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Adopting Solar for Irrigation

Farmers' Perspectives from Uttar Pradesh

ABHISHEK JAIN AND TAUSEEF SHAHIDI


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List of Abbreviations

FGD	Focus Group Discussion
HP	Horsepower
INR	Indian Rupee
KCC	Kisan Credit Card
MNRE	Ministry of New and Renewable Energy
MoAFW	Ministry of Agriculture and Farmers' Welfare
MoWR	Ministry of Water Resources, River Development & Ganga Rejuvenation
MPCE	Monthly Per Capita Expenditure
NABARD	National Bank for Agriculture and Rural Development
SPIS	Solar-Powered Irrigation System
UP	Uttar Pradesh
WTP	Willingness-to-pay

x

Executive Summary

More than 50 per cent of all livelihoods in India depend on agriculture. Access to reliable and affordable irrigation is one of the most important enablers to increase agricultural productivity and incomes for farmers. Irrigation in the country predominantly depends on groundwater pumped through 19 million electric, and about 9 million diesel pumps. Despite such high numbers of pumps, 53 per cent of the net-sown area in the country remains unirrigated. Moreover, access to irrigation among the 132 million Indian farmers remains inequitable, across size-groups, and geographies.

Against such a backdrop, solar pumps are emerging as an alternative to conventional pumps, filling in gaps of unreliable supply to electric pumps, and high fuel costs in running diesel pumps. The central and state governments are providing significant subsidies to promote the adoption of solar pumps for irrigation. But a majority of these programmes reflect a top-down, supply-side push with limited consideration of farmers' perspectives. Against a target of 1 million pumps by 2021, India has deployed 142,000 pumps till November 2017. While the high capital cost of technology is the biggest barrier to its adoption, limited consideration of farmers' perspectives on solar pumps is also one of the key reasons for their limited uptake under government programmes.

Research, so far, on solar pumps has focused on their sustainable deployment, their economic viability, budget-neutral promotional approaches for governments to consider, and analysing different models to deploy them. But, documented evidence of farmers' perspectives on solar pumps, and understanding the barriers that prevent them from adopting solar for irrigation remains limited.

The report attempts to bridge the knowledge gap through the analysis of 1600 farmers' interviews, and 10 focused group discussions with farmers. The study is focused on Uttar Pradesh, the state with the largest population of farmers in the country. It focuses on understanding farmers' perspectives on farming constraints, their expenditure on, and satisfaction with their irrigation arrangements, and their views on investment in


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farming and its financing. The study particularly focused on farmers' awareness of solar pumps, their interest in adopting them under different deployment models, and their willingness-to-pay to own a solar pump. Based on quantitative survey approaches, and qualitative research through focused groups discussions, the major findings are as follows.

Major findings

- Access to reliable and affordable irrigation remains a challenge. **Fifty-five per cent of the farmers surveyed mention insufficient irrigation as the biggest bottleneck to increasing incomes from farming.** Moreover, 30 per cent of the farmers also reported limited water availability for irrigation as a challenge.
- Farmers observe a perceptible change in climate over the year. **As many as 92 per cent of them mentioned that the summers were becoming warmers over the years.** At the FGDs, they agreed that the need for irrigation is increasing to adapt to the changing climate manifested through warmer summers and decreasing rainfall.
- **Sixty per cent of marginal farmers depend on buying water, the costliest option for irrigation, or renting pumps to meet their needs.** While the estimate for the number of irrigation diesel pumps in the country varies from six to nine million, as many as 30 million farmers reported using them for irrigation, as of 2012. This indicates a high degree of sharing of diesel pumps.
- Borewell ownership is skewed towards large and medium farmers and decreases with decreasing size group. **Only 41 per cent of marginal farmers reported owning a borewell as compared to 95 per cent of large farmers.** Current government policies promoting solar pumps are not sensitive to the skewed access to borewells.
- **Renting of farm equipment - including pumps - is a common practice among farmers that has increased farmers' access to technology.** We found that while only 14 per cent of farmers owned a tractor, almost 99 per cent of them reported using one. **We also found that the existing owners of farm machines, typically medium and large farmers, are more likely to invest in newer technology in the future to be able to rent them out.**
- **While 86 per cent of farmers reported having irrigation access on all sections of their land, only 51 per cent of them were satisfied with their current irrigation situation.** Depleting water tables, and high expenditures on diesel were two major reasons behind farmers' dissatisfaction. This was further exhibited through a higher dissatisfaction level (30 per cent) among diesel pump users than among electric pump users (20 per cent). Those dissatisfied with their current irrigation arrangement had 26 per cent higher odds of adopting solar pumps than those satisfied.
- Awareness of solar pumps is abysmally low among farmers. **Only 27 per cent of farmers have heard of SPIS, 14 per cent of them have seen solar pumps in reality or on television, and only 2 per cent of them have heard about the government schemes on solar pumps.** We found that farmers' perception of the successful operation of a solar pump increased with actual demonstrations of its use. Further, **a farmer who had seen a solar pump in action and had positive views about its successful operation had double the odds of adopting a solar pump, compared to a farmer who was not aware of them.**
- **About 41 per cent of farmers were interested in adopting solar pumps.** Zero operational cost and convenience of use were the main reasons behind farmers' interest in adopting solar pumps. Whereas, high capital cost was the main reason behind those not interested in adopting one.
- Our regression analysis revealed that the strongest determinants for the adoption of solar pumps were the practice of agriculture as a primary source of income, farmers' future investment plans for renting out farm machinery, and their awareness and views on SPIS.

- **The willingness-to-pay (WTP) for solar pumps was quite low compared to conventional pumps, and on average varied from 12 to 30 per cent (varying with the size of the pump) of the market price.** Small and marginal farmers showed lower WTP than large and medium farmers. To purchase solar pumps, their own savings, and credit from banks were the two main sources of finance available to farmers.
- **About 20 per cent of farmers - 39 per cent of the potential adopters - were interested in the joint ownership model of solar pumps.** About 4 per cent of farmers, who are otherwise not interested in adopting solar pumps, would be willing to adopt one under this model. Compared to large and medium farmers, a higher proportion of small and marginal farmers were interested in opting for the joint ownership model.
- **About 80 per cent of farmers were willing to buy water directly from a solar pump run by a private entrepreneur, provided the price was competitive to prevailing local water market prices.** Owners of electric pumps were least likely to adopt the water-as-a-service model.
- Awareness of efficient irrigation practices and micro-irrigation was very low. **None of the farmers surveyed were using drip or sprinkler irrigation, less than a quarter had heard about them, and only seven per cent farmers were willing to adopt either practice.**

Key policy recommendations

1. **Focus on awareness generation and technology demonstration.** Deploy at least five solar pumps in each block of the country, prioritising regions with better groundwater availability, to enable demonstration effect to yield bottom-up demand. Ministry of New and Renewable Energy should consider engaging with channels already reaching out to farmers, such as the Ministry of Agriculture and its extension services, bank correspondents, and agricultural assistants for awareness generation.
2. **Improve targeting of prevailing government support schemes on solar pumps.** Focus on marginal farmers by promoting smaller (sub-HP to 3HP) solar pumps through capital subsidy. For larger pumps, focus on strengthening the financial ecosystem rather than offering capital subsidy support, which mainly benefits medium and large farmers.
3. **Encourage innovative deployment approaches** such as solar-powered water-as-a-service model, and the joint-ownership model to cater to marginal farmers, who otherwise are not interested to own solar pumps due to high upfront cost, and limited irrigation needs.
4. It is important to consider the pattern of borewell ownership while framing policies to support solar pumps, otherwise, the targeting of policy support could remain significantly skewed towards medium and large farmers.
5. **MNRE should work with banks and financing institutions to develop financial products suitable for farmers' needs.** Moreover, banks need to simplify and standardise processes, and provide pro-active support to avoid customer harassment during loan applications.
6. **It is important to consider the pattern of borewell ownership while framing policies supporting solar pumps**, otherwise the targeting of policy support could remain significantly skewed towards medium and large farmers.
7. **MNRE should closely collaborate with Ministry of Agriculture and Ministry of Water Resources to enable adoption of efficient irrigation practices and effective management of water resources.** While reliable energy access can be provided through solar panels, sustainable access to and use of water resources is a precursor to expand irrigation access.
8. **Deployers of solar-powered irrigation systems should focus on after-sales services.** While successfully operational solar pumps have a positive demonstration effect, defunct solar pumps in the vicinity of

potential buyers create an equally significant negative perception that hinders adoption, and scale-up of the market.

To sum up, solar pumps hold the potential to enhance irrigation access, advance low-carbon agriculture, reduce burden of electricity subsidies on governments, and improve resilience of farmers against a changing climate. To scale-up solar pumps, the government must adopt context-specific deployment strategies, improve targeting of its subsidies, adopt a customer-centric approach, and focus on improving awareness about the technology. Only a multi-pronged approach sensitive to the farmers' need, social context and environmental situation would help achieve sustainable deployment of solar for irrigation.

1. Introduction

Agriculture in India holds a dual importance: it is essential for the nation's food security, and it also provides livelihood to more than 50 per cent of the rural population (MoAFW, GOI, 2017). One of the biggest bottlenecks in increasing agricultural productivity in India is the lack of reliable access to irrigation (Agrawal & Jain, 2016). Despite being home to 19 million electrical pumps and about 9 million diesel pumps, 55 per cent of India's net sown area remains unirrigated as per the Agriculture Census 2010–11 (MoAFW, 2015). While electrical pumps witness overwhelming subsidies, their use is highly restricted because of unreliable power supply. On the other hand, the adoption of diesel pumps has put undue economic pressure on farmers and also has an adverse ecological impact. In this situation, solar pumps have emerged as an alternative providing reliable access to irrigation. However, apart from being a new and relatively untried or unknown technology, the need for high upfront capital has resulted in the limited adoption of the technology so far. As of 31 December 2016, 100,521 SPIS have been installed in India, of which 38,687 were installed in 2016–17 alone, indicating the high growth in the adoption of this device in 2016 (MNRE, 2017). Given the high capital requirement for SPIS, the majority of these installations have relied on extensive government subsidies (Sass & Hahn, 2016). While the role of government support in stimulating demand for solar pumps and in strengthening the market ecosystem for solar pumps should not be underestimated, market-led approaches supported by the availability of formal finance are also imperative in scaling up the deployment of this alternative pumping solution.

Indeed, to promote solar pumps through a market-based approach, the Ministry of New and Renewable Energy (MNRE) launched a 'credit-linked capital subsidy' scheme through the National Bank for Agricultural and Rural Development (NABARD) in 2014 (MNRE, GOI, 2014). Under the scheme, a farmer contributes 20 per cent of the cost of the solar pump upfront, the ministry contributes 40 per cent as subsidy, and the remaining 40 per cent is made available to the farmer as debt by NABARD. However, as of March 2017, MNRE has discontinued the scheme due to the very limited uptake under it (NABARD, 2017). Against the targeted deployment of 30,000 solar pumps by June 2016, only 1,744 systems were installed under the scheme until December 2016 (MNRE, 2017). This scheme actually found itself in competition with another subsidy-heavy SPIS promotion scheme by MNRE, where both the centre and the state government contributed to the subsidy, taking it up to 86 per cent of capital cost. This alternate scheme, in turn, reduced the farmer contribution, making it much more attractive to the farmers in comparison to the credit-linked subsidy scheme.

The limited uptake of solar pumps by farmers under both the above-mentioned schemes raises important questions about the views of farmers regarding such a technology. While the literature looks at policy-, market-, and financing-related barriers to the uptake of solar pumps from the perspectives of policymakers, enterprises, and financiers, there is a glaring gap on the need to understand the views of the end users themselves (Pullenkav, 2013) (KPMG, 2014) (Agrawal & Jain, 2017).

With the aim of understanding farmers' perspectives on their irrigation choices, their views on solar pumping technology and its financing, and their overall outlook on irrigation and agriculture, we conducted a mixed-method study in the state of Uttar Pradesh to answer the following questions:

1. What is the level of awareness and perception among farmers regarding solar pumps? What is their intent in adopting solar pumps? Do their awareness and perception of the technology influence their intent to adopt solar pumps? How does the intent to adopt solar pumps vary (if at all) among the different size groups of farmers?

2. Do the farmers' prevailing practices of investment in, and renting of, agricultural technology affect their intent to adopt solar pumps?
3. Do factors like the farmers' prevailing expenditure on irrigation, ownership of pumps, and satisfaction with the existing irrigation situation affect their intent to adopt solar pumps?
4. What are the farmers' views on the adoption of solar pumps under different models such as individual ownership, joint/group ownership, water-as-a-service from solar pump, etc.?
5. What are the primary sources of financing that farmers would prefer to tap into while adopting solar pumps? What are the challenges (if any) they face in availing institutional credit for such financing?

1.1 Organisation of the report

The rest of the report is organised as follows. Chapter 2 provides details about our data-collection strategy and the methodological approach taken. It describes the sampling approach as well as its representativeness, and outlines the key focus areas covered in the different components of the study.

Chapter 3 reports the findings emerging from the qualitative and quantitative data gathered from the survey of farmers in UP. In addition to discussing the current irrigation situation in the state, the chapter dwells on farmer-level insights on their enterprising nature, investment, and renting models; and the farmers' outlook on the various input- and weather-related shocks they face. Further, it discusses farmers' perception of SPIS, presents the findings on their awareness of and views on SPIS, and analyses the major determinants for the farmers' intent to adopt SPIS.

Based on the research results, Chapter 4 synthesises the major lessons and describes a possible way forward for the key stakeholders, policymakers, enterprises, and financiers for scaling up the deployment of solar pumps. It summarises the insights emerging from the study into a set of short- and long-term recommendations.

Chapter 5 provides the concluding remarks, emphasising the need for a more holistic approach to assessing the views of various stakeholders while the government promotes the adoption of solar pumps for irrigation.

2. Data and Methodology

We employed a mixed-methods approach for gathering data for the study. The approach consisted of (i) a review of the relevant literature on the adoption and financing of solar pumps to gain an understanding of the existing challenges and knowledge gaps; (ii) focused group discussions (FGDs) with farmers to obtain their perspectives on investment and renting practices, the irrigation situation, availability of institutional credit, and their awareness of, and views on, solar pumps; and (iii) a quantitative survey of farmers to collect primary data on the themes that emerged during the FGDs.

2.1 Selection of state and districts for the study

Given the constrained resources available for conducting a survey of 1,200–1,600 farmers, we deliberated on various possibilities regarding the selection of the state and various districts within it. From the different options, we finally selected Uttar Pradesh. The choice of the state was mainly guided by the following sets of considerations: (i) UP is the most populous state in the country (equivalent to the sixth largest country in the world by population), with the largest number of farmers, and with a primarily agrarian rural economy. It shows significant variation in agro-climatic conditions, groundwater development, economic situation of farmers, and cropping pattern across the state. The variations exhibited within the state represent sufficient diversity of contexts of, and constraints on, the resources required by farmers; (ii) high potential for the sustainable deployment of solar pumps in the state as estimated by the authors using a multi-criteria decision support tool (Agrawal & Jain, 2017); and (iii) literature indicating the vast potential in the state for the utilisation of solar pumps for irrigation (Pallav & Michaelowa, 2005) (Pullenkav, 2013).

