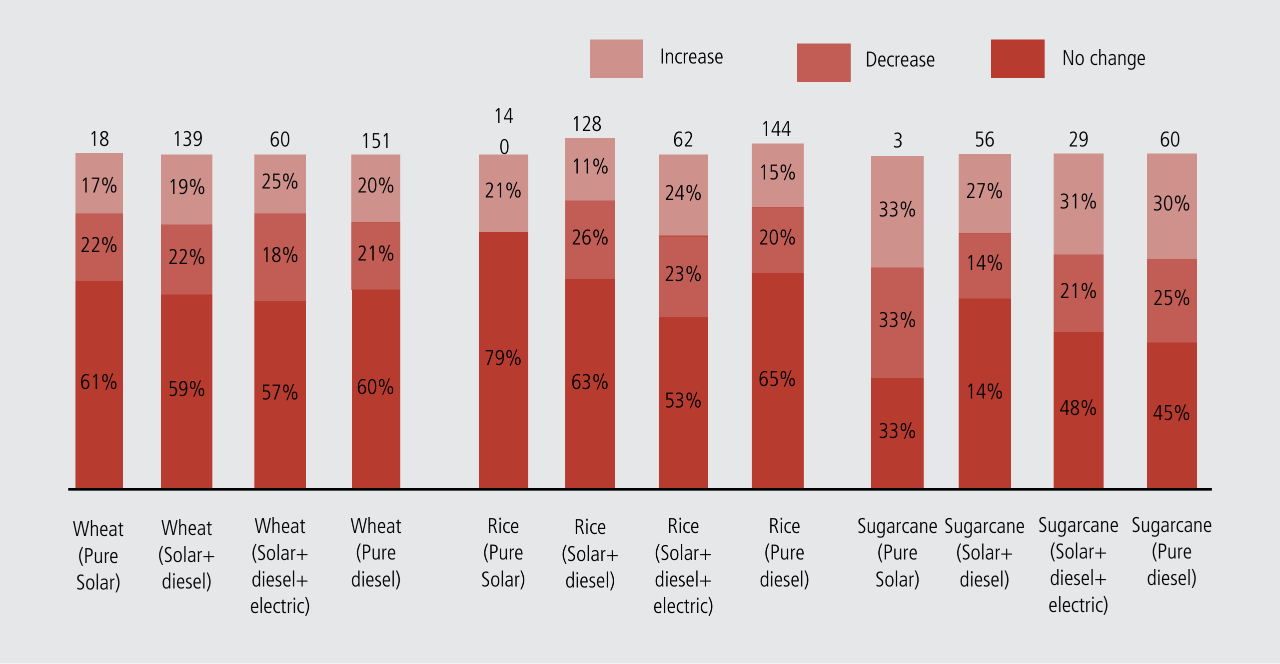
In hours per hectare, UP, n=404



The famers stacking solar and diesel pumps irrigate for ~3 additional diesel-equivalent[41] hours as compared to the baseline. Despite the additional water output, most farmers reported no change in the area under irrigation or productivity for the three major crops–rice, wheat and sugarcane–that constitute 93-96% of the total cultivated area. Also, only a small sample of pure solar farmers displayed higher diversification gains than the control group, largely into vegetables, possibly due to a lower baseline in the absence of previous pump use.

FIGURE 16: Proportion of farmers reporting change in irrigated area for major crops

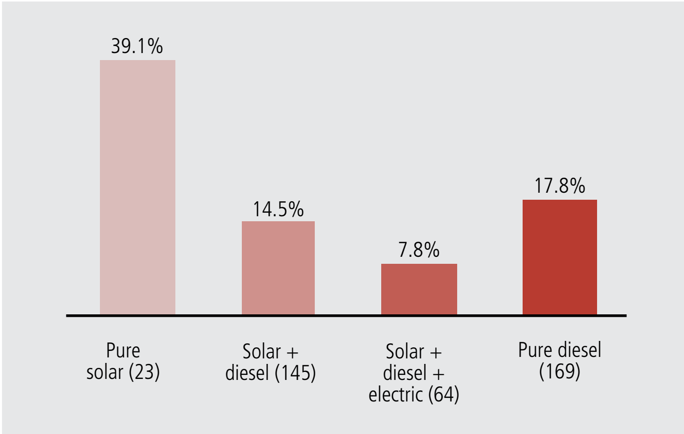
In %, UP, n=510



[41]Hours of solar and electric pumping converted to equivalent diesel hours based on the different discharge rates

FIGURE 17: Proportion of farmers growing new crops

In %, UP, 2010-17, n=401



Other impact:

- *Environmental:* SWP use has led to a decline in CO_2 emissions due to partial substitution of conventional pumps by stacked farmers. The average 1.3-hour decline in daily diesel use for most stacked farmers has led to an annual reduction of 718 kg of CO_2 emissions per farmer. Further, by reining in the increase in electric pump use for 26% of stacked users, SWPs have been responsible for a per capita reduction of 474 kg annually.
- *Household use: ~20% of farmers reported using the panels and the water from SWPs for other purposes, largely for household electrification, feeding cattle or as drinking water.* 48 farmers used the solar panel for household purposes, with 77% of them using it for electrification. 50% of the 57 farmers who reported other uses of water drawn from SWPs, used it for feeding cattle and as drinking water. Anecdotal evidence from FGDs supported these figures, with farmers mentioning that *"The water drawn from the solar pump is sweeter as compared to the handpump...as the boring is present at a greater depth" and "I use the water for household purposes. The water is then channelled to the field through a mini canal and used for irrigation."*

Main challenges:

1. *A weak after-sales service network for SWPs as compared to conventional pumps, and a long application timeline.* ~70% of solar pumps have to be taken to the installer for repair, while most conventional pumps have local repair networks. This has resulted in 12% of SWPs being unoperational for more than a month, while >95% of other pumps are repaired within a week. Further, it takes the median farmer 10-11 weeks to receive a solar pump, while electric and diesel pumps can be purchased immediately.
2. *High upfront cost per HP as compared to conventional pumps, and the rising availability of low-cost electricity are limiting adoption.* The upfront cost of SWPs per HP is six times the monthly income of an average farmers in UP, and eight times the cost of a diesel or electric pump with similar power. There has also been a 50% increase in electricity availability in the state in the past few years, and most connections are unmetered with a low fixed-monthly cost.

5.3 Rajasthan

Context:

Key characteristics of the state:	**Policy highlights:**
Farmer Population: ~6,888,000 *Chosen districts:* Jaipur, Rajsamad, Hanumangarh *Average farmer income:* Rs. 7,350 *Landholding:* Small (average size is 0.6-1.2 hectares) *Major crops:* Barley, wheat, bajra *Water situation:* 60% of farmers have water levels within 20 meters, remaining 40% have wells deeper than 20 meters	*Nodal agency:* UPNEDA, Department of Agriculture *Subsidy cover:* 75% *Type of pumps:* 2 HP *Target beneficiary:* Marginal and small farmers

Rajasthan has only ~40% of its area covered by irrigation sources. The state has attempted to expand this by encouraging electric pumping in various ways—continued electricity subsidies to protect farmers against power tariff hikes, low monthly costs for unmetered connections (0.85 paise per HP), the disbursement of a record number of electric connections through camps, and the prioritisation of marginal and small farmers in the waiting list. However, despite these efforts, the daily availability of electricity for agriculture in the state has declined by 19% from 2010-17.[42] This has positioned SWPs as a viable alternative to electric pumps in the state, a view several farmers expressed in FGDs, one of whom said, *"It is extremely difficult to get electric connections for agriculture these days. Many of those who applied for it in 2009 are still awaiting the connection. On the other hand, it is relatively easier to get a solar pump."*

Rajasthan has the highest number of sanctioned pumps in the country. The state has sanctioned 10,000 pumps, of which 4000 have been installed (as of April 2016). The SWP scheme in the state is implemented by the Directorate of Horticulture. Solar pumps of 3-5 HP are currently provided as part of the program, though an expansion to 7.5 HP and beyond is planned to compensate for the state's low water table levels. Also, implementing the technique of drip irrigation is mandatory for SWP owners possessing more than 0.5 hectares of land.

