Solar Irrigation Pumps
Farmers' Experience and State Policy in Rajasthan

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Price of solar panels has declined rapidly. Encouraged by increasing affordability of the technology and its promise to curb the demand for subsidised electricity, state governments in India are aggressively promoting solar irrigation pumps. Rajasthan became the pioneer by announcing a scheme in 2011 with 86% subsidy to horticulture farmers who used drip irrigation and farm ponds. Based on extensive fieldwork and survey in three districts of Rajasthan, this paper looks at the farmers' experiences, the design and implementation of the policy, and makes recommendations for a faster and more equitable diffusion of the technology, which could attack India's invidious nexus between energy and groundwater irrigation, and change it for the better.

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The hydrological cycle in nature is powered by the Sun, but use of solar energy for artificial irrigation is rare. This is because, up until recently, systems to capture solar energy were expensive. That is changing, however. Over the last 30 years, the price of solar panels to capture solar energy has dropped exponentially from Rs 1,320/watt power (wp) in 1980 to Rs 60/wp in 2013.[1] Most analysts agree that solar panels will become still cheaper, making solar energy an increasingly cost-effective option in the future (Naam 2011). Several studies in India and other countries of the world show that the life cycle cost of solar-powered pumps is lower than that of liquid-fuel-based pumping systems (Kolhe et al 2002; Odeh et al 2006). In India, electricity from solar panels now costs only half as much as that from diesel generators, even when diesel is subsidised.[2] This is mainly because photovoltaic (PV) systems have long lifetimes, need minimal attendance and little maintenance, and have near-zero operational costs. PV systems have an additional advantage over fossil fuels: they provide emission-free power using a renewable source of energy.

Still, according to an estimate in 2005 (Purohit and Michaelowa 2005), there were only 7,000 solar pumps in operation in India, compared to more than 1.9 crore diesel and electric pumpsets. The high initial capital cost of PV panels remains the major barrier to their widespread use (Firatoglu and Yesilata 2004). PV pumpsets have been possible mainly where subsidies have been available from either governments or aid agencies (Short and Oldach 2003).

Encouraged by the plummeting cost of solar power systems and its environmental benefits, but even more by its promise to reduce the demand for new electricity connections and subsidised electricity for irrigation, the Government of Rajasthan (GoR) launched a Rs 515 crore scheme in 2011 to provide subsidised solar irrigation systems to 10,000 farmers in the state over three years. In 16 districts of the state, 1,675 farmers got solar pumps of 2,200 or 3,000 wp at a subsidy of 86% (Table 1, p 57) in the first year of the scheme (2011-12). Most of these pumps were installed in farmers' fields in the summer (March-June) of 2012. In the second year, the state government plans to install an additional 4,500 solar pumps in all 33 districts of Rajasthan.

This paper is based on extensive fieldwork and a survey of a random sample of 107 farmers in north Rajasthan and Jaipur who had installed PV pumps in their fields in 2012 with subsidy from the GoR. To the best of our knowledge, this is the first study of a large number of farmers using solar-powered pumps for irrigation anywhere in the world. The rest of the paper is divided into three parts. In the first part after the introduction, we discuss different aspects of the design and implementation of the subsidy policy to promote solar pumps based on what we learned in our fieldwork in Bikaner, Jaipur, Hanumangarh and Sri Ganganagar districts of Rajasthan. In the first year, more than 80% of all subsidised PV pumps (1,357 of 1,675) were installed in these four districts only.

In the second part of the paper, we present results of our survey with a random sample of 107 solar pump owners spread across 105 villages in Bikaner, Jaipur and Sri Ganganagar districts. Here, we focus on farmers' experience with solar pumps, challenges they faced in using them, main benefits and limitations of solar-powered irrigation, and the ways in which solar pumps could be made more useful to farmers.

The third and final part of the paper brings together our findings from the fieldwork and the farmers' survey, and draws some policy conclusions.