The districts for the intervention were then selected based on purposive sampling. The approach[1] enabled the inclusion of districts exhibiting sufficient variation in the following parameters:

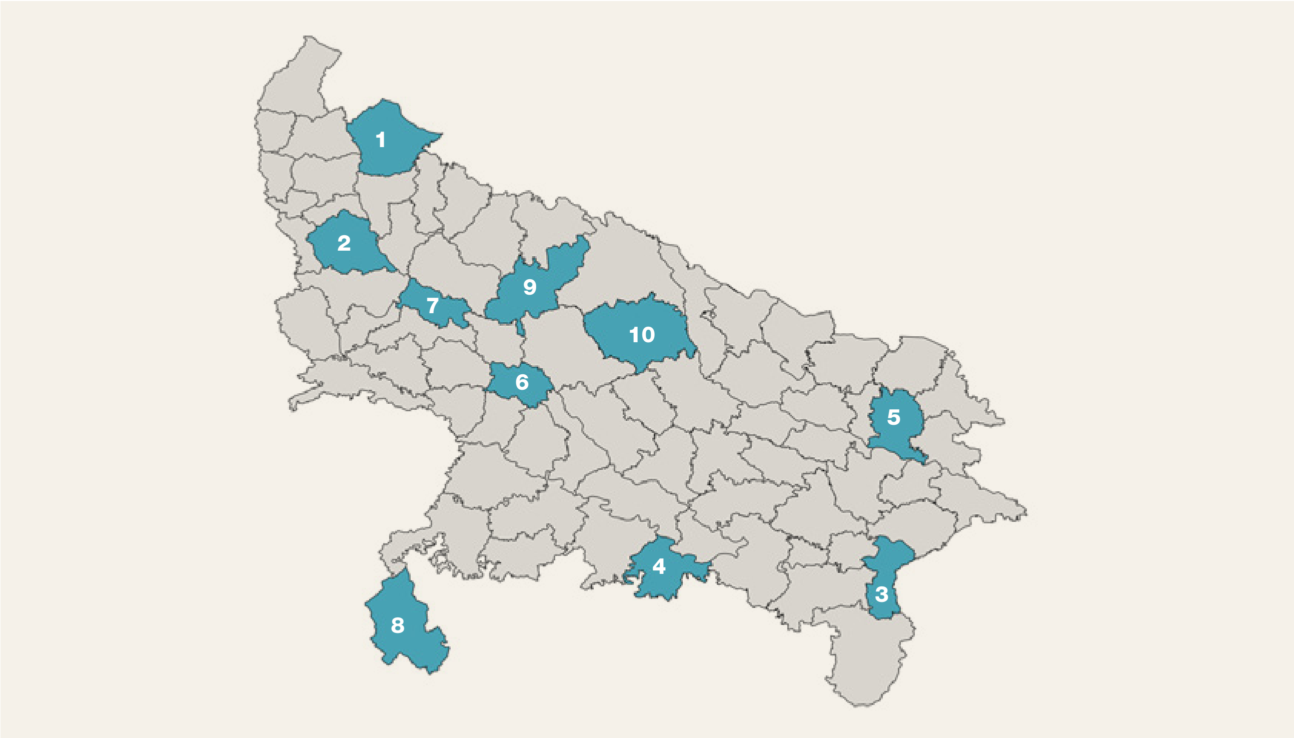
1. Use of diesel pumps
2. Agro-climatic zone
3. Development of groundwater resources
4. Cropping pattern
5. Economic situation of cultivators

Data for these parameters were obtained from the Agriculture Census 2010–11, the Input Survey 2011–12, the Central Ground Water Board, and the National Sample Survey 68th Round 2011–12. Based on the above-mentioned parameters, the following ten districts in UP were selected. These districts were used both for conducting FGDs and the farmers' survey.

1. Bijnor
2. Bulandshahr
3. Chandauli
4. Chitrakoot
5. Gorakhpur
6. Kannauj
7. Kasganj /Kansiram Nagar
8. Lalitpur
9. Shahjahanpur
10. Sitapur

1 A detailed document on the selection of districts has been prepared, along with their corresponding scores for each parameter. The document is available on request.

Figure 1: Districts of Uttar Pradesh included in our sample



Source: GADM, 2015; CEEW

2.1.1 Focus group discussions (FGDs) with farmers

We conducted one focus group discussion (FGD) with a group of 10–12 farmers in each of the selected districts. We began by conducting four pilots in two districts of UP to test the FGD design and prompts with the intended target audience. Villages were selected through simple random sampling at the district level, and the farmers were chosen on the basis of inputs received from local resources while keeping the representativeness of the groups in mind. The discussions focused on understanding the farmers' overall outlook on farming (as a source of livelihood and as an enterprise), farm mechanisation, access to and expenditure on irrigation, current financing options, views on institutional credit, and views on the solar pump as a potential option for irrigation. The data gathered at these meetings were fed into the design of our survey questionnaire, and, more importantly, they also served to further enrich and validate the quantitative analysis based on the survey findings.

2.2 Survey exercise

2.2.1 Sampling and questionnaire design

The survey covered 1,600 farmers in the ten selected districts. In each district, we selected 16 villages based on simple random sampling using the Census Village list for UP. Further, in each village we randomly sampled ten farming households using the right-hand rule and periodic skipping.[2] We only included farming households for whom either agriculture was the primary source of income or who were selling at least some part of their produce. Thus we excluded those farmers who were pursuing agriculture only for subsistence and/or for whom agriculture was not their primary source of income. We decided to exclude these households based on our experience during FGDs and pilot surveys where it became evident that such farmers have

2 The numbering of the households begins from a particular corner of the village. After marking the first structure, the enumerator numbers the households in an anti-clockwise manner, systematically marking the households on his right. The enumerator then records an observation for every eighth household and proceeds further. This process ensures that no household is missed and that the numbering is systematic and is carried out in one particular order.

very limited interest in making significant investment in their farms and are also usually much less interested in solar pumps. The exclusion of these households from the survey should not in any way undermine the importance of looking at this group of farmers to better understand their irrigation needs and choices, and to determining how policymakers could best support them. However, it seems apparent that a financing-based market approach for the deployment of solar pumps may not be the best option for these farmers.

The findings from FGDs and the gaps we had identified in the available literature were central in identifying the key themes for the survey instrument. The instrument evolved through several rounds of revisions, with critical inputs from pilots conducted to confirm the ease of administration and the ease with which respondents could follow the questions.

The final questionnaire (designed to be completed in about 40 minutes) focused on the following themes:

1. Household demographics
2. Perception of climatic conditions and their effect on agriculture and agricultural productivity
3. Land profile, cropping pattern, state of mechanisation
4. Condition of, expenditure on, and satisfaction with the prevailing irrigation situation
5. Awareness of and views on adoption of and WTP for solar pumps
6. Access to financial services, financial situation, and experiences with formal lending institutions

2.2.2 Data collection and cleaning

We hired a team of enumerators from the state of UP who were familiar with the local geography and culture to ensure the smooth administration of the exercise. We trained them on the use of the survey tool and on the due diligence required for the successful administration of the survey through multi-day in-person training sessions. The survey had all the necessary instructions to minimise individual discretion at the enumerator level. The survey was conducted using hand-held smart devices, enabling wider and quicker access to tools for monitoring and quality control. Field supervisors and managers oversaw on-the-ground activities to ensure data quality and consistency. We regularly assessed data for outliers and missing values to identify incorrect observations, which were later cross-verified and resolved.

We used descriptive as well as econometric approaches to analyse the survey data. All the analysis was performed on statistical software package Stata 13 and MS Excel 2017.

2.3 Limitations

While we have attempted to collect high-quality data to the best of our ability and then performed rigorous analysis, we acknowledge the following limitations in our study:

1. While the findings are robust at the state level, the external validity of this study is limited. Although our purposive sampling may have facilitated an improvement in the contextual variations, the findings should be generalised beyond UP with caution.
2. Some questions aimed at providing an estimate of annual expenses and income could be influenced by the bias of farmers. It is prudent to assume that some of these values as stated by farmers might not account for everything that is entailed by such a parameter. Although the absolute values reported might not be equal to the actual values, the relative trends for income and expenditure are fairly robust.

3. Key Findings

The findings of the FGDs and the outcomes of the quantitative survey conducted among farmers in UP revealed their outlook on entrepreneurship, their on-farm investment, their prevailing expenditure on irrigation and their choice of pumping technology; their current economic status and the challenges they face in gaining access to institutional credit; and their awareness of and their willingness to adopt and pay for solar pumps.

3.1 Sample profile

As per the Agriculture Census 2010–11,[3] the distribution of size group (classification based on the size of operational holdings) in UP is as follows: marginal (79.5 per cent), small (13 per cent), semi-medium (5.7 per cent), medium (1.7 per cent), and large (0.11 per cent) farms. Whereas in our survey, 57 per cent of farmers were marginal, 23 per cent were small, 13 per cent were semi-medium, 5.5 per cent were medium, and 1.4 per cent were large. The difference between the two sets of distributions could be due to the exclusion of certain farmers from our sample. As a protocol, farmers who pursue agriculture neither as a primary source of income nor for the marketing of their produce were excluded from our survey. Table 1 provides the distribution of the sample along with the basic demographic characteristics of the respondents.

Table 1: Demographic profile of the sample

S. No.	Demographic characteristics of the respondents	Distribution in sample
1	Age	18–25: 11%; 26–0: 31%; 41–60: 42%; 61 and above: 17%
2	Gender	Female: 4%; Male: 96%
3	Education	Illiterate: 25%; Up to std.10: 51%; Intermediate/diploma: 13%; Graduate and above: 12%
4	Caste	SC: 21%; ST: 6.5%; OBC: 42%; General: 30%
5	Ration card	None: 26%; APL: 37%; BPL: 30%; Antyodaya and Annapurna: 7%

Source: Authors' analysis

3.2 Farmers' outlook on mechanisation, investment, and renting models

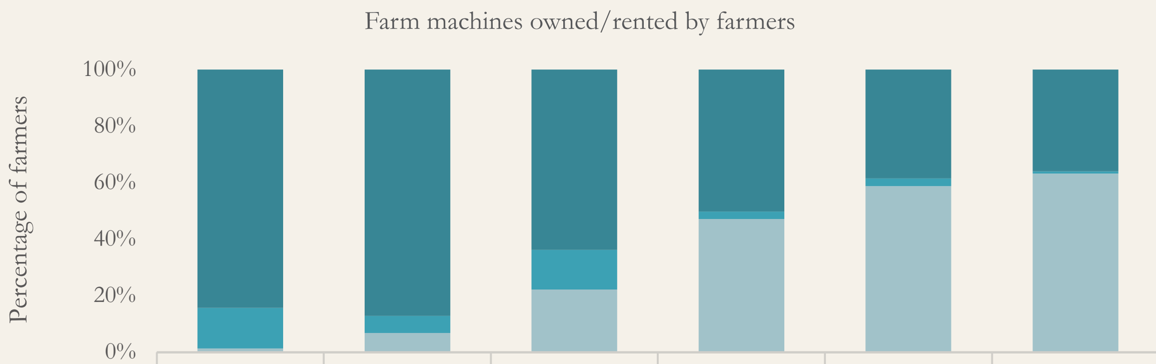
The average size of landholding for the farmers in our survey was 3.4 acres against the state average of 1.9 acres as per the Agriculture Census 2010–11; the positive difference here could be attributed to our sampling strategy. Close to 86 per cent of the respondents pursue agriculture as a primary source of income for themselves. Seventy-five per cent of the farmers surveyed were able to harvest at least two crops in the last year. The mean cropping intensity was 1.8 for the state, with almost no variation across size groups, an interesting finding. About 15 per cent of farmers reported growing crops in all three seasons (monsoon, winter, and summer). Only one-third of the farmers cultivate a continuous piece of land and almost half of them have their land divided into three or more pieces, which are typically situated between 0.5 km and 1.2 km from each other. It is important to understand the prevalence of ownership of land in fragments, as it may reduce the utility of the solar pump, given the limited mobility of this device.

3 As per the Agricultural Census, the classification of operational holdings into five categories is based on size, which is as follows: Marginal: < 1 ha; Small: 1–2 ha; Semi-medium: 2–4 ha; Medium: 4–10 ha; and Large: > 10 ha.

In terms of the economics of agriculture, farmers exhibited significant variation in their input costs and incomes. The median annual operational expenditure was close to INR 25,000 in 2016, ranging from INR 0 to INR 500,000. The median income from farming for the sample was around INR 28,000.[4] It is important to understand the basic cash flows of farmers, and the variation therein, in order to contextualise the investment required for solar pumps, which is of the order of INR 50,000 for a 0.5 HP pump to INR 450,000 for a 5 HP pump.

Compared to other states in India, Uttar Pradesh has a high level of farm mechanisation (Grant Thornton, 2015). During FGDs, farmers expressed a strong consensus on the contribution of mechanisation in improving yields, increasing time savings, reducing drudgery, and decreasing reliance on draught animals. The views expressed are in consonance with the literature, indicating an increase of up to 30 per cent in productivity and an increase of 15–20 per cent in saving in time due to farm mechanisation (Grant Thornton, 2015). Tractors and threshers were the most widely adopted mechanisation technologies, with 99 per cent and 93 per cent farmers, respectively, using them (see Figure 2). The extent of mechanisation varies across different stages of cultivation, from sowing to harvesting, and across different kinds of equipment. For instance, harvesters were reported to be used by less than 40 per cent of farmers.