Rajasthan has also begun targeting high ROI beneficiaries by prioritizing farmers without electric connections. The state has three subsidy slabs—75% for those willing to give up their place in the queue for electric connections, 60% for farmers without an electric connection, and only the 30% MNRE subsidy for those unwilling to give up their electric connection/place in the queue.

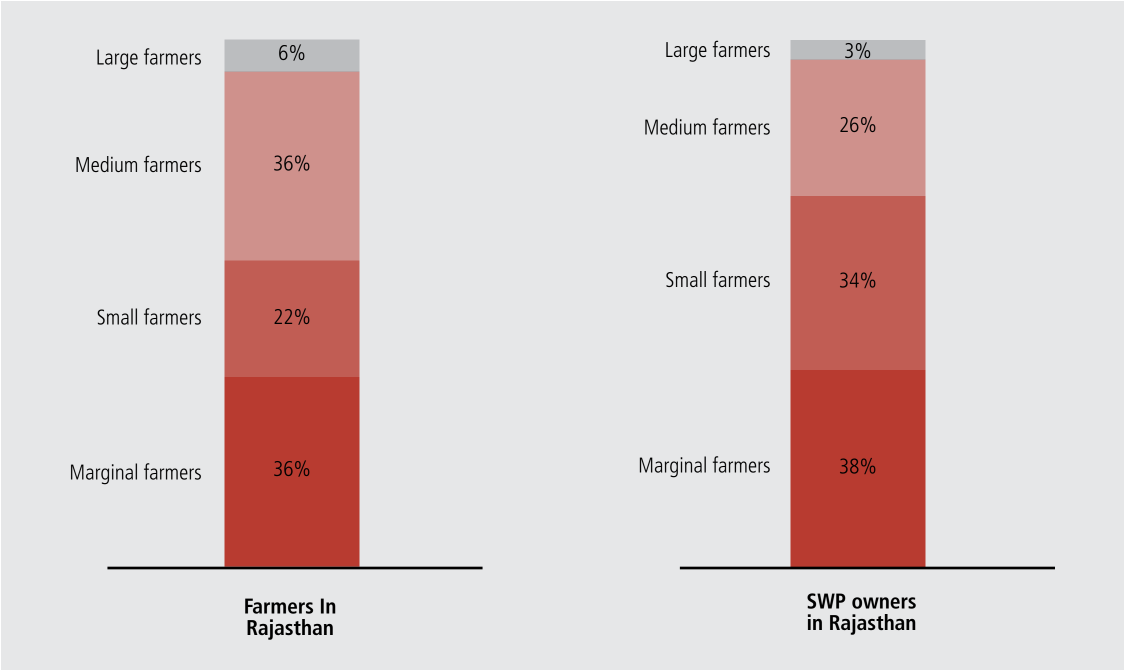
Further, marginal and small farmers have been able to successfully access the SWP policy. 72% of SWP owners in the state own less than 2 hectares of land and belong to the marginal and small categories. Considering that these two categories make up only 58% of the total population, the state's efforts to target smallholders seem to be bearing fruit.

Going forward, the state should balance the trade-off between pump sizes (irrigation potential) and cost barriers. Due to the relatively large sizes (3-5 HP vs 2 HP), the pump cost is ~33% greater than that in UP, despite the same 75% subsidy level. Also, the per HP cost of SWPs is already four times the average monthly income of a Rajasthan farmer. The planned expansion into even larger pump sizes to address the low water table levels can only be successful if the state explores financing mechanisms to ensure that marginal farmers can still afford these pumps. A farmer expressed this concern in an FGD, saying, *"The payment for the solar pump has to be made in lumpsum amounting to INR 70,000. That is why small and marginal farmers are unable to purchase the pump as they are unable to arrange the entire*

[42]According to the data from our sample

FIGURE 18: Proportion of Farmers and SWP owners across land categories[43]

In %, Rajasthan, N=6.888 million, n=260



amount in lumpsum…in terms of payment mechanism, the NABARD scheme is better as payment towards solar pumps can be made in instalments."

Recommendations:

Our findings suggest that the design and implementation of the scheme can be improved. Keeping state-specific factors in mind, we recommend the following:

Technical recommendations:

- *Pump size:* We support the state's move to expand pump sizes to 5 and 7.5 HP to address the needs of 40% of farmers having water table levels below 20 meters.
- *AC vs DC:* We recommend a shift to AC pumps to take advantage of the well-developed service networks for AC electric pumps, and to encourage the observed household use, especially for drinking water purposes—~40% of farmers reported using water drawn from SWPs as drinking water. Further, the quality issues that might arise from using locally-manufactured AC pumps instead of the imported DC pumps, can be addressed by using a price discovery supplier selection process—where the SNA conducts market research and benchmarks costs per HP—instead of the lowest bid (L1) process.

Policy recommendations:

- We recommend a greater focus on targeting marginal farmers with limited access to electricity, based on evidence that SWPs are addressing the irrigation gap due to declining electricity availability in the state, and the fact that the substitution of electric pump use by SWPs is highest for marginal farmers.
- Policymakers also need to monitor the integration of the drip irrigation scheme to ensure effective compliance, possibly by utilizing the UID scheme, as only ~11% of solar farmers have adopted the mandatory micro-irrigation technique in the state.

[43]Marginal- <1ha, Small- 1-2 ha, Medium- 2-10 ha, Large- >10 ha

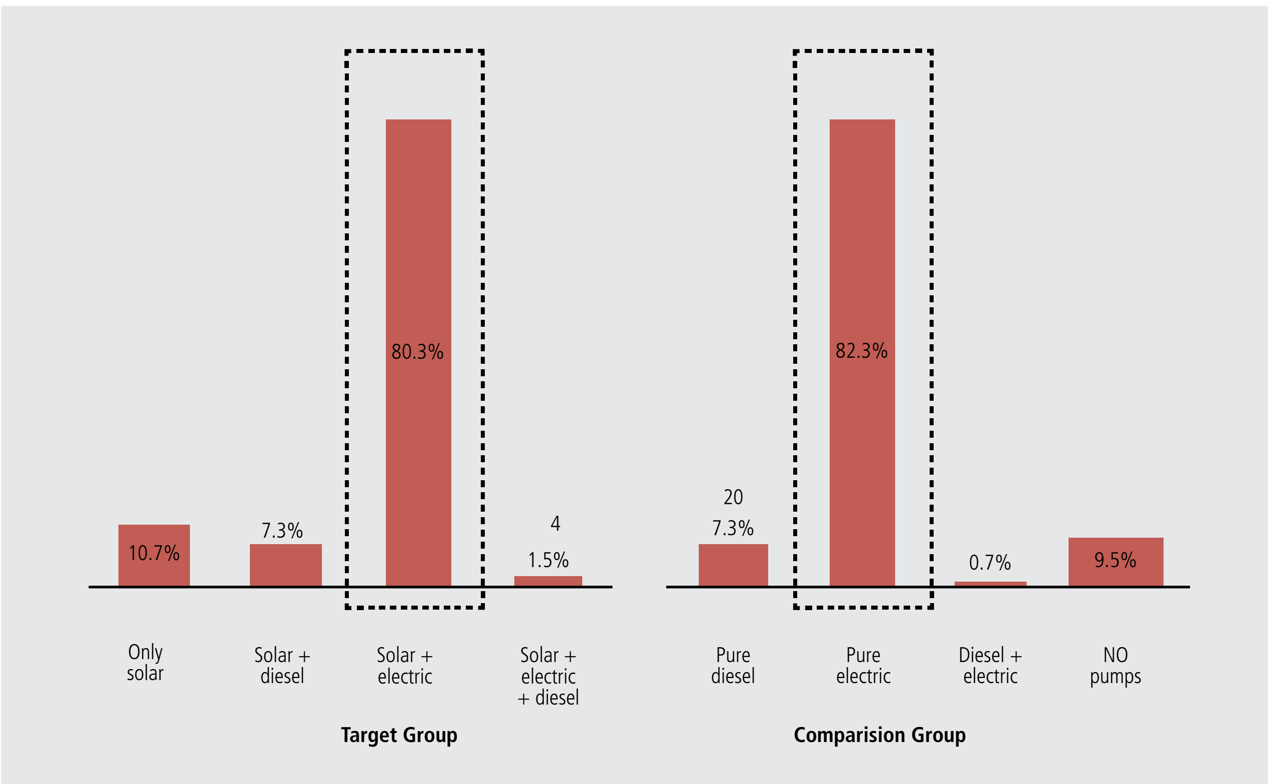
- As pump size is increased, the upfront cost must be kept in check to ensure continued access for marginal farmers. This can be done by incentivizing private lending from RRBs and MFIs using a credit guarantee mechanism that covers farmer default to a certain extent, exploring community financing models such as Joint Liability Groups and SHGs, and encouraging the establishment of pay-as-you-go systems by private vendors.
- The state can also adopt best practices such as Tamil Nadu's price discovery tendering to ensure quality, and the remote pump monitoring, data retrieval and e-corrective mechanisms, currently implemented in UP, to keep track of pump use and improve servicing.