1 Promoting Photovoltaic Pumps

1.1 The Rajasthan Solar Water Pumping Project

Rajasthan has the best solar radiation in India and is amongst the best in the world (GoR nd). Solar radiation potential in the state is up to 6-7 kwh/sq m, and there are more than 325 sunny days in a year when a solar-powered pump can provide an uninterrupted irrigation supply for 6-8 hours in a day (ibid). In 2009-10, the state government installed 14 PV pumps in its own farms to test the technology's feasibility. In 2010-11, 50 solar pumps were installed in farmers' fields to see if the technology worked in the field. After two years of successful tests, the state government launched a Rs 515 crore scheme in 2011 to provide 10,000 subsidised solar PV pumping systems to farmers across the state. The state government expects to save an estimated nine crore units of electricity per year once all 10,000 solar power systems are installed.[3]

The scheme provides farmers with 86% subsidy on the capital cost of the pump. The subsidy comes from two sources: 56% from the Rashtriya Krishi Vikas Yojana (RKVY) implemented by the state government with funds allocated by the central government, and the balance 30% from the Ministry of New and Renewable Energy (MNRE) of the Government of India (GoI) under the Jawaharlal Nehru National Solar Mission (JNNSM). The Rajasthan Horticulture Development Society (RHDS) in the Directorate of Horticulture, Rajasthan is the nodal agency for implementing this project.

1.2 Selection of System Suppliers and Price Fixation

The directorate invited online bids from interested companies for supply and commissioning of solar photovoltaic (SPV) pumps in farmers' fields through an open tender. Companies that had been manufacturing SPV modules or panels in India for more than three years, were approved or recognised by MNRE, Rajasthan Renewable Energy Corporation Limited (RRECL), RHDS or Department of Horticulture, Rajasthan, and had a minimum turnover of Rs 10 crore in any of the three years, were eligible to sell subsidised solar power systems under this scheme. In 2011, four companies – Jain Irrigation Systems, Rajasthan Electronics and Instruments Limited (REIL), Topsun Energy and WAAREE Energies – qualified. The subsidy was payable only on systems purchased from one of these four companies. The number of empanelled companies has gone up to 12 in the second year.

The lowest price quoted by empanelled firms becomes the base price on which the government offers the subsidy. The base price varies across different technical configurations of PV pumping systems (Table 3, p 58). Once the base price is decided, all other empanelled manufacturers have to match this price. They cannot sell their systems at a price higher or lower than the base price decided after the bidding. The farmer gets 86% of the base price as subsidy support to buy the PV pumping system. For example, the base price for a 3,000 wp surface pump with a 20 metre head was Rs 5,37,000 in 2011-12. A farmer who bought a PV pump of this configuration received a subsidy of Rs 4,61,820 (= 0.86*5,37,000) from the government and paid Rs 75,180 as his share.

The base price includes the cost of all components (solar panels, SPV pump, galvanised iron (GI) support structures and accessories), their delivery to the farmer's field and the installation therein, including civil works, training of farmers in proper use and maintenance of the system, and its free repair and maintenance in the guarantee period of first five years after installation.

1.3 Selection of Beneficiaries and Installation

The manufacturer receives its payment in three instalments. The RHDS invites applications from farmers for subsidy through advertisements in newspapers. Manufacturers have recruited local dealers who work as intermediaries between them and the farmers. Dealers and other company representatives contact farmers to generate demand for their product. A farmer, who wants a PV pump, submits the order for pump installation to the horticulture directorate's office in the tehsil with a demand draft of Rs 10,000. This forms the first instalment of the payment. Dealers help farmers with the paperwork, somewhat like in the Million Wells Scheme in Bihar and Uttar Pradesh (Shah 2001).