Figure 2: Renting of farm machines increased access to a larger proportion of farmers



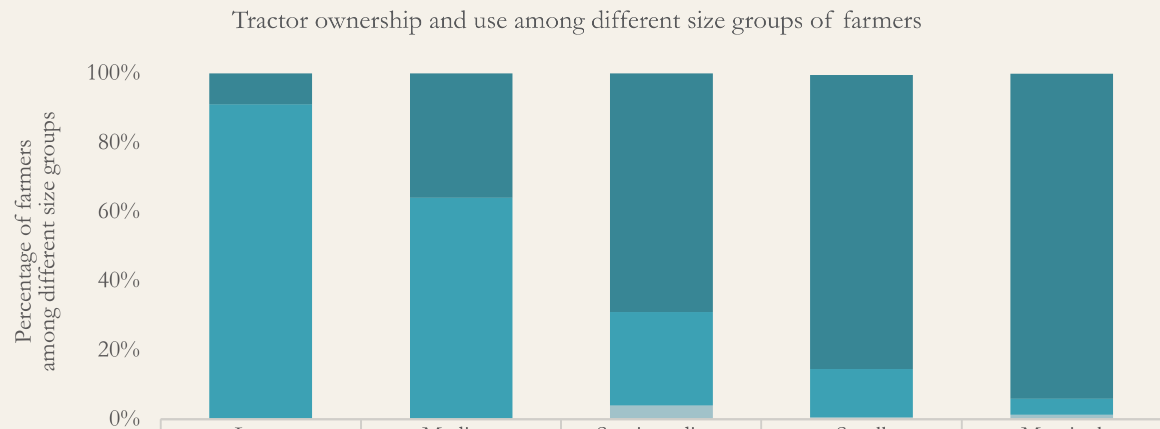
	Tractor	Thresher	Manure sprayer/ Spreader	Roller	Transplanter/ Tillage planter	Harvester
Yes, rented	84%	87%	64%	50%	39%	36%
Yes, owned	14%	6%	14%	3%	3%	1%
No	1%	7%	22%	47%	59%	63%

Source: Authors' analysis

While the use of some of this equipment is extensive across all size groups, its ownership is mostly limited to large and medium farmers. For instance, 90 per cent of large farmers own a tractor, whereas less than 5 per cent of marginal farmers own one (see Figure 3). Most small and marginal farmers rent such equipment from large farmers. The high capital cost of some of these machines limits the ownership to larger size groups. However, the leasing of this equipment has emerged as a way of dealing with low levels of ownership, thereby increasing access for a much larger base of farmers, providing higher economic returns to owners, and improving the utilisation levels of the equipment. A farmer confirmed these findings during the FGD: "*Those who own farm equipment are using it in their fields and even those who do not own this equipment are also using it. The latter are renting it from the former, but almost everyone is using farm equipment*." Given the capital-intensive nature of solar pumps, we may expect a similar arrangement to emerge regarding their adoption. However, the constraint of mobility is likely to limit the extent of sharing or renting of solar pumps.

4 Income has been calculated as: revenue - operational expenditure. It does not include investment cost, if any.

Figure 3: Ownership of tractors is skewed towards higher size group

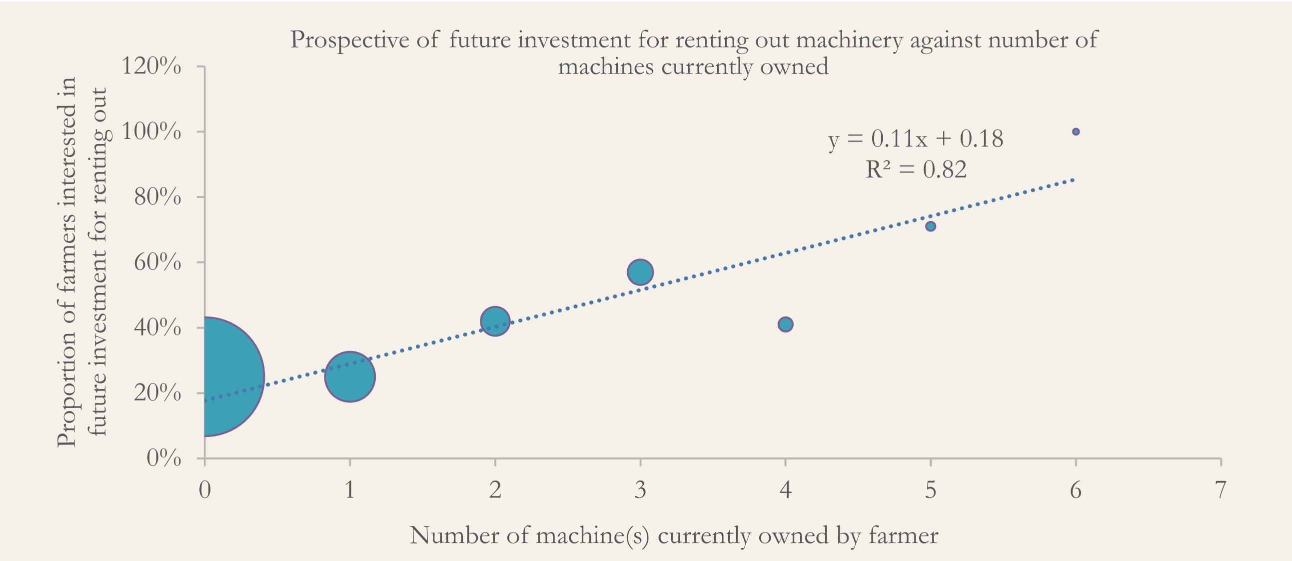


	Large	Medium	Semi-medium	Small	Marginal
Yes, rented	9%	36%	69%	85%	94%
Yes, owned	91%	64%	27%	14%	4.6%
No	0%	0%	4%	0.5%	1.3%

Source: Authors' analysis

When asked about their plans for making an investment in their farm in the future, more than three-quarters of the farmers said that they are thinking about it, irrespective of the fact whether they owned the equipment at present or not; this is an encouraging finding. But only a third of the farmers expressed the desire to buy equipment for the purpose of renting it out, thereby showing limited interest in utilising their machines beyond personal use. Such farmers are likely to be more interested in equipment like the solar pump which requires high capital investment. Having said that, a farmer currently owning more machines is more likely to buy equipment in the future with the intention of renting it out (see Figure 4).[5] Given the high correlation between ownership of farm machines and size group, larger farmers could be the potential target population for adopting a solar pump with the intention of renting it out.

Figure 4: Farmers currently owning more machines likely to invest more in future for renting out machines



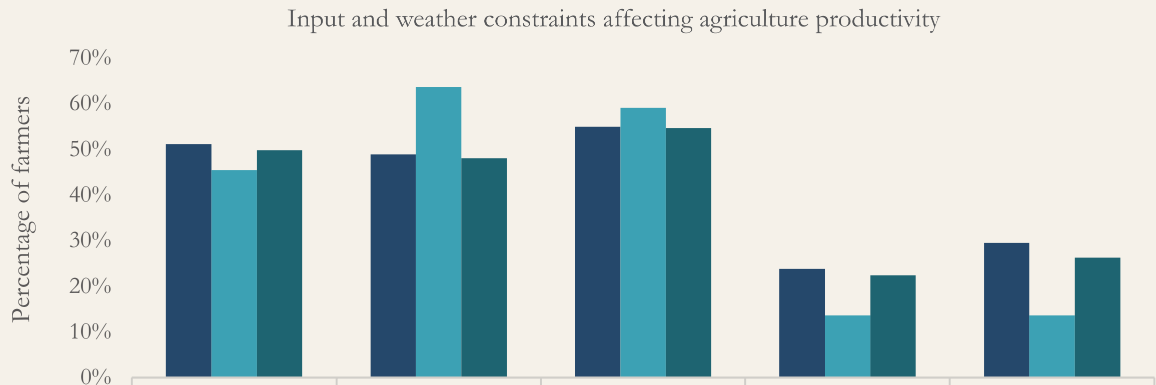
Source: Authors' analysis

5 There was a strong dependence between the number of machines and the investment required for renting out these machines using the chi-square test of independence: χ^2=51.1 and p-value =0.000

3.3 Input and weather constraints on agricultural productivity

In order to determine whether irrigation is an important issue for farmers in UP, we asked them about the key barriers to agricultural production faced by them. Insufficient irrigation, unavailability of high-yielding-variety seeds, and unavailability of fertilisers emerged as the top three impediments to agricultural production (see Figure 5). More than 50 per cent of farmers reported insufficient irrigation as the biggest barrier to the achievement of their desired productivity, with no significant variation across the different size groups of farmers. While solar pumps may be a potential solution to the problem of insufficient irrigation, limited water availability also emerges as a significant barrier to farm production, with 30 per cent of farmers reporting it. Thus, in the context of such areas and conditions, solar pumps may be useful only if they are coupled with water-harvesting solutions at the farm level.

Figure 5: Insufficient irrigation affects agricultural productivity for majority of farmers



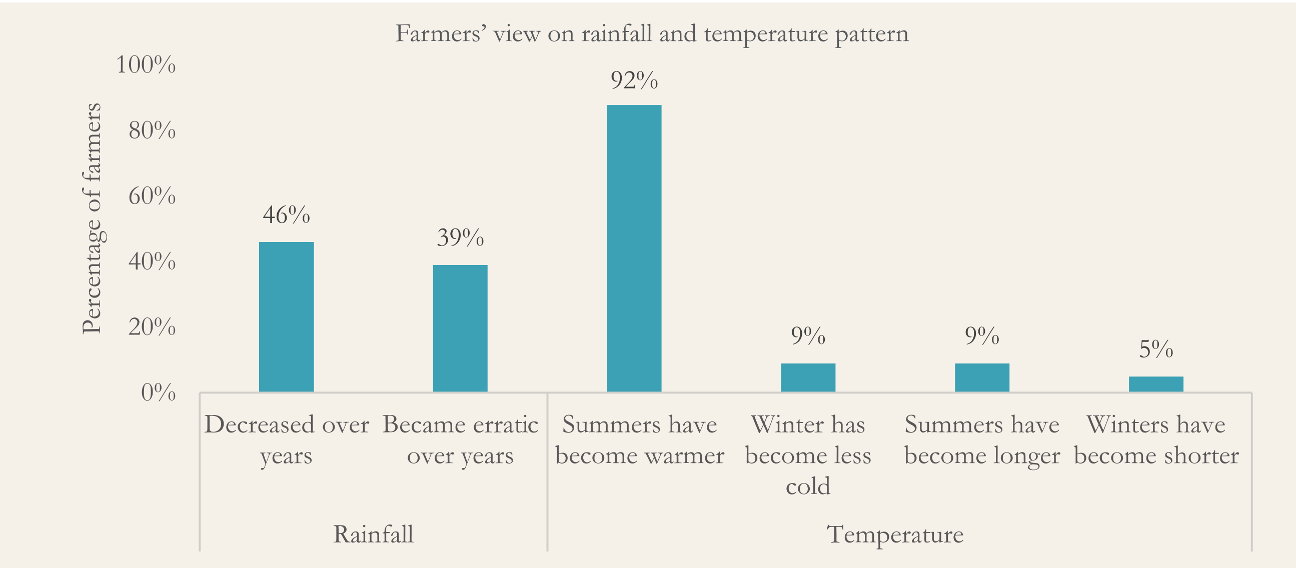
	Unavailability of HYV seeds	Unavailability of fertilisers	Insufficient irrigation	Insecure about market price	Water availability
All	51%	49%	55%	24%	30%
Large	45%	64%	59%	14%	14%
Marginal	50%	48%	55%	22%	26%

Source: Authors' analysis

The solar pump is often considered to be both a climate-mitigation as well as a climate-adaptation solution (by building resilience against drought). The literature suggests that changing climate—as seen in increasing temperatures and the late arrival of the monsoon—is already affecting agricultural productivity in India (Guiteras, 2007). To understand farmers' perspectives on the prevailing climatic conditions and the effect of these conditions on agriculture, we asked them about the climatic factors affecting their farm yields. Three-fourths of farmers cited drought or insufficient rain as the main climatic factor adversely affecting their agricultural productivity, followed by untimely rainfall (44 per cent) and flooding/excessive rain (22 per cent). Only about 10 per cent of farmers mentioned the rise in average temperature as adversely affecting their agricultural productivity. No significant variation regarding climatic factors adversely affecting agriculture was observed across the size groups. This finding was confirmed by the respondents. When asked about the pattern of rainfall over the years, 46 per cent and 39 per cent of farmers, respectively, believe that rainfall has decreased and has become more erratic over the last five years (see Figure 6). Regarding change in temperature, 92 per cent believe that summers have become warmer over the years. We observe a convergence in the views of farmers on weather, that is, rainfall has become more unpredictable and temperature has been increasing over the years. The lack of physical infrastructure and the absence of access to insurance have only exacerbated the adverse situation.

We hypothesise that the unpredictability of climatic factors (rainfall pattern, change in temperature, and duration of seasons) could potentially have a positive or negative influence on the likelihood of adoption of solar pumps by farmers. Increasing unpredictability of rainfall is likely to move farmers from practising rain-fed farming to seeking irrigation from a reliable source. Indeed, during FGDs, farmers reported that changing weather conditions, especially rainfall patterns, have increased their irrigation requirements. One farmer said, "The need to moisten the soil with water before and after sowing has increased over the years." They reported that crops that were earlier only rain-fed are now also irrigated. Here, solar pumps could be a potential solution in providing irrigation. However, given that changing rainfall patterns also necessitate the need for a more controllable and reliable pumping solution, diesel pumps may continue to remain the technology of choice or may increasingly become this choice in the future. This aspect may be worth further exploration by researchers.

Figure 6: Farmers believe rainfall is decreasing and summers are becoming warmer



Source: Authors' analysis

3.4 Current state of irrigation in Uttar Pradesh

As per the Agriculture Census 2010–11, while only 45 per cent of the net sown area in the country is irrigated, as much as 81.1 per cent of the net sown area in UP is irrigated. Even in our survey, as many as 86 per cent[6] of the farmers reported having access to irrigation on all fragments of their land. Moreover, 84 per cent of the farmers, without significant variations across size groups, reported having timely access to irrigation on most occasions.