Findings and challenges:

The emerging broader socio-economic impact facilitated by SWPs in Rajasthan has centered around the ability of SWPs to address the increasing electricity gap for stacked users, leading to reduced pressure on the state grid, a fall in carbon emissions, and improved access to drinking water.

FIGURE 19: Pumps owned by farmers

In %, Rajasthan, 2017, n_1=260, n_2=272



Economic impact: SWPs have enabled electricity unit savings by accelerating the across-the-board fall in electric pump use, driven by the declining electricity availability in the state, for the stacked target group farmers.

80% of SWP owners surveyed in Rajasthan reported combining SWPs with electric pumps. For these stacked users, daily use of electric pumps declined by 20% or 1.2 hours, as compared to the 0.5 hour decline for the control group of pure electric farmers. The across-the-board decline is being driven by the fall in the daily availability of electricity from 7.2 hours to 5.8 hours, as pointed out by a farmer in an FGD, who said, *"At this point of time, the grid electricity for agriculture comes for about 6 hours. For fifteen days I get electricity in the morning from 5 to 11 am and for 15 days it comes in the evening from 5-11 pm. Even during the 6 hours the electricity isn't available consistently."* However, SWPs have accelerated this fall for stacked users by being used as a viable alternative to electric pumps, especially since the average SWP user receives electricity for 0.34 fewer hours a day than an average pure electric user.

FIGURE 20: Average daily use of electric pumps

In hours, Rajasthan, n=407

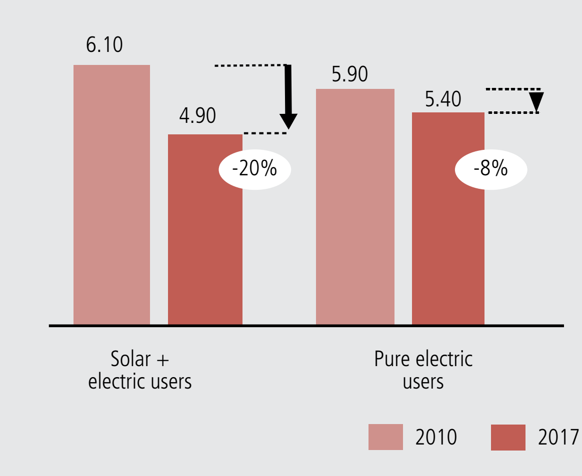
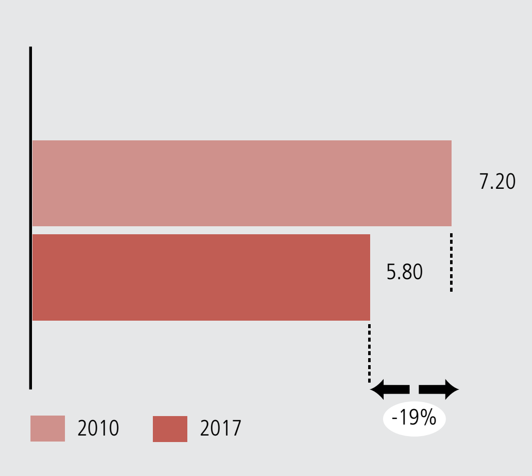


FIGURE 21: Availability of electricity for agriculture in a day

In hours, Rajasthan, n=452

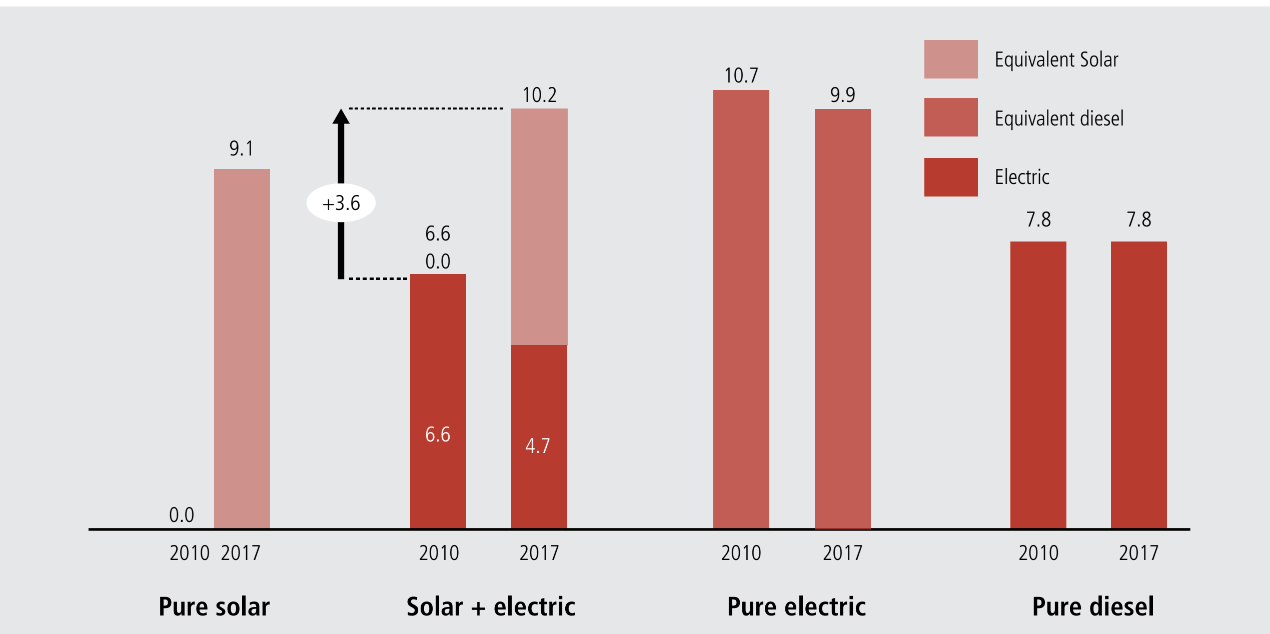


This substitution of electric pump use has led to annual savings of 2,684 units per farmer. The impact on cost savings is unclear as unmetered, fixed-cost connections are common, as discussed in an FGD, where a farmer mentioned. *"My electricity bill has not changed as I have to pay a fixed amount once in two months."* Nevertheless, the unit savings can reduce pressure on the state electricity grid if the SWP policy achieves greater scale.

Agricultural impact: The increase in irrigation pumping by stacked users has not resulted in an increase in irrigated area or productivity benefits for the major crops, and only a small sample of pure solar users have displayed higher diversification gains than the control group.