The tehsil office forwards the application to the district office, where every application is assessed to make sure that the farmer meets the three eligibility criteria for the subsidy: (i) he should own at least 0.5 hectares (ha) of land; (ii) his land should have a *diggi* (a farm pond) or other water storage structure; and (iii) he should have installed a drip irrigation system in his farm. Farmers who own up to 2 ha of land could apply for a 2,200 wp pump, and those with more than 2 ha of land were eligible to apply for a 3,000 wp pump. The eligibility criteria are transparent and known to the applicants. A farmer has to deposit her share (14%) of the base price of the system within 15 days of the announcement of her selection for allocation of a subsidised PV system.

The supplier is required to deliver all components of the system – solar panels, the pumpset, GI support structures and other accessories – to the farmer's plot within 45 days of his depositing the money. The farmer signs a paper certifying that she has received all the material on her plot. The company gets the second instalment of money (36%) on submitting this receipt to the department. The company, then, has to finish the installation and start the system operation within 20 days of the material's delivery. A committee nominated by the RHDS visits the farm and certifies that the system installation is complete and that it is working. The manufacturer gets the balance 50% of the base price after this verification. The manufacturer is also required to submit an irrevocable bank guarantee of 10% of the base price of the system in favour of the mission director, RHDS, valid for five years to ensure its commitment of five years of free maintenance of the pumping system.

The government had set a target of installing 1,600 solar pumps in 16 districts of the state in 2011-12.[4] The Directorate of Horticulture allotted a fixed quota of subsidised solar pumps to each district (Table 1). This district-wise quota was made public at the launch of the scheme itself. It does not seem to follow a clear formula, but districts where horticulture is more common and where more farmers have diggis got higher allocations. If eligible applications for solar pumps exceeded the quota in a district, then the final allocation was to be decided by an open lottery in the district collector's office. In some districts, like Sri Ganganagar, the number of eligible applications exceeded the quota in 2011-12, while in others, like Alwar, the opposite was true. The RHDS moved excess allocations from districts with too little demand to districts with excess demand. As a result, every eligible farmer who applied for a PV system ended up getting one in the first year of the programme.

Table 1: Number and Capacity of Solar Pumps Installed in Rajasthan as on 30 September 2012

District	2,200 wp	3,000 wp	Total
Alwar	4	10	14
Bhilwara	0	34	34
Bikaner	10	382	392
Chittorgarh	0	24	24
Dholpur	0	0	0
Sri Ganganagar	16	605	621
Hanumangarh	12	252	264
Jaipur	9	71	80
Jaisalmer	2	30	32
Jhalawar	0	0	0
Jhunjhunu	8	19	27
Jodhpur	0	51	51
Kota	7	13	20
Nagaur	4	30	34
Sawai Madhopur	0	37	37
Sikar	1	44	45
Total	73	1,602	1,675
Total kwp	161	4,806	4,967

Source: Directorate of Horticulture, Rajasthan.

1.4 Limiting Provisions in the Subsidy Policy

The Rajasthan government's policy allows only companies that manufacture solar panels in India to bid for supplying subsidised PV pumps to farmers. This is an unusual requirement given that the solar power sector in India and the rest of the world is dominated by system aggregators[5] and it restricts entry and competition. A solar panel manufacturer can, however, outsource solar pumps from other Indian or international companies. In the first year of the scheme, only manufacturers who provided pumps running on direct current (DC) were eligible to bid. DC pumps are more energy efficient than their alternating current (AC) counterparts and can work at lower radiation levels, but they are also significantly more expensive. Also, there are very few DC pump manufacturers in India and they mainly produce surface pumps. Submersible DC pumps, the most commonly demanded variety in Rajasthan, are imported from other countries like Germany, Australia and China.

In the second year of the scheme, AC pumps configured with the solar power system and approved by the MNRE, have also been allowed. Partly due to this change in the policy, the number of empanelled manufacturers eligible to sell subsidised solar PV systems to farmers has increased from four to 12. The resulting increase in competition, the continuing fall in the cost of solar panels, and the permission to use cheaper AC pumps as a part of the system have brought down the base price of a 3,000 wp PV system from Rs 5.7 lakh in 2011-12 to Rs 4.75 lakh in 2012-13 – a decline of nearly 17% in one year.