3.4.1 Sources of irrigation: Access, expenditure, and pump types

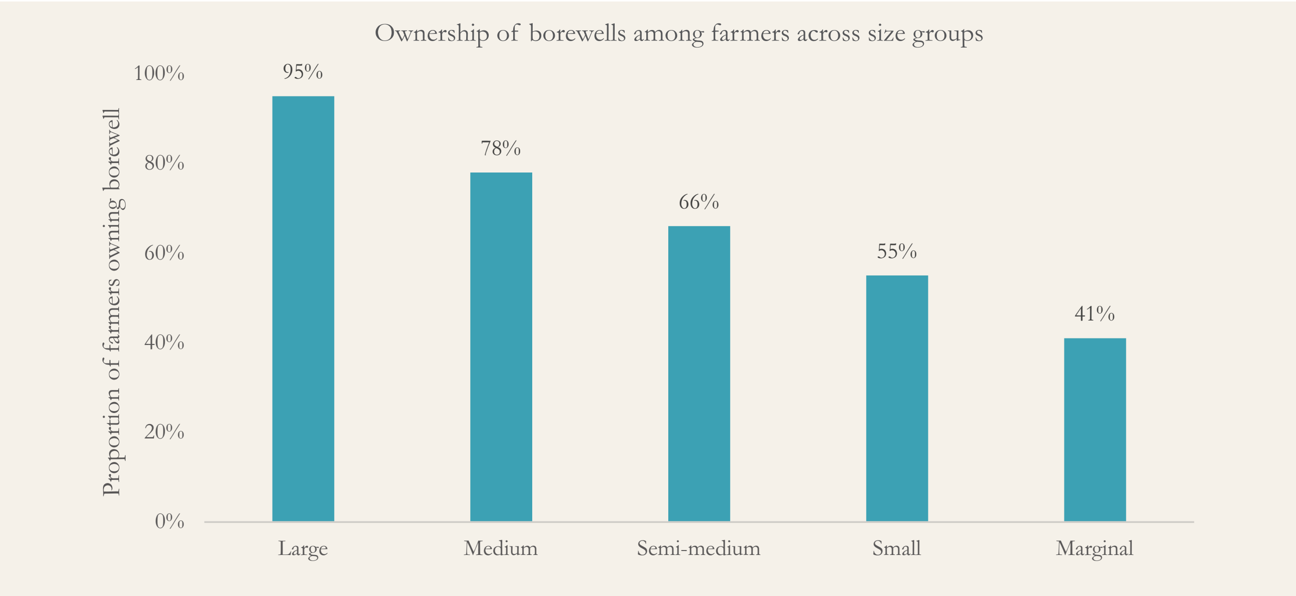
The high rate of access to irrigation in UP is largely, if not entirely, dependent on underground water. As of 2012, tube-wells met 72 per cent of irrigation needs in the state, followed by canals (19 per cent), wells (7 per cent), and tanks (0.75 per cent) (MoAFW, 2015). There are 5 million diesel and 0.68 million electric pump users, respectively, in UP.

In our sample, 82 per cent of farmers indicated tube-wells as their primary source of irrigation, followed by 11 per cent who reported canals. Less than 2 per cent of farmers use government tube-wells, ponds, or other sources. The absence of government tube-wells puts the onus on farmers to dig bore-wells themselves. The reported median depths of borewells and the pre-monsoon water table in the 10 districts of UP where the study was conducted were about 100 feet and 40 feet, respectively. Farmers also reported an average reduction of about 13 feet (1.3 metres) in the groundwater level in the last five years, potentially due to the high number

6 These data have been recorded only for farmers with a non-continuous piece of land. N=1037

of tube-wells and borewells operating in the state. The declining underground water level poses a serious threat to the long-term sustainability of solar pumps. Indeed, the researchers have raised concerns about the issue of excessive withdrawal of water through the use of solar pumps given their negligible operational cost (Kishore, Shah, & Tewari P., 2014). However, much sooner than solar pumps could potentially pose a threat to water tables, declining water tables would render the majority of solar pumps non-functional; hence it is important to deploy additional solar panels and pumps of greater size to compensate for this potential loss. Thus, the management of water tables through efficient use practices as well as rainwater harvesting is imperative for the long-term sustainability of solar pumps. Water-as-a-service or irrigation-as-a-service could be one of the potential approaches for ensuring the sustainability of water and of solar pumps; this is discussed in detail in 3.6.3.

Figure 7: Ownership of borewell decreases with decreasing size group



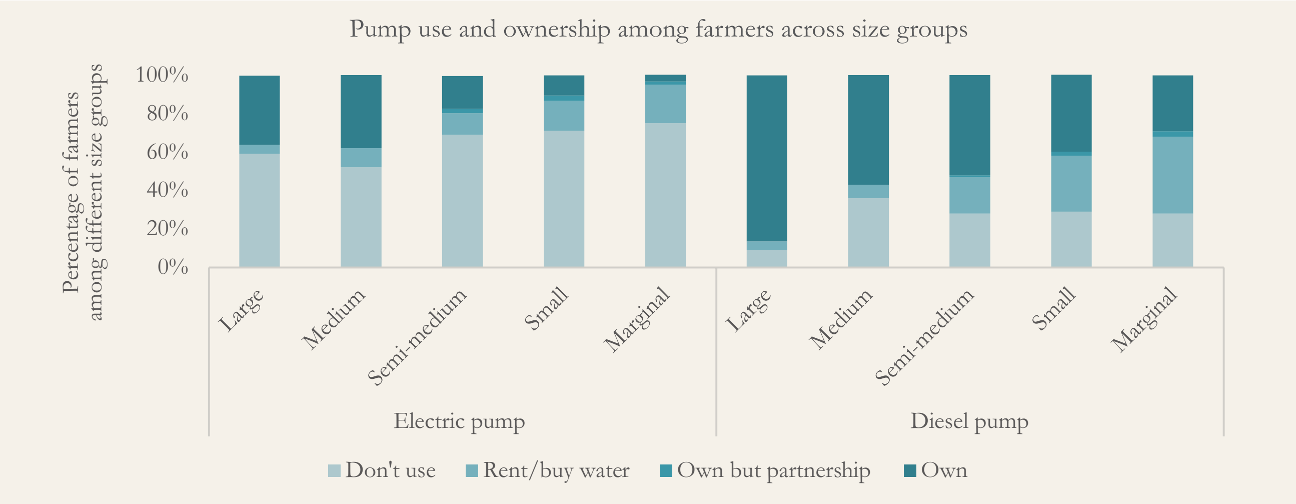
Source: Authors' analysis

Only about half the farmers own a borewell, and the rest either rent it or purchase water directly. Like the ownership of farm machines, the ownership of borewells is also skewed towards higher size groups of farmers. Ninety-five per cent of large farmers own borewells as compared to 41 per cent of marginal farmers (see Figure 7). While ownership has been registering a consistent decline, there is a steady rise in the purchase of water ranging from larger to smaller size groups.

In our sample, 66 per cent and 22 per cent farmers, respectively, use only diesel pumps and electric pumps. Another 6 per cent farmers—32 per cent among large farmers—use both diesel and electric pumps. As per Input Survey report 2011-12 of Ministry of Agriculture, there are 5 million diesel pumps and 0.68 million electric pump users in Uttar Pradesh (MoAFW, 2016). The difference between the proportion of electric pump users in our survey and the numbers reported in input survey could be primarily because of the purposive sampling to exclude very small farmers who do not pursue agriculture for commercial purposes at all. Also, the purposive selection of districts as well as the increase in agricultural electricity connections over the last five years could have led to the difference in the two statistics. During FGDs, farmers attributed the high demand for diesel pumps in the state to the very limited number of agricultural electricity connections, compounded by unreliable grid supply, usually for 4–6 hours, and that too mostly in night. One also sees a sharper decline in the use of electric pumps compared to diesel pumps with decreasing size group (see Figure 8).[7]

7 There was higher dependence between usage and size group for electric pump: χ^2=134.0 and p-value=0.000 vs. diesel pump χ^2=98.3 and p-value=0.000.

Figure 8: Ownership declines with decreasing size group sharper for electric pump users than for diesel pump users



Source: Authors' analysis

Only 39 per cent and 17 per cent farmers, respectively, own diesel pumps and electric pumps. There is a sharp decline in ownership of electric and diesel pumps with decreasing land ownership[8] (see Figure 8). The trend may continue in the immediate future in the case of electric pumps, as only 4 per cent of electric pump renters reported having applied for an electric connection.

Eighty-two per cent of farmers reported using electric pumps of size between 5 and 10 HP, with an almost equal split between pumps of 5, 7–7.5, and 10 HP. In comparison, more than 98 per cent of diesel pump users use pumps of size between 5 and 10 HP, with more than 50 per cent using 7.5–8 HP diesel pumps. Farmers reported that usually a higher power rating is, ceteris paribus, required in the case of diesel pumps against electric pumps due to the lower output of the former. A possible reason for this observation could be the difference in the effectiveness of surface vs. submersible pumps, particularly at greater water depths, and the lower generation output of diesel pumps.

Table 2: Size group wise break-up per acre and total pumping costs (in INR)

Size group	Electric pump				Diesel pump			
	Owner (per acre)	Owner (total)	Renter (per acre)	Renter (total)	Owner (per acre)	Owner (total)	Renter (per acre)	Renter (total)
Large	630	17,500	1,200	25,000	960	30,100	2,000	4,000
Medium	1,100	18,600	1,600	16,900	1,500	28,900	1,100	14,200
Semi-medium	2,200	19,900	2,500	12,900	2,400	20,300	2,500	20,400
Small	3,000	15,400	2,500	11,400	2,700	13,500	2,100	9,600
Marginal	6,000	14,400	2,900	6,500	3,900	9,200	3,400	5,900
Overall	3,100	16,900	2,700	8,500	3,100	14,500	3,100	7,900

Source: Authors' analysis

We found a consistent rise in the pumping cost per acre and a simultaneous decline in total pumping cost (except for a few anomalies due to the low number of observations in that category) with decreasing size group for both electric and diesel pumps (see Table 2).[9] These trends are in agreement with what has been reported in the literature on decreasing input cost per hectare with increasing size group due to economy

8 Dependence between ownership and size group was significant for both pump types: electric: χ^2=89.8 and p-value=0.000; diesel: χ^2=90.8 and p-value=0.000

9 One-way ANOVA was performed and the difference between the mean of the different size groups for each category (electric pump owner & renter and diesel pump owner & renter) is significant. p-value=0.000

of scale, lack of appropriate technology, and cropping pattern (Gaurav & Mishra, 2011) (Foster D. & Rosenzweig R., 2017).

Irrigation outlay (total pumping cost) as a proportion of the total operational expenditure for agriculture increases with the decreasing size group of all kinds of pump users except electric pump renters[10] —leaving less cash with smaller farmers, who are largely dependent on diesel pumps, to spend on the other inputs.

All the farmers practise water-intensive irrigation methods, either flood or furrow irrigation. When asked about drip or sprinkler irrigation, only 24 per cent have heard about either one or both of them. Of them, only about 27 per cent are willing to adopt one or both (i.e. about 7 per cent of farmers in all). In our FGDs, we found that mainly farmers who had visited other states like Maharashtra or Gujarat knew about these approaches. After being given a description of what these methods entail, the farmers said, *"These methods [drip/sprinkler] are not suitable to our region's crops and weather conditions."* Two-thirds of them stated that these methods are not suitable for their crops while 10 per cent and 9 per cent, respectively, said that these methods are not successful and are far too complex, requiring efforts to deploy them properly. Given the prevailing depletion of underground water and changing climate, the reluctance to shift to more efficient irrigation practices may pose a significant challenge to the sustainability of irrigation, in general, and to the sustainability of solar pumps, in particular.

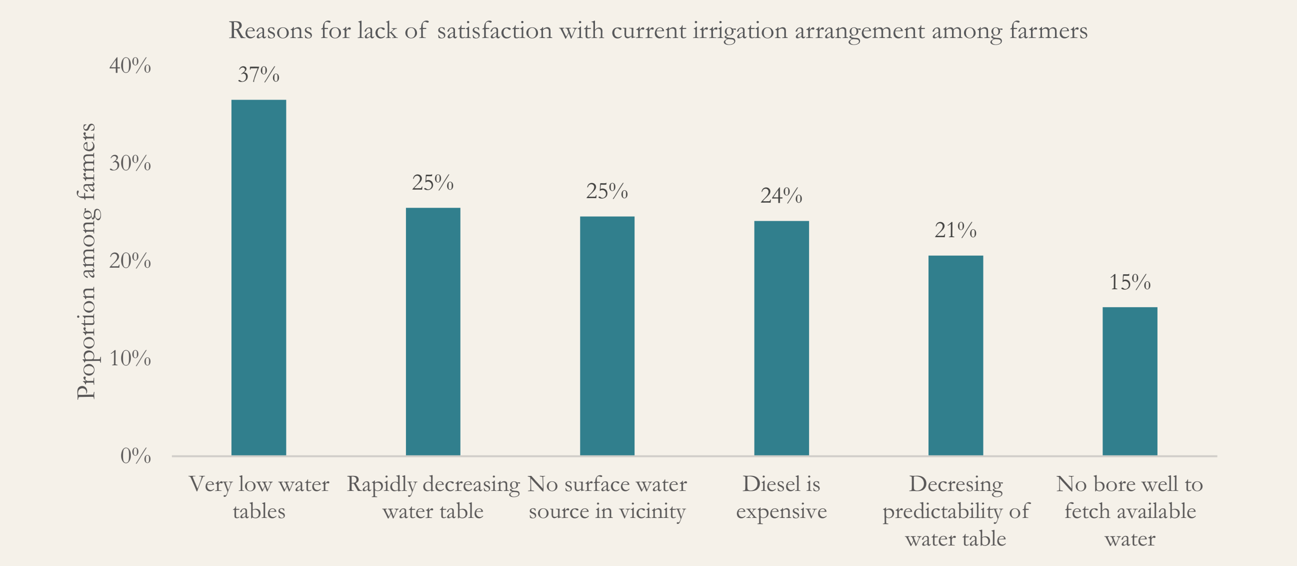
3.4.2 Satisfaction with irrigation situation

Despite increasing access, only 51 per cent of farmers in the study expressed satisfaction with their current arrangement of irrigation, while 28 per cent indicated complete dissatisfaction. Although farmers in Uttar Pradesh seemingly have better access to irrigation than farmers in the rest of the country, that does not necessarily translate into satisfactory irrigation for all of them. More than 60 per cent of farmers expressed lack of satisfaction, citing low or falling water tables as the biggest bottlenecks to irrigation (see Figure 9). Also, about 24 per cent of farmers mentioned high expenditure on diesel as a reason for their lack of satisfaction. These two factors are somewhat correlated, because the lower the water table, the higher is the requirement of power from diesel pumps, which in turn means incurring high cost on diesel. A farmer described the situation clearly: *"The water table in our area is very low and hence we incur high costs on running our diesel engines."* About a quarter stated lack of surface water in their vicinity as a reason for their lack of satisfaction.

While only half the farmers are satisfied with their current access to irrigation, almost all the farmers (99.6 per cent) believed that having a reliable irrigation service would have a tangible and positive impact on their income from farming. Eighty-seven per cent believed that reliable irrigation would improve their crop productivity and 61 per cent believed that it would reduce crop failures. About 57 per cent and 55 per cent said that a reliable irrigation system would improve the extent of their land utilisation and cropping intensity, respectively.