FIGURE 22: Change in average daily use of pumps (electric-equivalent[44], land size-adjusted)

In hours, Rajasthan, n=481



[44]Hours of solar and diesel pumping converted to equivalent electric hours based on the different discharge rates

Despite the 3.6 hour increase in irrigation by stacked users as compared to their baseline, there has been no corresponding increase in irrigated area or crop productivity for the major crops. Wheat, barley and bajra make up 60% of crops sown, and farmers growing these have seen no significant area or productivity gains. Further, diversification gains higher than the control group have been displayed by only a small sample of pure solar farmers, possibly due to a lower baseline, and primarily into vegetables. According to a farmer in the Jaipur district, *"We have to water the vegetables every second day unlike many other crops. Solar pump gives continuous water so many farmers in my village have started growing vegetables after they started using solar pumps."*

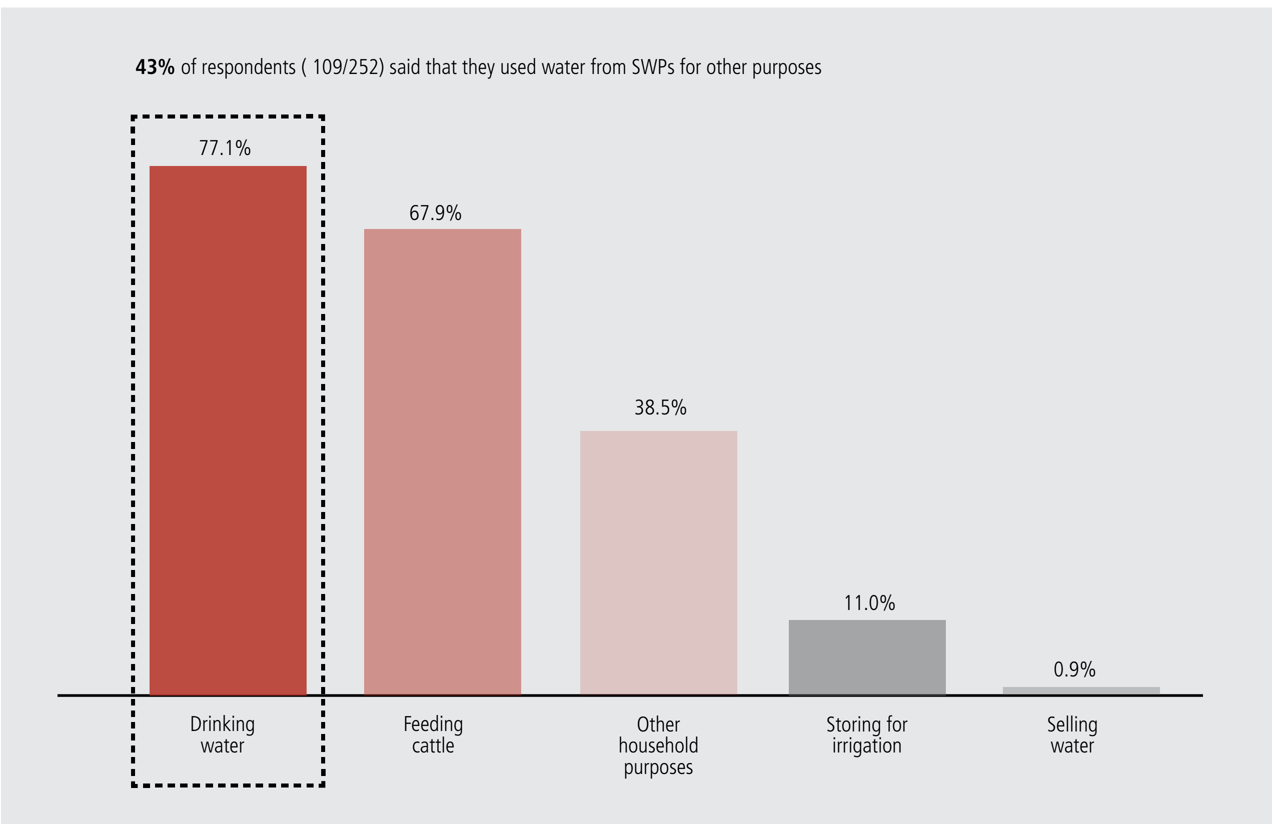
One driver of the low agricultural impact could be the fact that despite the use of drip irrigation being mandatory for SWP farmers, only 11.5% (30/260) farmers reported having implemented the drip system. Monitoring the integration of the scheme is essential to ensure that agricultural benefits are being maximised.

Other impact:

- ***Environmental:*** *SWP use has led to a decline in CO_2 emissions due to partial substitution of electric pump use by stacked farmers.* The fall of 2,684 units in annual electricity consumption per stacked farmer has led to a reduction of 1,454 kg in CO_2 emissions per farmer. While these figures represent a moderate reduction, by improving adoption and ease of use, the state can achieve significant environmental benefits.
- ***Household usel:*** A substantial proportion of farmers are using solar pumps to improve access to drinking water. 43% of solar users reported using water drawn from SWPs for other purposes, of which 77% used it as drinking water. Farmers seemed to prefer the reliability of SWPs for this task, with one farmer reporting that, *"in case of electric pumps, we have to wait for the electricity supply while in case of solar pumps, I can extract fresh drinking water anytime of the day."*

FIGURE 23: "For what purpose did you use water from solar pumps?"

In %, Rajasthan, 2017, n=109 (multiple response)



Main challenges:

1. **Trade-off between pump sizes (irrigation potential) and cost barriers.** The state is looking to expand into larger pump sizes given the low and declining water tables in the state, and will have to explore financing mechanisms to ensure that marginal farmers can still afford these pumps. 40% of farmers have water table levels below 20 meters and require pumps larger than the current 3-5 HP. However, the per HP cost of SWPs is already four times the average monthly income of a Rajasthan farmer.

2. **Lack of monitoring of integration of allied policies such as drip irrigation.** Despite the use of drip irrigation being mandatory for SWP farmers, only 11.5% (30/260) farmers reported having implemented the drip system. Monitoring the integration of the scheme is essential to ensure that agricultural benefits are being maximised.

3. **Targeting beneficiaries for whom SWPs are a viable alternative to electric pumps.** Most solar pump beneficiaries from 2013-2015 had electric pumps, or received electric connections at the same time. Since both the upfront cost of electric pumps and the electricity costs in the state are low, only farmers suffering from electricity shortages have utilised SWPs. The five-year ownership cost (per HP) of SWPs turns out to be twice as much as that of electric pumps.

5.4 Tamil Nadu

Context:

Key characteristics of the state:

Farmer Population: ~8,118,000
Chosen districts: Coimbatore, Theni, Erode
Average farmer income: Rs. 6,980
Landholding: Large (average size is 2-2.5 hectares)
Major crops: Banana, coconut, bajra, onion
Water sit*uation:* 98% of farmers have water levels within 20 meters

Policy highlights:

Nodal agency: Tamil Nadu Energy Development Agency (TEDA), Agriculture Engineering Department
Subsidy cover: 80%, moving to 90%
Type of pumps: 5 HP, expanding to 7.5, 10 HP
Target beneficiary: Off-grid farmers, farmers willing to give up electric connections (or applications)

Tamil Nadu is an energy rich state, with annual surplus of power. Since 2016, the state has been supplying free electricity to farmers up to 100 units for every two months. The state has high coverage of irrigation, with 55.7%[45] of its net sown area under irrigation, with the remaining area dependent on rainfall, and prone to droughts. There are two supporting rationale for expanding the solar pumping program – first, the waiting list for electric connections in the state has a backlog extending up to several years, and for those with connections, electricity supply remains intermittent, thereby limiting pump irrigation.

In Tamil Nadu, the SWP policy is implemented by the Tamil Nadu Energy Development Agency (TEDA) and the Agriculture Engineering Department. The farmers covered in the study received 5 HP pumps with 80% subsidy (50% state subsidy + 30% MNRE subsidy). However, now the state has expanded pump sizes to include 7.5 and 10 HP pumps, with a total subsidy of 90% (40% state + 20% MNRE + 30% Tamil Nadu Generation and Distribution Corporation). The state is also looking to shift to a price discovery supplier selection process, involving market research by the SNA to benchmark costs