Interestingly, rules in Rajasthan do not allow manufacturers who provide more efficient and more expensive DC pumps, like the Jain Irrigation Systems, to charge a price for their product higher than other manufacturers that sell PV pumping systems with an AC pump. The base price is decided by the watt-power rating of solar panels and not the make of the pumpset. Systems with AC and DC pumps have to be sold to farmers at the same price in spite of a significant difference in their costs.[6] Manufacturers who sell systems with DC pumps could still stay in the market because the base price arrived at after the open bidding is much in excess of what competitive prices would be. We met an independent entrepreneur, who sells unsubsidised PV pumps directly to farmers without any intermediation by the government. He offers a 3,000 wp solar power system with an AC pump for Rs 1.4 lakh compared to the Rs 4.75 lakh charged by empanelled firms in 2012-13.[7]

The taxpayers and beneficiary farmers lose money in the current system not only due to overpricing, but also due to the long time-lapse between the bidding and the actual installation of PV pumps in farmers' fields. For example, the base prices of PV irrigation systems for the second cycle of the programme were decided after open bidding in June 2012, while actual installation of systems was to start only in the second quarter of 2013. Meanwhile the price of solar panels has come down from Rs 49/wp to Rs 32/wp. This implies that a 3,000 wp solar array, the most popular configuration in Rajasthan, is now cheaper by nearly Rs 50,000, compared to the time when the bids were submitted. This significant reduction in the cost of solar panels increased the aggregate profit margins of all empanelled manufacturers by Rs 22.5 crore, while the taxpayers, bearing the lion's share of the cost, would not gain anything.[8]

1.5 Suggestions for Improving the Subsidy Scheme

Our quick review of the ongoing subsidy scheme for promotion of solar pumps in Rajasthan suggests that there is ample scope for improvement in the design and implementation of the policy.

(a) Reduce Entry Barriers to Increase Competition among Suppliers*:* Firstly, the scheme should be designed in a way to foster more competition among firms supplying solar power systems to farmers. We saw that as the number of empanelled firms increased in the second year, the base price reduced sharply by almost Rs 1 lakh. This reduction exceeds that in the cost of solar panels and other components during the two years. Clearly, in the absence of enough competition, the bidding mechanism did not work well in the first year. The overpricing seems to persist in the second year too, but to a lesser degree than the first time, when there was much less competition. Besides panel manufacturers, the GoR should allow credible system aggregators to participate in the programme too in order to increase competition.

(b) Shift from Pro Rata to Lump Sum Subsidy: The existing way of subsidising PV systems distorts farmers' incentives. They pay only one-seventh (14%) of the incremental cost of an added feature or higher capacity; the rest is paid for by the taxpayer. As a result, farmers tend to make choices that are privately beneficial, but socially suboptimal. Often, they overinvest in the capacity and design features of the system. For example, even where a surface pump would suffice, farmers went for the more expensive submersible option. Submersible pumps give higher discharge for the same pumping head than a surface pump; still, more farmers may have selected surface pumps if they had to pay the full incremental cost of the submersible system.

The GoR should shift from the system of offering a fraction of the total cost (86% now) as subsidy, to a new system where they give a fixed amount as a lump sum subsidy[9] to every eligible farmer who installs a solar irrigation pump. The lump sum subsidy would allow a greater choice to farmers, foster more price competition among firms selling solar power systems, and it would not distort incentives of farmers or the firms. The Gujarat Green Revolution Company (GGRC) uses this model of lump sum subsidy (Rs 50-60,000/ha) to promote drip and sprinkler irrigation with success (Kishore 2013). The GoR would do well to emulate this model for promotion of solar pumps.