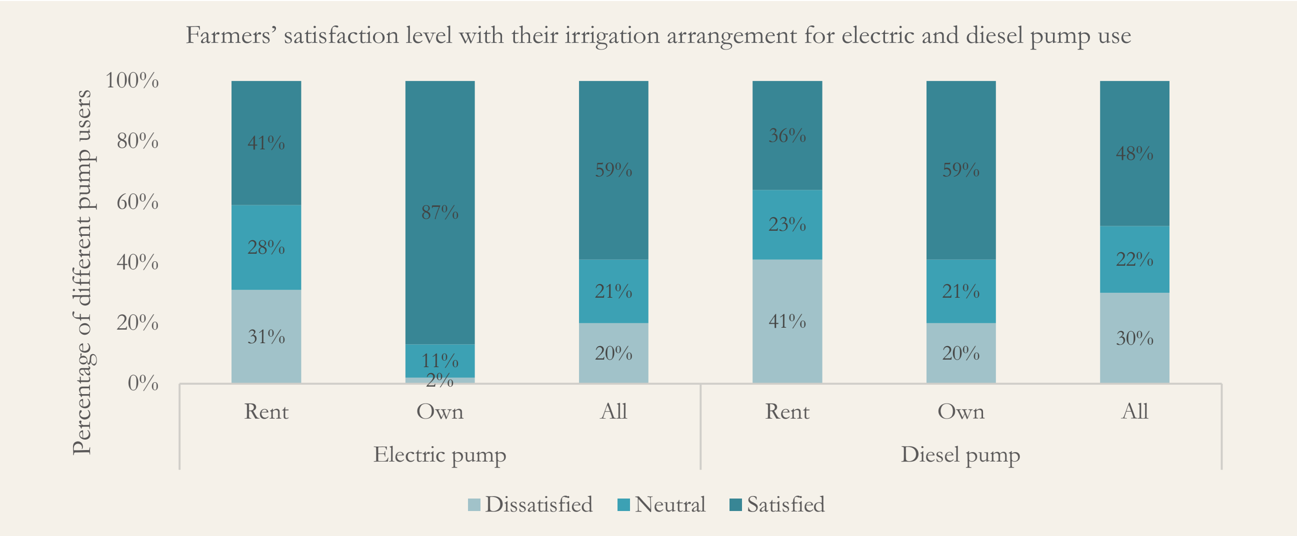
10 One-way ANOVA produced the following results: Electric pump owners: F=8.2 and p-value=0.000; Electric pump renters: F=1.9 and p-value=0.115; Diesel pump owners: F=5.1 and p-value=0.000; Diesel pump renters: F=16.8 and p-value=0.000

Figure 9: Low and rapidly declining water table are two of the biggest reasons for lack of satisfaction with prevailing irrigation situation



Source: Authors' analysis

Figure 10: Farmers are more dissatisfied with diesel pumps than with electric pumps

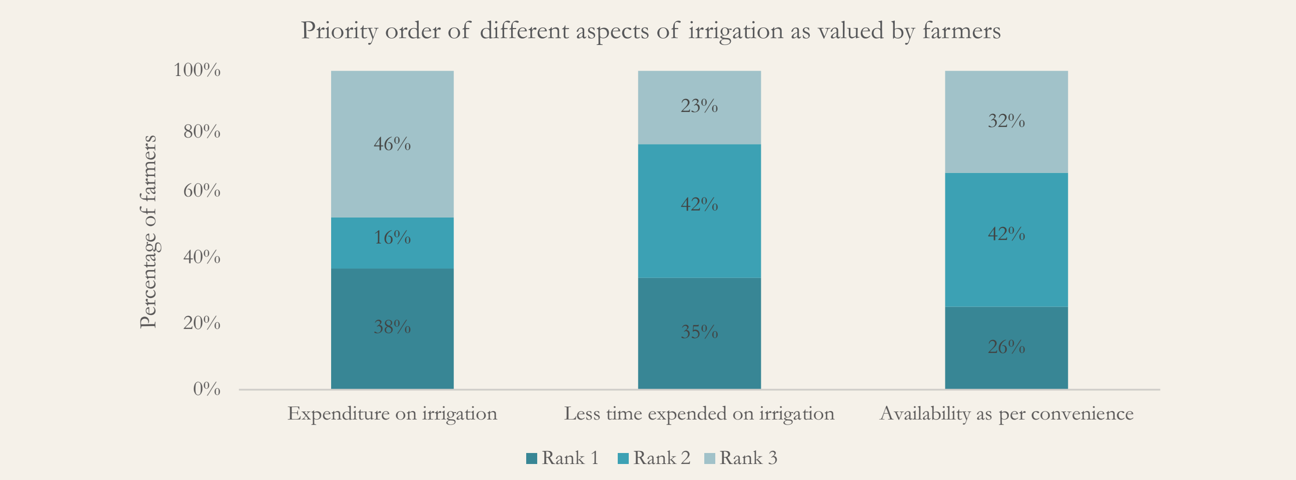


Source: Authors' analysis

We further find that a much higher proportion of electric pump users are satisfied with their current irrigation arrangement as compared to diesel pump users (see Figure 10).[11] The difference between the owners in the two categories is starker. Remarkably, only 2 per cent of electric pump owners expressed dissatisfaction with their current irrigation situation.

11 Satisfaction showed dependence upon pump type: χ^2=20.8 and p-value=0.000. Also, ownership showed strong dependence upon satisfaction level for both pump types: Electric: χ^2=90.5 and p-value=0.000; Diesel: χ^2=71.9 and p-value=0.000

Figure 11: Farmers value equally, the factors of expenditure, time spent, and availability regarding their irrigation sources



Source: Authors' analysis

Further, to understand what characteristics of the irrigation arrangement are valued more by farmers, we asked them to rank irrigation expenditure, time expended on irrigation, and availability as per convenience. We found that all three characteristics are almost equally valued by farmers, with no clear-cut preference for one over the other (see Figure 11).

The comparatively higher lack of satisfaction among diesel pump users could be attributed to the relatively higher recurring cost of the pump, 72 per cent of which is spent on fuel and the rest on maintenance (on average). The high cost of diesel was the second biggest reason for dissatisfaction with the current irrigation situation among diesel pump users. Could the zero operational cost of solar pumps be an attractive proposition to such farmers? We examine this question in the next section on willingness to adopt and pay for solar pumps.

3.5 Financing situation and experience of farmers

The solar pump employs a capital-intensive technology. Thus, the role of financing is imperative to enable the large-scale adoption of solar pumps. This section explores farmers' views and their needs with respect to financing.

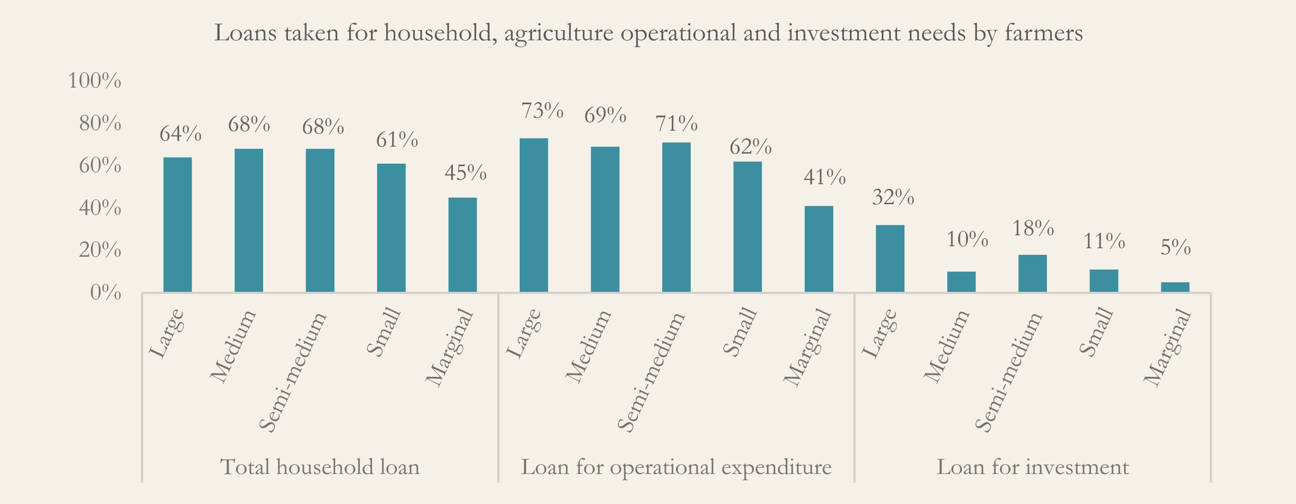
3.5.1 Existing state of credit access and main sources of credit

Almost half (47 per cent) of the farmers stated that they do not have any existing debt on their household (see Figure 12). The average loan taken out by the borrowers is INR 100,000, varying widely from INR 1,000 to INR 2,500,000. It fluctuates notably among the different groups of farmers, ranging from INR 235,000 among large farmers to INR 58,000 among marginal farmers.

Half of the farmers reported that they have never taken a loan for meeting operational expenditure for agriculture. The proportion of such farmers decreases with increasing size group. On average, the last loan drawn for meeting operational expenditure was close to INR 50,000, varying between INR 1,500 and INR 2,000,000.

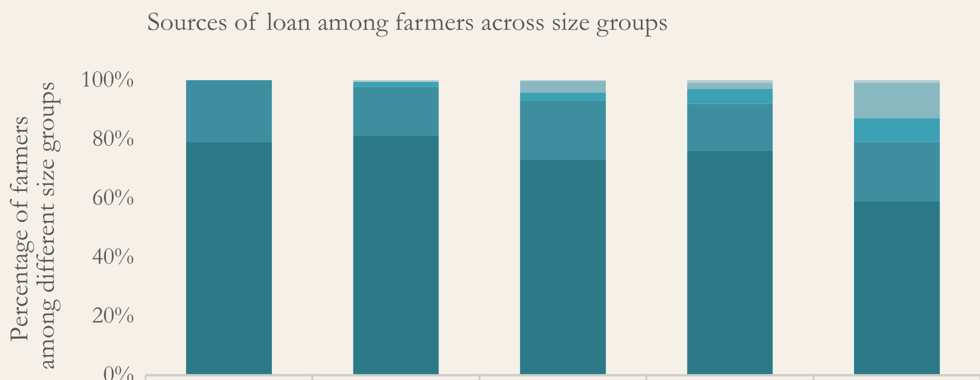
Further, only 9 per cent of farmers reported having ever taken a loan for making an investment (purchasing farm machines, pumps, etc.) in agriculture. The proportion is consistently low across all size groups, except large farmers (32 per cent). The amount of the loan ranged from INR 4,000 to INR 700,000, with the average amount of money borrowed being INR 100,000. Such a low prevalence of borrowing for agricultural investment may pose significant barriers to the adoption of solar pumps under a conventional product-financing model. Financiers, policymakers, and system deployers need to work towards improving the uptake of credit for farm investments as well as look at alternative deployment approaches.

Figure 12: Very few farmers are availing loans to invest in their farms



Source: Authors' analysis

Figure 13: Kisan Credit Card is the largest loan source of loans across size groups among borrowers



	Large	Medium	Semi-medium	Small	Marginal
Other	0%	0.6%	0.2%	1%	0.9%
Friends/Relatives/Neighbour	0%	0%	4%	2%	12%
Moneylender	0%	1.7%	2.8%	5%	8%
Bank	21%	16.7%	20%	16%	20.1%
KCC	79%	81%	73%	76%	59%

Source: Authors' analysis

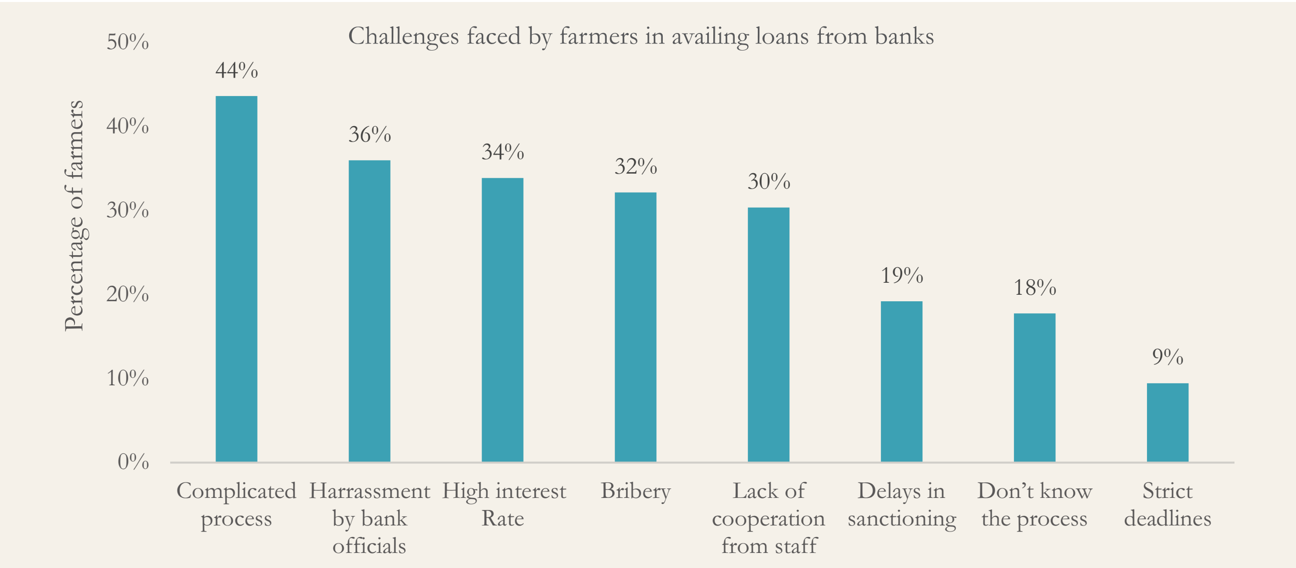
Access to the physical banking infrastructure does not seem to be a major challenge in UP, with more than 75 per cent of farmers reporting the existence of a bank branch within 5 km of their home. Among the borrowers, the Kisan Credit Card (KCC) appears to be the primary credit source for two-thirds of them (see Figure 13). About 18 per cent of farmers rely on public banks for their loan needs. While large and medium farmers, by and large, rely on formal sources of credit, about 20 per cent of marginal farmers rely on informal sources (moneylenders, friends, and relatives) for their largest loan needs. The average rate of interest reported by non-KCC borrowers was 15 per cent per annum.

Bankers financing solar pumps frequently cite the lack of collateral as a challenge, since the secondary market for solar pumps is still non-existent (Agrawal & Jain, 2017). They usually demand land as collateral in such situations. However, most bankers indicate that farmers seeking solar pumps already have their lands mortgaged for existing loans. We found that overall about 28 per cent of our respondents had currently mortgaged their land, with no variation across size groups. However, the intent to adopt a solar pump is consistently higher among farmers whose land is already mortgaged than among farmers whose land is not mortgaged. Among farmers whose land is mortgaged, 52 per cent of them are interested in adopting a solar pump as compared to 36 per cent for the remaining. Also, land mortgage shows significant geographical variation, with the western regions of the state having a higher proportion of farmers with mortgaged lands. Districts such as Lalitpur (64 per cent) and Bijnor (51 per cent) have a particularly high proportion of such farmers.