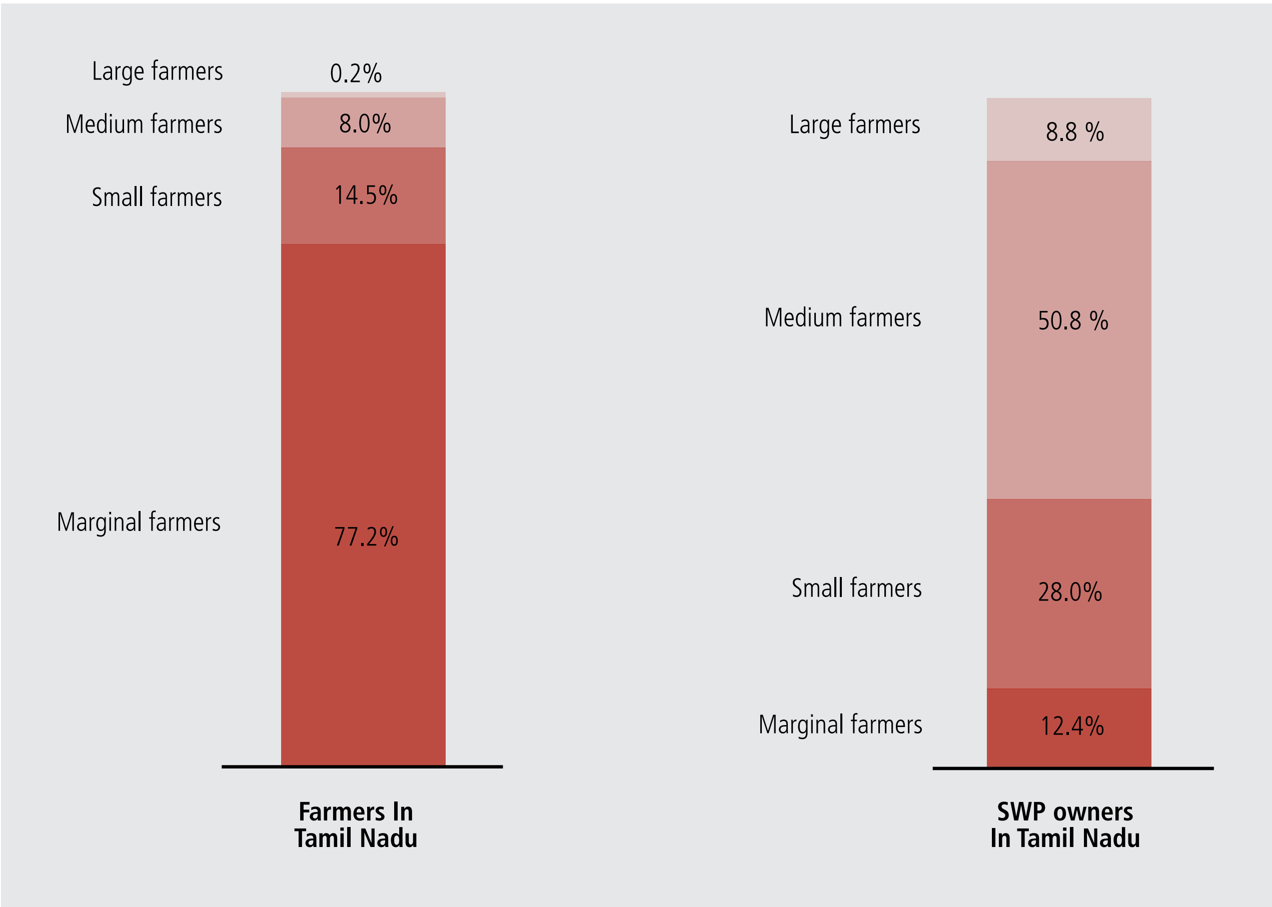
[45]As of 2005-06, Department of Economics and Statistics, Government of Tamil Nadu

to market values for a given pump size or type, to improve pump quality, as the current lowest bid (L1) tendering process induces suppliers to sacrifice quality to lower costs.

Tamil Nadu has a high installation rate, and well-targeted eligibility criteria. Out of the 5,150 sanctioned pumps, 2,669 have been installed (as of April 2016)—the ~52% installation rate is one of the highest in the country. The eligibility criteria prioritises farmers without, or those willing to give up, electric connections, to maximise SWP impact. Despite the eligibility criteria, medium farmers form the majority of SWP owners, while marginal farmers are underrepresented. The 8% medium farmers in the state make up 50% of SWP owners, while the 77% farmers classified as marginal own only 12% of the solar pumps.

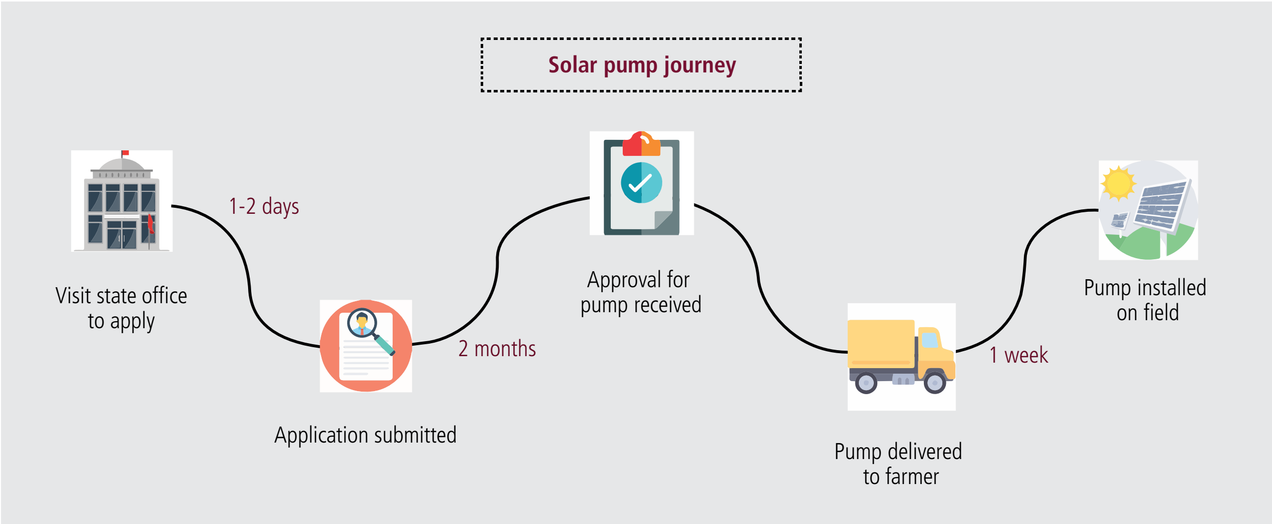
FIGURE 24: State farmer population and SWP owners classified according to land size categories

In %, Tamil Nadu, 2017, N=8,118,000, n=250



The lengthy application approval time in Tamil Nadu is deterring adoption. The journey from deciding to apply for a solar pump to being able to use it on the field takes 14 weeks for the median Tamil Nadu farmer, which is almost a month more than in other states. This delay is largely because the 2 months taken for pump applications to be approved is twice as long as the time taken by other states. On the other hand, electric pumps can be purchased immediately. Anecdotal evidence indicates an even longer solar journey, with one FGD participant stating, *"It (electric pump) is also easily available in the market unlike solar for which we have to wait for about 4-5 months."*

FIGURE 25: Solar pump journey for the median farmer in Tamil Nadu



Recommendations:

Our findings suggest that the design and implementation of the scheme can be improved. Keeping state-specific factors in mind, we recommend the following:

Technical recommendations:

- *Pump size:* We support the expansion of pumps sizes to 7.5 and 10 HP from the current 5 HP size to provide adequate irrigation capacity for the average Tamil Nadu farmer, who has more than 2 hectares of land. A farmer in Coimbatore supported this conclusion, saying that *"Most of us here have about 10 acres of land which are present in more than 1 plots of land. It becomes important to use more than 1 motor pump for irrigation."*
- *AC vs DC:* We recommend a shift to AC pumps to take advantage of the well-developed service networks for AC electric pumps, to encourage household use and to take advantage of the well-developed service networks for AC electric pumps. Pump quality will be ensured by the price discovery tendering process that the state is planning to implement—where the SNA conducts market research and benchmarks costs per HP—in place of the present lowest bid (L1) process.

Policy recommendations:

- We support the state's efforts to target farmers who are either off-grid or have limited access to electricity, as they can benefit most from SWP use. Farmers supported this view in FGDs, mentioning that *"Solar pumps can be most useful for farmers who do not have grid connection for agriculture…"*, and *"We have erratic power cut in the day time followed by cuts in the night time. We are willing to buy solar pumps as we can use the pump in times of such power cuts."* However, the targeting efforts need to be monitored effectively, as ~80% of solar farmers in the state have currently stacked SWPs onto electric pumps instead of using them as replacements.
- Further, integrating the scheme more effectively with the 100% subsidised micro-irrigation infrastructure scheme under PMKSY by the Agricultural Engineering Department can maximise agriculture impact. Also, combining the policy with TEDA's awareness programmes, such as the mobile exhibition van displaying techniques to use renewable energy products, can help build farmer capacity and scale adoption.
- As pump size is increased, the upfront cost can be kept in check by incentivizing private lending from RRBs and MFIs using a credit guarantee mechanism that covers farmer default to a certain extent,

exploring community financing models such as Joint Liability Groups and SHGs, and encouraging the establishment of pay-as-you-go systems by private vendors.

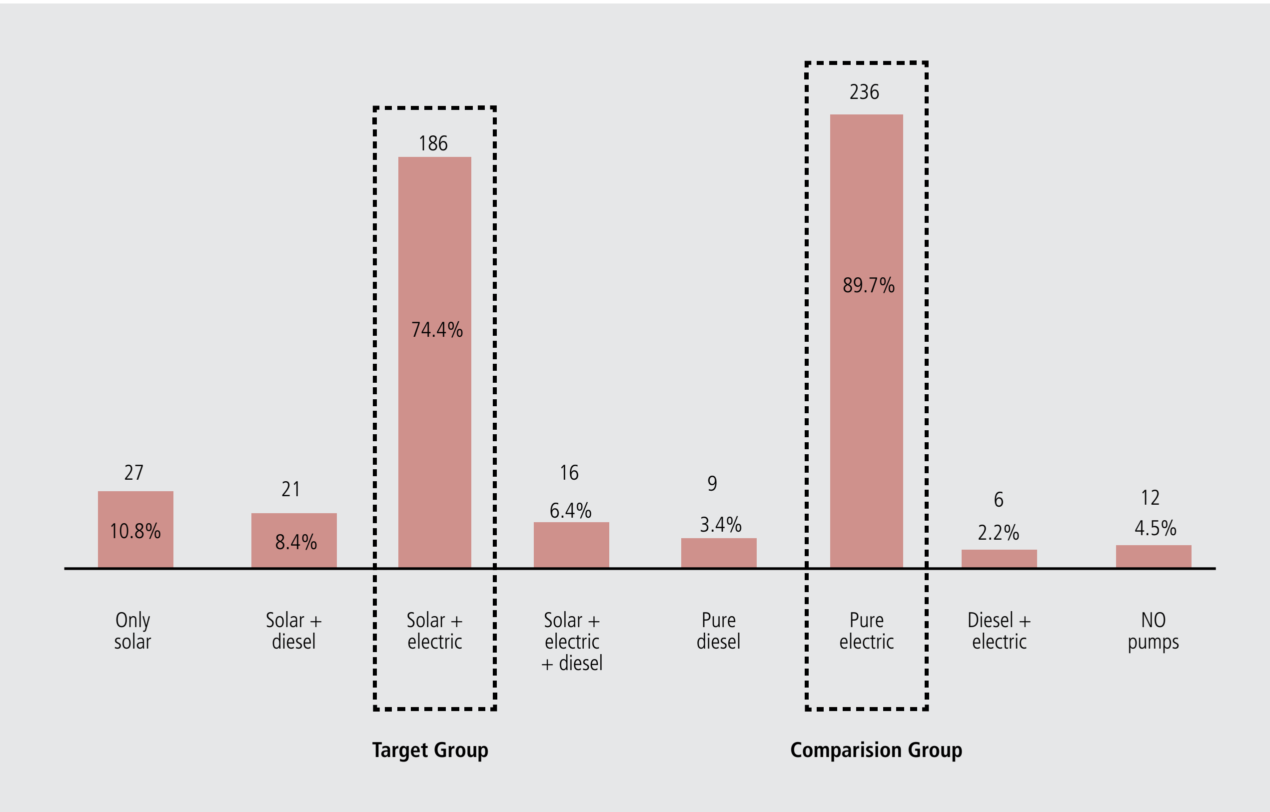
- The state can also adopt best practices such as remote pump monitoring, data retrieval and e-corrective mechanisms, currently implemented in UP, to keep track of pump use and improve servicing.

Findings and challenges:

There have been some emerging signs of broader impact in the state, but it remains low at this stage, largely because, as in the other states, SWP farmers have stacked solar pumps onto electric pumps instead or replacing them.

FIGURE 26: Pumps owned by farmers

In %, Tamil Nadu, 2017, n1=250, n2=263



Economic impact: *There has been limited economic impact of solar pumps in the state.*

~75% of farmers have stacked SWPs onto electric pumps. These stacked users own more land and are suing SWPs to complement, rather than substitute, electric pump use. The land-size adjusted irrigation use data indicates that stacked users are pumping ~40% more every day and across a month, supporting the hypotheses of complementary use by large stacked farmers, who own 1 hectare more than pure electric farmers on average.

The lack of substitution is driven by the increased electricity availability and the highly subsidised unit costs. A ~40% increase in state electricity availability and minimal fixed monthly power costs have led to a slight increase in electric pump use for both groups, and prevented substitution by SWPs. The preference for electric pumps was confirmed by an FGD participant, who said *"Electric pumps have many comparative advantages over solar pumps. The electricity is free, the after sales services are better, pump cost is low. In addition, free electricity is available in all seasons unlike solar pumps which work only during sunlight."*

FIGURE 27: Daily availability of electricity for agriculture

In hours, Tamil Nadu, n=413

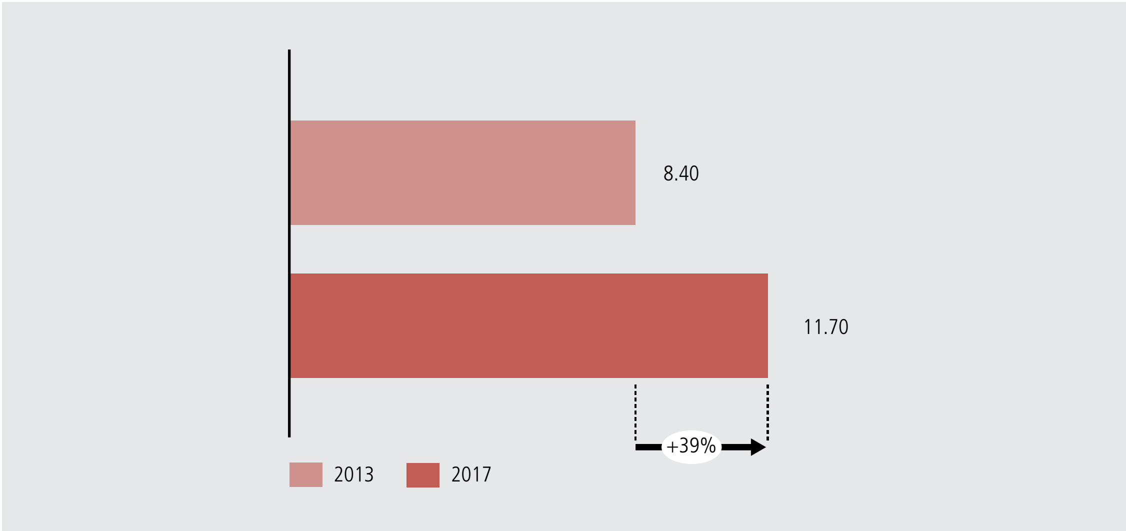
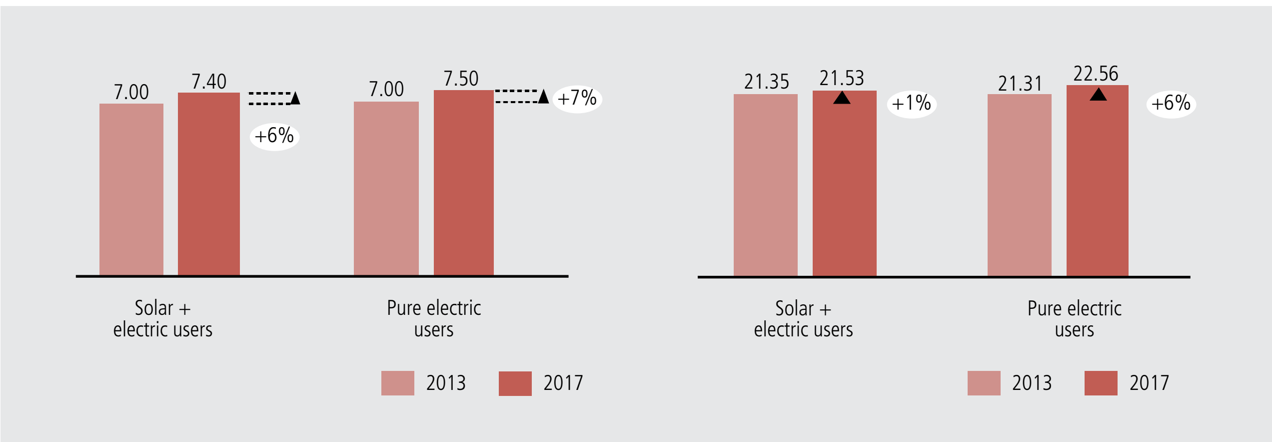


FIGURE 28: Average daily and monthly use of electric pumps

In hours, days, Tamil Nadu, n1=388, n2=393



Since only a very small proportion of farmers in the state use diesel pumps, both the current and potential impact of diesel pump displacement is limited. 27 farmers who use both solar and diesel pumps reported a 1.3 hour relative decline in daily diesel pump use, saving ~Rs 15,000 each annually.