3.5.2 Views on institutional credit and challenges in accessing credit

Despite their close proximity to banks, two-thirds of farmers still find it difficult to avail loans from banks. In the words of one such farmer, "*Though we have availed of loans from banks, it has not been easy to withdraw money from them.*" Complicated processes (44 per cent) and harassment by bank officials (36 per cent) are cited as the biggest challenges (see Figure 14). High interest rates, lack of cooperation on the part of bank staff, and demands for bribes by bank staff were cited as the other main challenges by farmers.

Figure 14: Complicated process and lack of support from bank personnel are the biggest bottlenecks in availing of bank loans



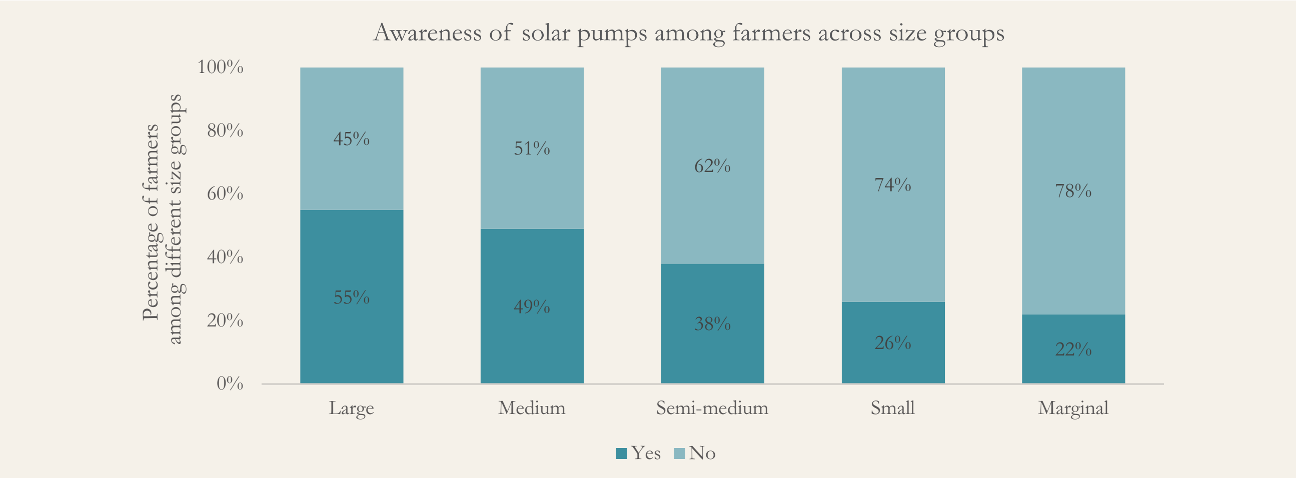
Source: Authors' analysis

3.6 Adoption and willingness-to-pay (WTP) for SPIS

3.6.1 Awareness of and views on SPIS

As of now, SPIS has low penetration in the country. None of our surveyed farmers has ever used a solar pump, but about 27 per cent of them are aware of it. The awareness level declines consistently with decreasing size group—from 55 per cent among large farmers to 22 per cent among marginal farmers (see Figure 15). We also observed decreasing awareness levels about SPIS with decreasing education levels of the respondents. One farmer during the FGD stated, "*I am uneducated and hence didn't enquire much about it.*" This is testimony to the fact that lack of education leads to behavioural barriers to gathering information about a new technology. About half of the farmers who have heard about the solar pump have seen it physically or on television. Only 7 per cent of those who have heard of the solar pump are aware of the government schemes for the same, indicating a major awareness gap.

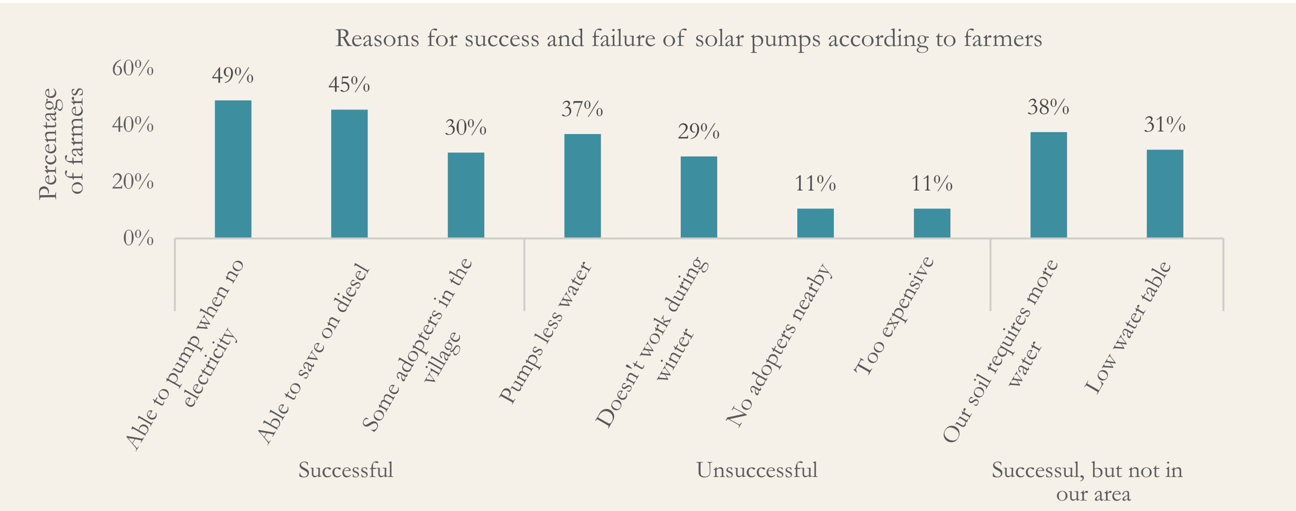
Figure 15: Awareness of solar pump decreases consistently with decreasing size group



Source: Authors' analysis

In regard to farmers who were aware of solar pumps, about 35 per cent of them believed that the pumps are successful, about 9 per cent believed that they are not successful, and 7 per cent thought that they are not successful in their area. A large proportion (48 per cent) did not have any opinion on whether solar pumps are successful or not. The main reasons for farmers to believe that solar pumps are successful are the ability to pump water even when there is no electricity and the saving on the cost of diesel (see Figure 16). The main reasons for farmers to believe that solar pumps are not successful in their area is because they believe that the soil in their area needs greater moisture and they also believe that solar pumps cannot deliver the commensurate amount of water needed for this purpose. Similarly, the limited water-pumping ability of the device is the main reason stated by those who said that solar pumps are not successful.

Figure 16: Ability to pump when no electricity supply and saving on diesel make solar pump a success in farmers' view



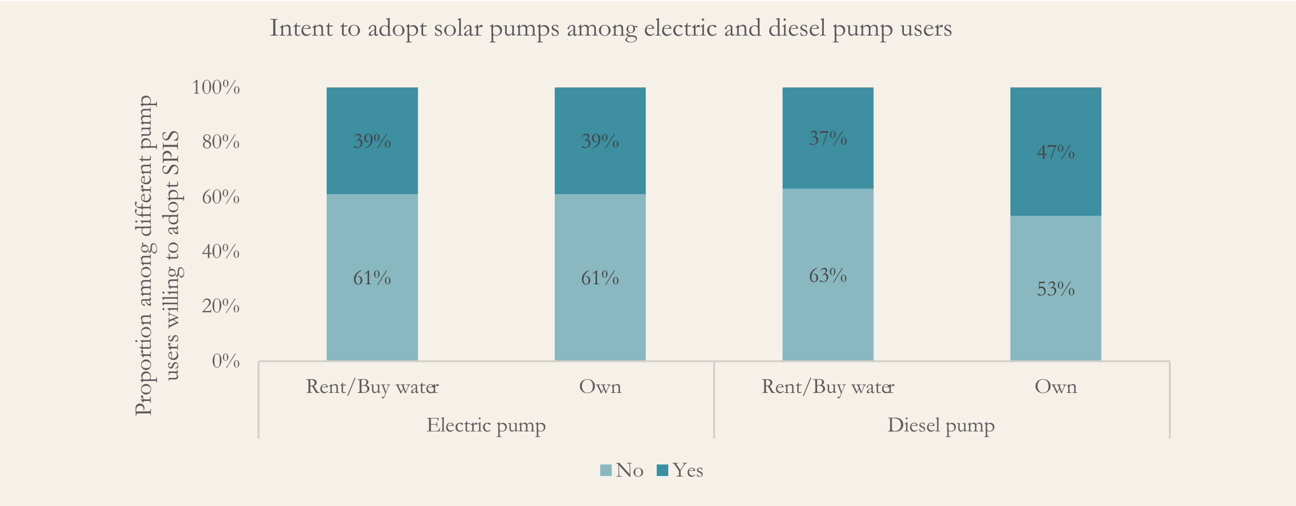
Source: Authors' analysis

3.6.2 Inclination to adopt SPIS

Almost 41 per cent of farmers indicate an inclination to purchase a solar pump from a certified provider, with no significant variation across size groups. Of them, 9 per cent would be willing to buy only when the government provides 30 per cent capital subsidy through suppliers and 5 per cent would purchase if they were allowed to use the installed solar panel for household utilities such as supplying drinking water and home lighting.

We find a slightly larger proportion of diesel pump users (42 per cent) willing to adopt solar pumps as compared to electric pump users (37 per cent). We observe no difference between the owners and renters of electric pumps in their respective willingness to adopt, whereas there is a significant difference of 10 percentage points between owners and renters of diesel pumps.[12]

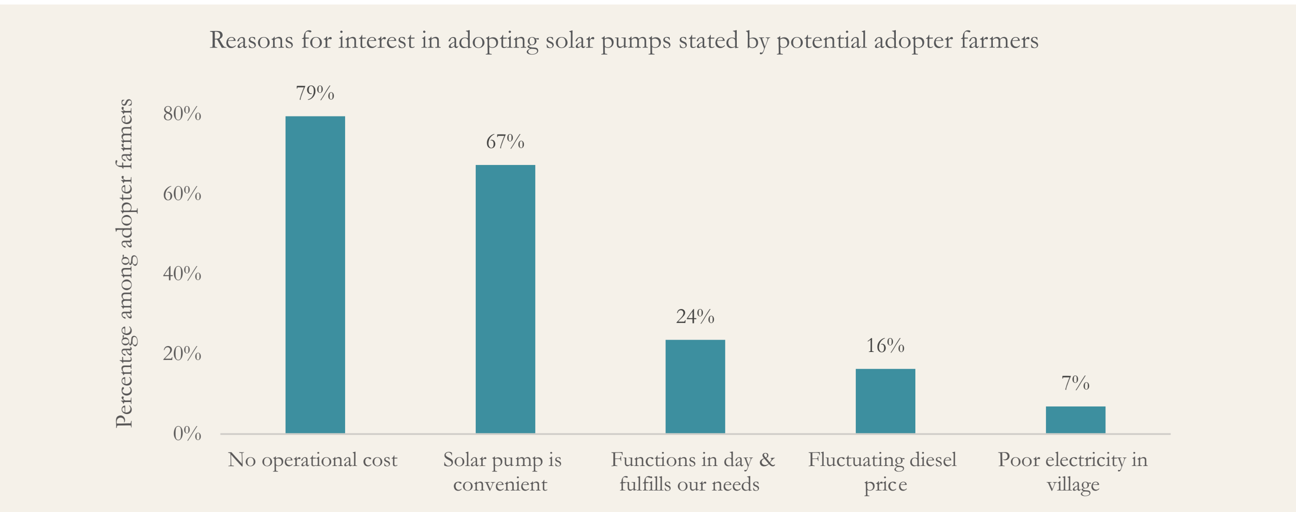
Figure 17: Among existing pump users, diesel pump owners are most likely to adopt solar pumps



Source: Authors' analysis

Zero operational cost (79 per cent) and convenience to use (67 per cent) are the two biggest reasons for farmers to adopt solar pumps (see). A farmer described the advantage of solar pumps over conventional pumps: *"They require only a one-time investment. They can also be used during the day, which usually does not happen in the case of diesel or electric engines."* In comparison, high upfront cost and reluctance to switch from the existing solution to another untried solution are the biggest reasons for farmers to not opt for solar pumps (see Figure 19). The reluctance to shift from the pump already in use is much higher among electric pump users, particularly electric pump owners.[13] This suggests that if the government wants the existing grid-connected farmers to transition to the use of solar pumps, it may encounter considerable reluctance from farmers.

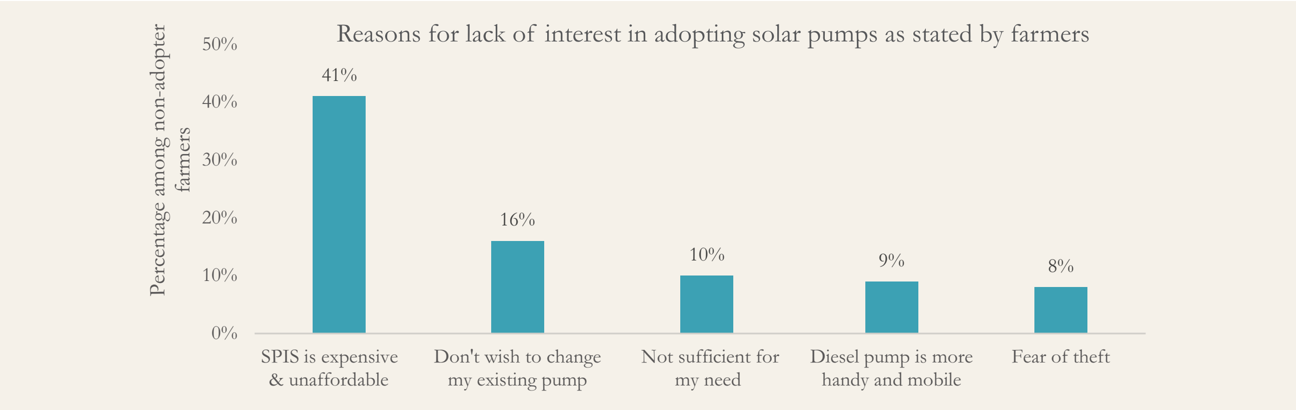
Figure 18: No operational cost and convenience of use of solar pumps encourage its adoption



Source: Authors' analysis

12 Willingness to adopt solar pumps showed significant dependence upon ownership among diesel pump users: χ^2=12.6 and p-value=0.000
13 Reluctance to shift from the existing pump to the solar pump is expressed by 22 per cent and 34 per cent of electric pump users and owners, respectively.