Agricultural impact: The increase in irrigation pumping by large, stacked users has not translated into an increase in irrigated area or productivity benefits for the major crops, and, similar to Rajasthan, only a small sample of pure solar users have displayed higher diversification gains than the control group.

Stacked users are pumping for ~3 more electric-equivalent hours per day than the baseline figure. However, the additional irrigation has not led to an increase in irrigated area or crop productivity for farmers growing the major crops of banana, coconut and bajra, which constitute 50% of total sown area. Only a small sample of pure solar farmers reported high diversification gains, with 63% reporting planting new crops, possibly due to a lower baseline in the absence of previous pump ownership. On the other hand, stacked solar and electric farmers, who form the majority of the target group, reported diversification gains of 30%, similar to the control group of pure electric pump users.

FIGURE 29: Change in average daily use of pumps (electric-equivalent, land size-adjusted)

In hours, Tamil Nadu, n=470

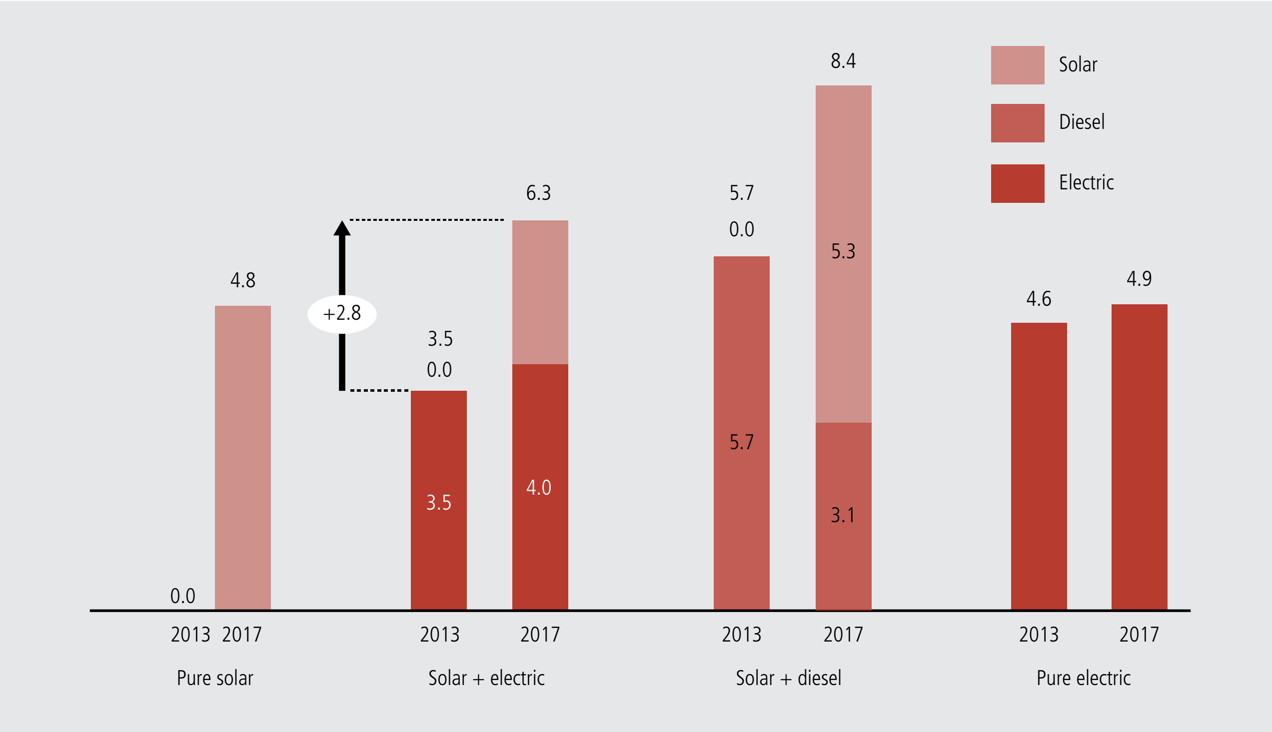
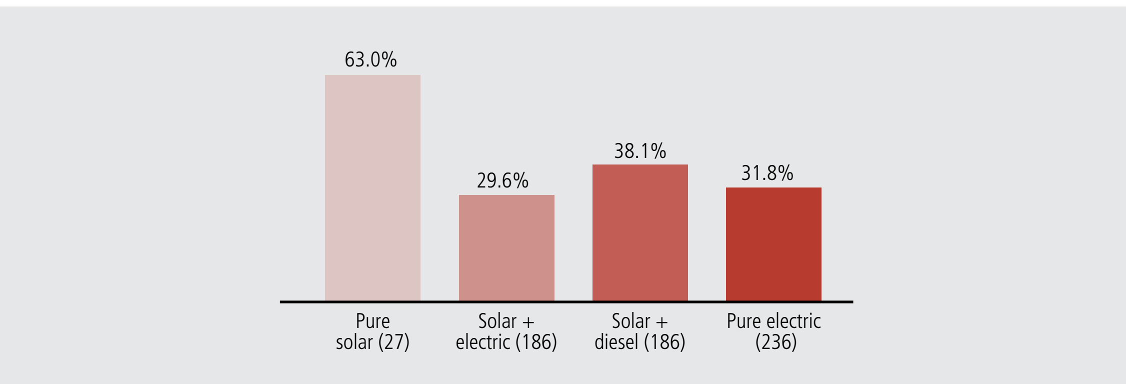


FIGURE 30: Proportion of farmers growing new crops

In %, Tamil Nadu, 2013-17, n=470



Other impact:

- ***Environmental:*** *A small sample of 21 solar + diesel farmers reported substituting diesel pump use by SWPs, leading to a decline in CO_2 emissions.* The 1.3 hour relative decline in diesel pump use by stacked users as compared to pure diesel users led to a reduction of 718 kg in annual CO_2 emissions per farmer. Given the small fraction of farmers using diesel pumps in the state, in the future, environmental benefits can only be attained by SWPs displacing electric pump use.

- ***Household use:*** *Beyond the farm, ~18% of SWP farmers are using the pumps to provide drinking water, but household electrification is limited.* Of the 18.7% of farmers who used water drawn from SWPs for other purposes, ~98% reported having used it as drinking water.

Main challenges:

1. **Monitoring of beneficiaries.** According to our field research 75% of solar pump users had electric pumps, and by that measure, electric connections as well. Given that the state policy prioritizes farmers with no electric connection, this indicates loopholes in the application screening process.
2. **Long application timelines that deter adoption.** The journey from deciding to apply for a solar pump to being able to use it on the field takes 14 weeks for the median Tamil Nadu farmer, which is almost a month more than in other states. This delay is largely because the 2 months taken for pump applications to be approved is twice as long as the time taken by other states.

6

Annexure

1. Input indicators

Indicator Domain	Indicator
Economic	• Income bracket (range) • HH expenditure categories and % of income allocated to each • Education status
Agriculture	• Land ownership status • Pump type, size, and age • Number of hours of pump operation • Daily water need for irrigation • Depth of water • Integration with other drip/sprinkler/filter systems • Total irrigated and non-irrigated land • Irrigation method and technology • Crop types by season
Environmental	• Type of soil/Depth of bed rock • Agro-climactic zone
Gender	• No of women engaged in farming in HH

2. Impact indicators

*Note: Prioritization was guided by the questions “what are the data points that are essential to understanding the direct impacts of a solar water pump (scored H or M)?” and “what are the data points that we would like to gather, but may not be possible, that may reveal indirect impacts of solar water pumps (rated L)?”