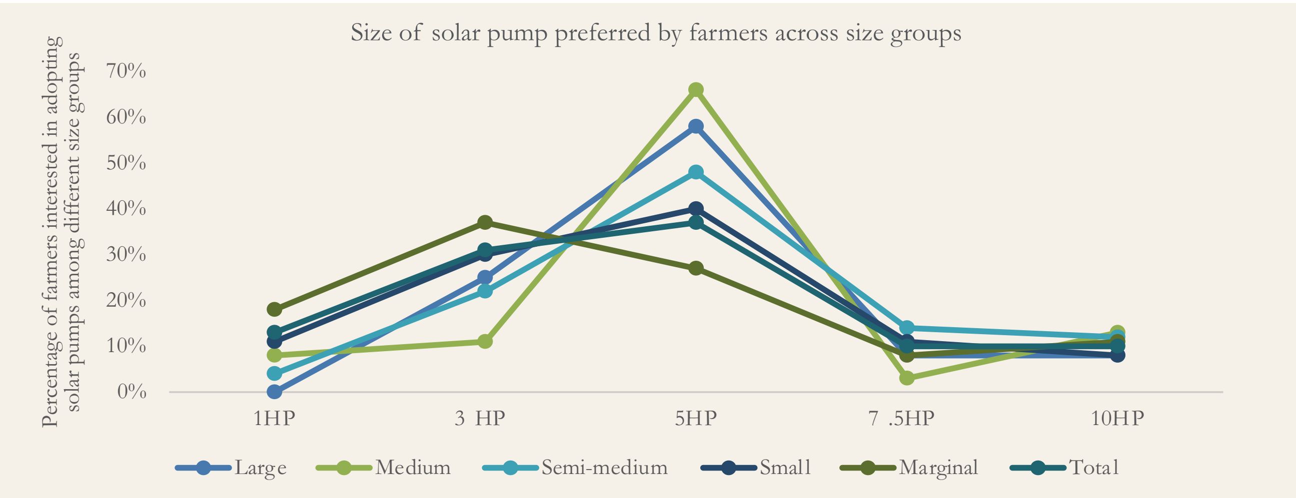
Figure 19: High capital cost is the major barrier to the adoption of solar pumps



Source: Authors' analysis

The choice of pump size varies significantly with size group (see Figure 20).[14] Five HP is the most popular choice (37 per cent) across all size groups, and 3 HP is the most preferred choice among marginal farmers. An important point here is that 36 per cent, the highest in the group, of farmers who do not think solar pumps have been a success would prefer 10 HP.

Figure 20: Choice of solar pump size shows significant correlation with size group



Source: Authors' analysis

3.6.2.1 Determinants for adoption

To understand whether awareness and perception of solar pumps, prevailing practices of agricultural investment and renting, and current expenditure on and satisfaction with the irrigation situation influence a farmer's intent to adopt the solar pump, we conducted a regression analysis. We used a conditional fixed-effects logistic model to test the effect of interest variables on the intent to adopt the solar pump. District was used as the group variable for both the models. The equation for the conditional fixed-effects logistic model is as follows:

Adoption of solar pump = Agriculture as a primary activity + Number of land parcels + Cropping intensity + Investment plan for renting + Groundwater depth + Log_2 (total irrigation outlay) + Satisfaction with present irrigation setting + Loan for agriculture (opex & investment) + View on SPIS + View on climatic variations + Outlook on agriculture + Education + Age + Monthly per capita expenditure + Ration card type.

14 Choice of pump size and size group showed significant correlation: χ^2=61.5 and p-value=0.000

The above model was arrived at after multiple iterations, eliminating all possible collinearity, and after establishing a strong correlation between the independent variables. For instance, extent of farm mechanisation and income from agriculture were dropped because they were highly correlated with the size of operational holding. Also, between loan for household and loan for agricultural investment, we chose to retain the latter because it is, intuitively speaking, more likely to affect a farmer's inclination to adopt a solar pump than the former. Overall, we have retained a wide set of variables pertaining to the economic and investment profile, irrigation experience, nature of credit, view on solar pump, behavioural aspect, and demographic profile. Table 3 provides summary statistics of the variables used in the regression model. It also presents the ways in which the responses to these variables have been coded.

Table 3: Summary statistics and coding/recoding of variables used in regression models

S. No.	Variable	Variable type	Response/recoding	Distribution
1	Agriculture as a primary economic activity	Categorical	Farmers were asked whether they pursue agriculture as a primary source of income / economic activity or not 0 = No; 1 = Yes	N = 1,600 0: 14% 1: 86%
2	Size of operational holding	Continuous	Farmers were asked to report the size of all their landholdings. The local units of land were converted into the standard unit, acre	N = 1,599 Mean = 3.4 Std. dev. = 4.0 Min. = 0.125 Max. = 40
3	Number of land parcels	Continuous	Respondents reported the number of parcels into which their land is divided	N = 1,600 Mean = 3 Std. dev. = 3.4 Min. = 1 Max. = 100
4	Cropping intensity	Continuous	Cropping intensity = total sown area in a year /max. sown area in one season	N = 1,595 Mean = 1.8 Std. dev. = 0.44 Min. = 1 Max. = 3
5	Investment plan for renting	Categorical	Farmers were asked if they would buy farm machinery in the future for the purpose of renting it out 0 = No; 1 = Yes	N = 1,600 0: 72% 1: 28%
6	Groundwater depth	Continuous	Respondents reported the maximum depth of groundwater last summer. Unit is in feet	N = 1,598 Mean = 54.3 Std. dev. = 40.0 Min. = 5 Max. = 350
7	Total irrigation outlay	Continuous	Respondents were asked to report the annual amount spent on pumping	N = 1,600 Mean = 11,600 Std. dev. = 13,300 Min. = 0 Max. = 115,000
8	Satisfaction with present irrigation setting	Categorical	Farmers were asked how satisfied they are with their current irrigation setting 1 = Unsatisfied; 2 = Neutral; 3 = Satisfied	N = 1,600 1: 28% 2: 21% 3: 51%
9	Loan for agriculture (opex & investment)	Categorical	Farmers were asked to state whether they had taken a loan to meet operational and investment expenses in agriculture 0 = No loan at all; 1= Loan availed only for opex; 2 = Loan availed for investment	N = 1,600 0: 48% 1: 43% 2: 9%
10	View on SPIS	Categorical	Recoded using two questions on awareness of and views on success of solar pumps 0 = Aware and negative view; 1 = Aware but no view or not aware; 2 = Aware and positive view	N = 1,598 0 = 4% 1 = 86% 2 = 10%
11	View on climatic variations	Categorical	Recoded using farmers' views on rainfall and temperature change 0 = Believes in neither rainfall change nor temperature change; 1 = No opinion on one and do not believe in another; 2 = No opinion on both 3 = Believes in at least one 4 = Believes in both	N = 1,600 0 = 0.06% 1 = 0.38% 2 = 0.75% 3 = 7.8% 4 = 91%

S. No.	Variable	Variable type	Response/recoding	Distribution
12	Outlook on agriculture	Categorical	Farmers were asked if they or their family members would be practising agriculture 10 years hence 0 = No; 1 = Don't know; 2 = Yes	N = 1,600 0 = 4% 1 = 27% 2 = 69%
13	Education	Categorical	1 = No formal education; 2 = Up to class 5; 3 = Up to class 10; 4 = Class 12 or diploma; 5 = Graduate or above	N = 1,600 1 = 25% 2 = 25% 3 = 26% 4 = 13% 5 = 12%
14	Age	Continuous	Age was reported in years	N = 1,600 Mean = 46 Std. dev. = 15 Min. = 18 Max. = 100
15	Monthly per capita expenditure (MPCE)	Categorical	Farmers were asked to report their household monthly expenditure and the number of members in their household. The calculated MPCE values were then categorised into deciles which have been used in regression.	N = 1,600 Mean = 1,170 Std. dev. = 1,040 Min. = 100 Max. = 17,500
16	Type of ration card	Categorical	Farmers were asked to state the kind of ration card they hold 1 = None & APL; 2 = BPL; 3 = Antyodaya & Anapurna	N = 1,600 1 = 63% 2 = 30% 3 = 7%
17	Adoption of solar pump	Categorical	Farmers were asked if they would be willing to adopt the solar pump or not 0 = No; 1 = Yes	N = 1,600 0 = 59% 1 = 41%

Source: Authors' analysis

Table 4: Determinants for adoption of solar pumps

Dependent variable: Adoption of solar pumps			
Independent variable	**Coefficient (B)**	**Std. error**	**Exp(B)**
Agriculture as a primary economic activity	0.54***	0.20	1.7
Size of operational landholding	0.01	0.02	1.01
Number of land parcels	(0.01)	0.02	0.99
Cropping intensity	(0.03)	0.13	0.97
Investment plan for renting	0.65***	0.13	1.91
Groundwater depth	(0.005)**	0.002	0.995
Log2 (total irrigation outlay)	0.13**	0.06	1.13
Satisfaction with present irrigation setting	(0.17)**	0.08	0.84
Loan for agricultural investment	0.21**	0.10	1.24
View on solar pumps	0.63***	0.16	1.88
View on climate variations	0.17	0.18	1.19
Outlook on agriculture	(0.25)**	0.11	0.78
Education	0.19***	0.05	1.2
Age	(0.01)**	0.004	0.99
MPCE	0.003	0.02	1.00
Type of ration card	0.12	0.10	1.13

*χ^2=127.2; ***p<0.01; **p<0.05; Exp(B): Odd ratio; N=1,433*

Source: Authors' analysis

We found that **farmers for whom agriculture was the primary source of income have 70 per cent higher odds of adopting solar pumps than those who do not pursue agriculture as a primary livelihood activity**. Thus, it is important for policymakers and deployers to target farmers for whom agriculture is the primary occupation. Policymakers can target such farmers by focusing more on districts and blocks that have a higher proportion of households indicating agriculture as their primary source of income. Deployers can use it as a screening question to further gauge the interest of farmers in SPIS. Interestingly, increasing size of landholdings did not have any significant impact on increasing the interest of farmers in the adoption of solar pumps. **While we hypothesised that the ownership of fragmented land parcels may adversely affect a farmer's interest in adopting SPIS, we found it did not have any affect at all.**

We also found that **farmers who intend to invest in farm machines to rent them out after personal use have two-times higher odds of adopting solar pumps** than those who do not intend to make this investment.

Contrary to our hypothesis, we found that the prevailing groundwater levels have almost no influence on farmers' inclination to adopt solar pumps. This is a revelation because interest in, and adoption of, solar pumps in areas with low water tables may pose potential challenges to the sustainability of both the groundwater resources as well as the solar pumps themselves. However, a majority of the farmers in regions with low water tables are demanding higher-rating pumps (typically 7.5 HP or 10 HP). As long as the affordability of such pumps remains a barrier, there is less likelihood of farmers adopting solar pumps in areas with low water tables.

The current spending on irrigation by farmers has a significant impact on their inclination to adopt solar pumps. A 100 per cent increase in irrigation expenditure increases the odds of adoption by 13 per cent. Farmers who are satisfied with their current irrigation setting have 71 per cent lower odds to adopt solar pumps than those who are dissatisfied. If a farmer has previously taken a loan to make investments on her farm, she has 1.24 times higher odds to adopt a solar pump than a farmer who has not done so.

We also find that farmers with a positive view of the effectiveness of the solar pump have almost two-times higher odds to adopt it than those who are not aware of the technology, or who have no view on its potential success or failure. This underpins the importance of awareness generation and technology demonstration on the ground to increase farmers' positive perception of, and interest in, the adoption of solar pumps. **An educated farmer is more likely to purchase an SPIS. This could be because better education correlates with better awareness**. With an increase in the level of education, a farmer's odds to adopt an SPIS increases by 20 per cent.

The variable total irrigation outlay was highly correlated (r=0.44) with the size of the operational landholding, and hence we considered another regression model in which the former was dropped, and only the latter retained. Size of the landholding turned out to be a significant variable in this model but had only a marginal impact on a farmer's interest in the adoption of a solar pump (see Appendix). With every increase of one acre in the size of landholding, the odds of solar pump adoption increase by four per cent.

3.6.3 Deployment methods for SPIS

So far, solar pumps are predominantly deployed in India under a conventional individual ownership model. This model may continue to remain the mainstay approach for the deployment of solar pumps given the fact that high capital cost is a barrier for the majority of the farmers, particularly small and marginal farmers. Nevertheless, we explored farmers' views on alternative deployment approaches, namely joint ownership and water-as-a-service.

a) Joint ownership

Overall, 20 per cent of farmers are interested in joint ownership of a solar pump where the cost and the loan for the purchase of the pump would be shared between two or more farmers. Four per cent of farmers who are otherwise not willing to adopt solar pumps expressed willingness to adopt the technology under the joint ownership model. Among those who are willing to adopt solar pumps, 39 per cent are interested in joint ownership. This proportion is six times and ten times higher than the prevailing proportions for joint ownership of electric and diesel pumps respectively (see Figure 8). Higher proportions of marginal and small farmers are interested in opting for the joint partnership model as compared to medium and large farmers. The main reason stated by farmers for not adopting solar pumps under the joint ownership model is the possibility of future conflicts with fellow farmers. Long distances between farms is stated as the second main reason.

b) Water as service

When asked about their interest in buying water for irrigation, a little less than a quarter of the respondents were interested in buying water from a private entrepreneur selling it at a fixed price, and another 55 per cent were interested in buying water directly provided that it is available at an economical rate. About three-fourth of farmers, whether renters of electric pumps or diesel pumps (or those who are currently buying water) or whether owners of diesel pumps, are interested in purchasing water from solar pumps. In comparison, only 60 per cent of electric pump owners are interested in purchasing water from solar pumps.

3.6.4 Willingness-to-pay (WTP) for SPIS

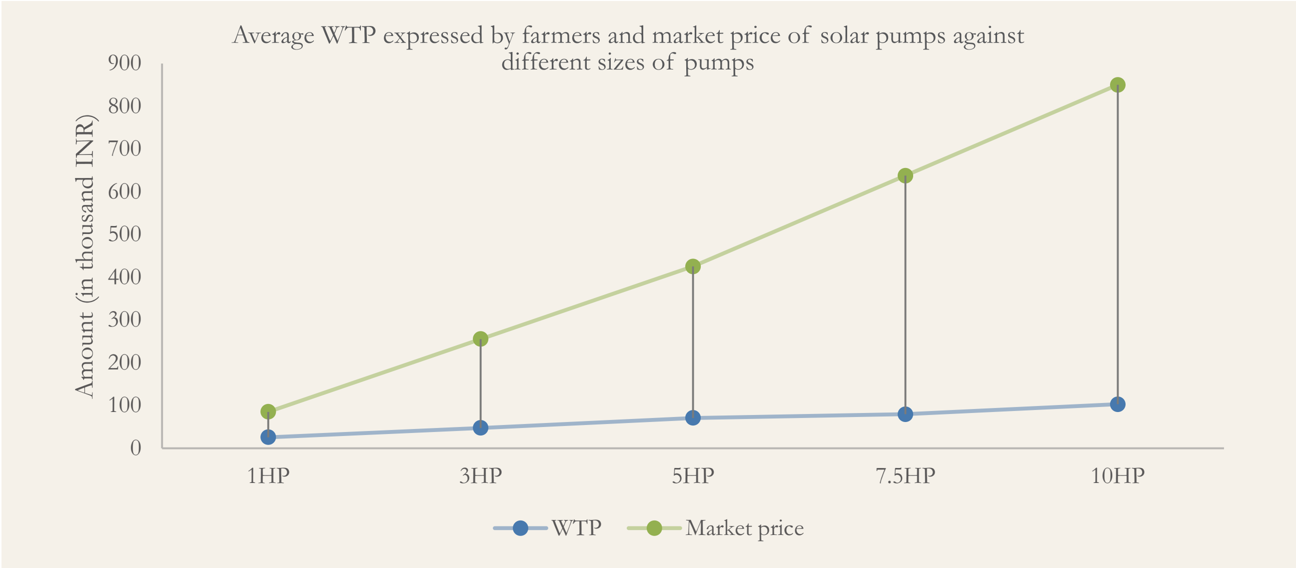
In the survey, we also asked farmers to indicate the amount they would be willing to pay for the solar pump of their chosen size after we provided them a tentative market price for the given size.[15] The WTP[16] expressed by farmers, as expected, shows a consistent rise with increasing pump size.

On average, the WTP indicated by farmers (translated into rupees) is much lower than the market price of solar pumps. For instance, against the quoted price of INR 425,000 for a 5 HP pump, the average WTP was INR 70,800, 17 per cent of the quoted price (see Figure 21). The average WTP, as a fraction of the quoted market price, declines with an increase in the pump size, from 30 per cent for a 1 HP pump to 12 per cent for a 10 HP pump. We also find that for each size of solar pump, marginal and smallholder farmers typically quoted a lower WTP than medium and large farmers.

15 The tentative market costs (in INR) that we provided to farmers were as follows: 1 HP: 85,000; 3 HP: 255,000; 5 HP: 425,000; 7.5 HP: 637,500; 10 HP: 850,000.

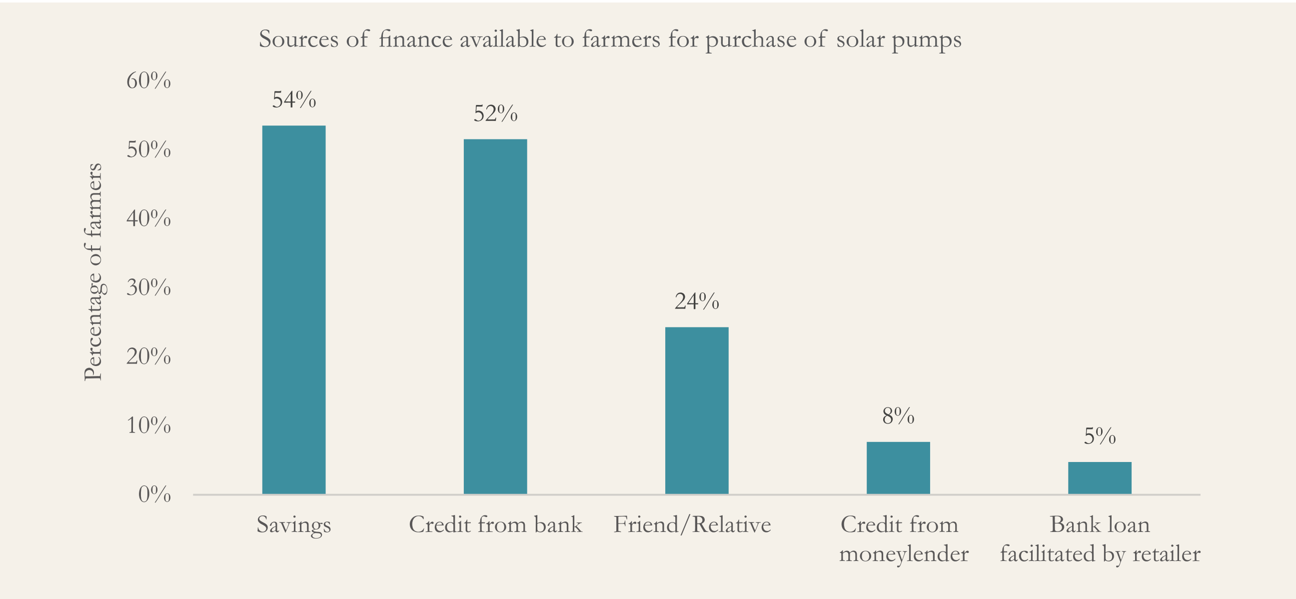
16 Aggregate considers all the three scenarios under which a farmer was asked to report her WTP.

Figure 21: WTP, as fraction of market price, decreases with increasing size of pump



Source: Authors' analysis

Figure 22: Savings and credit from bank are the two biggest sources available to farmers for financing purchase of solar pump



Source: Authors' analysis

About 54 of the farmers who were interested in adopting solar pumps said that they would use their savings, while 52 per cent would take credit from a bank to finance the purchase of the pump (see Figure 22). A farmer asserted during the FGD: "*I will have to exhaust all sources to finance the purchase of the solar pump.*" Ninety-two per cent large and 81 per cent medium farmers would rely on savings as compared to 51 per cent marginal farmers and 49 per cent small farmers. In terms of availing credit from banks to finance SPIS, large (67 per cent) and medium (49 per cent) farmers do not seem to have any significant lead over marginal (51 per cent) and small farmers (49 per cent).

4. Recommendations

The study has yielded various important insights that would serve the key stakeholders, policymakers, enterprises, and financiers who are working towards the large-scale adoption and financing of solar pumps. Based on our findings, the following key recommendations are made for the way forward.

I. Focus on awareness generation and technology demonstration

Only 27 per cent of farmers in UP had heard of solar pumps, with less than 2 per cent being aware of government schemes pertaining to solar pumps. We find that awareness, along with a farmer's positive view on SPIS, increases the likelihood of adoption by her by twice as much as compared to a farmer who is not aware of SPIS or who has no view on its relative success. We also find that technology demonstration plays a vital role in improving farmers' perception of solar pumps, which in turn increases the likelihood of its adoption by them. Our analysis suggests that demonstrations through videos and television programmes would help, but not as much as in-person physical demonstrations. Thus, the government should focus on raising awareness about the technology among farmers through different channels of communication.

1. MNRE should engage with MoA in order to use the latter's existing touch-points of information dissemination and farmer engagement to generate awareness about solar pumps for irrigation.
2. MNRE should consider deploying at least five solar pumps in each block across the country, prioritising regions with better groundwater availability. These pumps, about 30,000 in number, could have a significant impact through technology demonstration in increasing or strengthening farmers' inclination to adopt the technology.
3. Further collaboration with banks to use their local agricultural assistants, who spread awareness about the benefits of farm machines among farmers, could help enhance farmers' awareness about SPIS.
4. The private sector, particularly system manufacturers and deployers, should further sharpen their focus on both awareness generation and effective after-sales services. Technology demonstration also produces negative perceptions about the technology (as emerged in our study) if the existing pumps in the farmer's vicinity are not working effectively. Hence, the incentive to ensure the effective and proper performance of the exiting installations is significant, particularly for market players who are considering entering into a long-term business in solar pumps.
5. Efficient irrigation practices, such as drip and sprinkler irrigation, is another area where farmers' awareness should be improved. MNRE, MoA, and MoWR would need to work collectively on this. Efficient water-use practices reduce the requirement for irrigation, and hence also the size of solar pumps, thereby improving their economic viability and increasing their affordability.

II. Improve targeting of the prevailing subsidy programmes

We find that on average farmers are willing to pay only 12–30 per cent of the prevailing market prices of solar pumps. The gap between WTP and market prices increases for marginal and small farmers, indicating a greater need to support them through subsidy or preferential financing. However, majority of the beneficiaries of current government programmes are large and medium farmers (SSEF, 2018). From an equity perspective, there is a need to target marginal and small farmers who lack access to electricity connections for irrigation and who rely on costly (and usually rented) diesel-based irrigation. Also, we find that marginal and small farmers are typically interested in solar pumps of 3 HP or smaller, whereas medium and large farmers are typically interested in solar pumps of 5 HP or larger.

1. The government should target small and marginal farmers by supporting smaller pumps (up to 3 HP) through capital subsidy, whereas for larger pumps (more than 3 HP), it should facilitate the development of a strong financial ecosystem to enable the adoption of SPIS.
2. While electric pump owners indicate very high satisfaction levels with their current irrigation arrangement (87 per cent), close to 40 per cent of such farmers are interested in adopting solar pumps. Incidentally, the group also has the highest WTP among all the farmers. Such farmers could adopt SPIS through market mechanisms and should not be targeted under the government subsidy programme.

III. Encourage SPIS deployment under enterprise model (water/irrigation as-a-service)

The high upfront cost of solar pumps is the biggest barrier to their adoption. While financing and capital subsidies could help reduce that barrier, we find that the gap between farmers' willingness to pay and the prevailing market price of the technology remains very wide. The gap widens further in the case of marginal and small farmers. Apart from supporting them through subsidies or preferential financing to increase direct ownership of SPIS, access to irrigation for such farmers could be improved through the water-as-a-service model using solar pumps. More than three-fourths of farmers expressed willingness to buy water from solar pumps if it is available at competitive prices. High expenses on diesel pump-based water renting prevents marginal and small farmers from purchasing other agricultural inputs. Literature also suggests that solar pumps could provide water-as-a-service more economically than diesel pumps if shared effectively (Raymond & Jain, 2018). However, constraints on the physical mobility of solar pumps as well as the seasonality of irrigation loads limit their sharing and utilisation potential.

The water-as-a-service model could maximise access to irrigation for farmers with limited capital resources, while also offering the co-benefit of containing or restricting over-extraction of groundwater by individual farmers. Given the zero operational cost of solar pumps, individual farmers have limited incentive to avoid over-extraction of groundwater. Whereas if an enterprise or a farmers' collective were to provide water to farmers on the basis of a volumetric tariff, their incentive would be aligned to the goal of responsibly managing and recharging local aquifers to sustain their business or agricultural activity in the long run.

The government may consider supporting the water-as-a-service model for the adoption of SPIS among marginal farmers by encouraging cooperative and enterprise ownership.

IV. Design financing products to support SPIS adoption

Large farmers, particularly those with relatively high ownership of machines, and who are interested in adopting these devices in order to rent them out to others, could be targeted by financiers for SPIS adoption under a market-based approach. Such farmers have twice the odds of adopting solar pumps than others, and have the highest WTP for the technology, for any particular size of the pump. Financiers need to be trained to assess the economic viability of such investments.

Given the relatively high interest among farmers in the adoption of SPIS under the joint ownership models (particularly among small and marginal farmers), financiers should look for ways to support such an adoption through innovative approaches, while being cautious about the potential disadvantages of a group ownership model.

V. Improve ease of banking and loan disbursal process for farmers and develop SPIS financing products

The importance of due diligence during the disbursal of credit cannot be underemphasised. However as is evident from the survey findings, the loan disbursal process needs to be made easier and more user-friendly for farmers. The following recommendations are not specifically aimed at improving SPIS financing, but would in general improve farmers' experience and view of institutional financing, thereby increasing the likelihood of their investing in agriculture.

1. Bankers should simplify and standardise the process for SPIS credit approval as far as possible and communicate pertinent information about the process in even further simplified terms to farmers. SPIS deployers should facilitate communication between bankers and farmers and should aid the credit approval process.
2. Farmers should be empowered and should be made aware of the possibility and process of reporting incidents of harassment by bank officials to a central grievance facility of the concerned bank.
3. The central authorities of the banks should take proactive corrective actions to address and resolve such complaints.

Improving the interface between the bank and the farmer will go a long way in ensuring a steady and loyal customer base among farmers and will, in turn, broaden the base of access to institutional credit among those who need this resource. Such efforts would be particularly helpful in facilitating SPIS adoption, because at least half of the farmers interested in adoption are counting on receiving credit from banks to finance their purchase of solar pumps.

5. Conclusion

The increasing unpredictability of climatic conditions has already started affecting agriculture in India. Changing rainfall patterns, rising temperatures, and declining groundwater levels are major challenges that are already confronting farmers, and are likely to intensify in the future. Apart from these impending ecological constraints, the existing inequity in access to irrigation also worsens the situation of farmers. Marginal and small farmers are the worst hit, given their limited resilience against adverse climatic conditions, excessive expenditure on irrigation, and poor purchasing capacity to adopt climate-adaptation technologies like solar pumps.

While the government is making significant efforts to support the adoption of SPIS by farmers, the study highlights the need to better target the support among small and marginal farmers. We need to go beyond the conventional realm of the product ownership-based adoption model to look at alternative deployment approaches, such as irrigation-as-a-service and joint ownership of SPIS. Better targeting and innovative deployment approaches need to be complemented by greater awareness generation, more technology demonstration, and improved after-sales services to create a strong and positive perception of the technology and to encourage its long-term adoption and sustainability among farmers. In addition, the banking sector needs to support farmers by simplifying their processes as well as their communications; by extending proactive support to farmers, including hand-holding through the loan-application process, the documentation process, and the credit-disbursal process; and by developing financial solutions to cater to the SPIS market through different deployment approaches.

Only such consumer-centric approaches would help in improving access to irrigation through solar-powered technologies at the required pace. To begin with, it is important to undertake pilot projects for various adoption models in different contexts to learn from on-ground experience and then to scale them up further. While the present study endeavours to support the pursuit of scaling up the adoption of SPIS by highlighting the gaps and by describing the way forward, there is certainly a need to test and validate some of the findings in other agro-ecological and socio-economic contexts in order to gain a richer understanding of the realities across a country as vast and diverse as India.

Appendix

Table 5: Determinants for adoption of solar pump

Dependent variable: Adoption of solar pump			
Independent variable	**Coefficient (B)**	**Std. error**	**Exp(B)**
Agriculture as a primary economic activity	0.48***	0.19	1.61
Size of operational landholding	0.04**	0.02	1.04
Number of land parcels	(0.01)	0.02	0.99
Cropping intensity	(0.03)	0.13	0.97
Investment plan for renting solar pump	0.69***	0.13	1.99
Groundwater depth	(0.003)	0.002	0.997
Satisfaction with present irrigation setting	(0.15)**	0.07	0.86
Loan for agricultural investment	0.22**	0.09	1.25
View on solar pump	0.68***	0.15	1.98
View on climate variations	0.22	0.17	1.25
Outlook on agriculture	(0.22)**	0.11	0.80
Education	0.15***	0.05	1.16
Age	(0.01)	0.004	0.99
MPCE	(0.01)	0.02	1.00
Type of ration card	0.06	0.10	1.07
Type of ration card	0.12	0.10	1.13

*χ^2=120.0; ***p<0.01; **p<0.05; Exp(B): Odd ratio; N=1,590*

Source: Authors' Analysis

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