Indicator Domain	Hypothesis	Indicators	Research method	Stakeholder
Economic	SWPs lead to an increase in farmer income	Change in proportion of agricultural produce being sold after use of SWP	Structured interview schedule	Farmers owning SWPs who use for agriculture or farmers using SWPs on a rented model
		Change in cash income from agricultural activities after use of SWP	Structured interview schedule	
		Change in agricultural energy costs after use of SWP	Structured interview schedule	
		Proportion of SWP users with increased income	Structured interview schedule	
		Change in pump maintenance costs after use of SWP	Structured interview schedule	
	SWP value-chains create local jobs	Individuals employed as SWP operators	Village PRA exercise	Individuals engaged as trainers/pump operators/pump owners
		Individuals employed with SWP distributors	Village PRA exercise	
		Individuals engaged as SWP trainers	Village PRA exercise	
	SWP value-chains help local entrepreneurs and labourers diversify sources of income	Cash income from engagement as trainers	Unstructured Interview schedules with trainers	
		Cash income from engagement as SWP operators	Unstructured Interview schedules with operators	
		Change in cash income from renting/leasing out irrigation pumps after use of SWP	Unstructured Interview schedules with SWP owners	
		Cash income from other income generating avenues for owners because of SWP	Unstructured Interview schedules with owners	
		Cash income from irrigation distribution network by SWP owners	Unstructured Interview schedules with owners	
		Change in income from irrigation distribution network by pump owners who have converted to SWP from diesel/electric pumps	Unstructured Interview schedules with owners	
Agriculture	SWPs help increase net irrigated area	Change in land area under irrigation after use of SWP	Structured interview schedule	
	New irrigated area helps diversify crops	Change in number of crops cultivated per cropping season after use of SWP	Structured interview schedule	
	Increased quantity and quality of irrigation helps increase productivity	Change in number of crops cultivated per cropping season after use of SWP	Structured interview schedule	
		Change in proportion of land area under cultivation after use of SWP	Structured interview schedule	

Indicator Domain	Hypothesis	Indicators	Research method	Stakeholder
		Change in proportion of Crop wise cultivated land area after SWP	Structured interview schedule	
Environmental	SWPs lead to over extraction of ground water	Change in crop wise production after SWP per cropping cycle	Structured interview schedule	
		Water table depth across intervention and comparison areas	Secondary data	
		Change in hours of water pumping before and after use of SWP		
	SWPs reduce carbon footprint for irrigation	Change in diesel consumed for irrigation after use of SWP	Structured interview schedule	Farmers owning SWPs who use for agriculture or farmers using SWPs on a rented model
		Change in electricity consumed for irrigation after use of SWP	Structured interview schedule	
	SWPs reduce air and soil pollution	Perception on reduction of pollution air and soil pollution due to use of SWP	Community discussion tool	
Health	Lower pollution levels reduce incidence of respiratory illnesses	Change in incidence of respiratory ailments after use of SWP	Community discussion tool	Farmers owning SWPs who use for agriculture or farmers using SWPs on a rented model
	SWPs improve access to potable water	Ease in accessing clean drinking water before and after use of SWP	Community discussion tool	
		Change in incidence of water borne diseases after use of SWP	Community discussion tool	
Gender	SWPs reduce drudgery of women in agriculture	Change in time taken by women to collect water after use of SWP	Structured interview schedule	
		Change in distance covered by women to collect water after use of SWP	Structured interview schedule	
		Change in proportion of daily time spent on irrigation after use of SWP	Structured interview schedule	
	SWPs help improve time utilisation by women	Change in time spent by women in different daily activities by women after use of SWP	Structured interview schedule	

3. User experience indicators

Impact Domain	Key Indicator	Sub-indicators	Stakeholder
User Experience	Awareness	Awareness about SWPs	Farmers owning SWPs who use for agriculture or farmers using SWPs on a rented model
		Awareness about SWP distribution scheme	
		Sources of awareness	
	Access: Affordability	Ability to afford the pump after subsidy	
		Ease of availing credit from the bank/other financial institutions to purchase the SWPs vis-à-vis electric/diesel pumps	
		Transportation cost incurred to get the diesel pumps/ solar pumps to the agricultural site	
		Incentives provided by the SWP distributor/supplier vis-à-vis diesel/electric pumps	
		Type of purchase - collective, individual	
	Access: Availability	First point of contact for purchase	
		Waiting period for receiving SWPs	
		Convenience -Location of their manufacturer/distributor	
	Usage: Adaptability/ Adoption	Ease of operations of SWP vis-à-vis diesel/electric/treadle pumps	
		Availability of training services	
		Other alternate uses of the pump - lighting, TV, mobile charging	
	Availability of after-sales services	Access to the after-sales services for SWP vis-à-vis diesel/ electric pumps	
		Average cost of pump maintenance and repair services	
		Awareness about after sales service points for SWP vis-à-vis diesel/electric pumps	
		Frequency of after-sales services required for SWP vis-à-vis diesel/electric pumps	
		Turn-around time for complaint redressal for SWP vis-à-vis diesel/electric pumps	
		Irrigation efficiency of SWPs vis-à-vis diesel/electric/ treadle pumps	
		Perception of quality of SWP vis-à-vis diesel/electric/ treadle pumps	
	Preferences	Value positioning of SWPs vis-à-vis diesel/electric/treadle pumps	
		Willingness to pay for SWPs even after the grid system improves	
	Knowledge	Awareness of the benefits of solar pumps across - yield enhancement, fuel savings	
		Awareness of the scheme subsidy benefits/incentives	
		Sale of the owned solar pumps for immediate profit-making	

4. Resources used to develop framework/ hypotheses

Stakeholders covered through mixed-methods research methods in the study

Name	Organization	Designation
Sh. G Prasad	MNRE	Chief Scientist
Nitin Pandit	Water Resources Institute	Managing Director
Dr. Nirmalya Choudhury	TISS – Centre for Water Policy	Assistant Professor
Abhishek Jain	CEEW	Senior Programme Lead
Hari Natrajan	CLEAN Energy Access Network	CEO
Dr. Manoj Khanna	ICAR – Farm Operation Services unit	Principal Scientist
Shilp Verma	IWMI	Consulting Research
Nilanjan Ghose	GIZ	Head of SWP program
Nidhi Tiwari	Ex-IWMI	Researcher
Kartik Wahi	Claro	Co-founder
Mr. S. N. Gupta	Kirloskar Ltd.	Zonal Manager
K. C. Soni	Rajasthan Renewable Energy Development Corporation	Program Manager
Ms. Shanti	Department of Agricultural Engineering, Tamil Nadu	Program Manager
Mr. Manish Jadhav	BREDA	Program Manager
Mr. Srivastava	UP NEDA	Program Manager
Mr. Sunil Narula	Tata Power Solar Systems	Head of Sales & Marketing
Mr. Vinod Patil	Jain Irrigation Systems	Sales Engineer

List of literature and policy documents reviewed for the study

Document	Source
Jawaharlal Nehru National Solar Mission Phase II – Policy Document	MNRE
Solar Pumps for Sustainable irrigation	CEEW Policy brief
Guidelines For Capital Subsidy Scheme Of Government Of India For Promoting Solar Photovoltaic (SPV) Water Pumping Systems For Irrigation Purpose	MNRE
Implementation Framework for Solar Agriculture Pump Programme	KPMG (commissioned by Shakti Sustainable Energy Foundation)
Solar Water Pumping for Irrigation	GIZ
Co-Management of Electricity and Groundwater: An Assessment of Gujarat's Jyotirgram Scheme	IWMI
Feasibility analysis of agricultural water pumps in India	KPMG (commissioned by Shakti Sustainable Energy Foundation)
Operational guidelines for solar water pumping programme	NABARD
Energy irrigation nexus in South Asia	IWMI
Priming SWPs	AIREC
Rajasthan Solar Water Pump Programme: Sustainable future for farmers	Dinesh Goyal
Solar Pumping for Irrigation	IRENA

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