2 Farmers' Experiences: Evidence from a Primary Survey

2.1 Methodology and Sample Selection

The solar pumps scheme was launched in 16 of the 33 districts of Rajasthan in the first year. Of these 16 districts, the maximum number of pumps was allotted in Sri Ganganagar (691), Bikaner (279), Hanumangarh (264) and Jaipur (71). We did fieldwork in all four districts. However, when selecting farmers for the primary survey, we dropped Hanumangarh from our sample because it is very similar to Sri Ganganagar in its cropping pattern, water availability, and the profile of farmers. Indeed, Hanumangarh was a part of Sri Ganganagar district till 1994.

In the first year of the programme, 1,093 farmers had installed PV irrigation systems in these three districts. We got names of these farmers from the Directorate of Horticulture and randomly selected a 10% sample from each district using a random number generator in Stata for our primary survey. Thus, we had a sample of 110 farmers – 40 in Bikaner, eight in Jaipur, and 62 in Sri Ganganagar (Table 2). Three of these 110 farmers refused to talk to us, reducing our effective sample size to 107 solar pump users. We have a random sample of all solar pump users in these three districts of Rajasthan, but our sample is too small to be representative of the population. Budget and time limitations forced us to work with a small sample.

Table 2: Number of Solar Pumps Installed in Rajasthan and of Farmers Surveyed

District	Solar Pumps Installed in the Scheme	Sample Size
Bikaner	392	40
Jaipur	80	8
Sri Ganganagar	621	62
Rajasthan	1,675	110

Source: Directorate of Horticulture, Rajasthan.

Table 3: Base Rate (in Rupees) of Different Configurations of Solar Pumps in 2011-12

Type of Pumpset	2,200 wp		3,000 wp	
	Base Rate	Farmer's Share	Base Rate	Farmer's Share
Surface pump 20m head	3,76,500	52,710	5,37,000	75,180
Submersible pump 20m head	3,89,900	54,586	5,60,300	78,442
Submersible pump 50m head	3,95,800	55,412	5,62,300	78,722
Single axis auto tracker	38,000	5,320	54,000	7,560

Source: GoR (2011) .

2.2 Key Findings from the Survey

(a) All Pump Owners Met the Essential Criteria for Getting the Subsidy: All 110 farmers that we sampled from the list of beneficiaries provided by the Directorate of Horticulture had installed solar pumps. Each one of them had a diggi and all of them had purchased drip irrigation systems, even if some of them were not using it for irrigating their fields. Thus, every beneficiary we surveyed fulfilled the essential criteria set by the policy to qualify for subsidised solar pumps. We highlight this fact because compromising selection criteria in targeted schemes is common in India (Niehaus and Atanassova 2013), but it did not happen in this scheme, at least in its first cycle, perhaps because of the small number of beneficiaries involved.

When we surveyed farmers in December-January 2012-13, they had used their new pumps in the summer and the kharif seasons and also had some experience of how useful these pumps would be in winter, when dense fog blocks the sun for days together in parts of rural Rajasthan.

(b) Local Dealers Had a Big Influence on Farmers' Choices: Among the four empanelled companies, Jain Irrigation Systems was the preferred choice of farmers, followed by Topsun, WAAREE and REIL, in that order. All but two farmers chose to buy the 3,000 wp systems, and given a choice, most of them would have gone for a more powerful system. Nearly half of our respondents did not even consider any other brand except the one they had purchased. Familiarity with the company's dealer was the biggest influence on their choice of supplier. Sixty-five out of the 107 farmers in our survey chose their present brand of solar pump because they knew the company's dealer beforehand. This confers advantage to Jain Irrigation

Systems over its competitors because it has a dense network of dealers in the state through its micro-irrigation business. Local dealers of PV system suppliers helped respondents prepare the paperwork for availing the subsidy.

(c) Farmers Thought PV Systems in the Scheme Were Overpriced: Farmers paid Rs 78,000-80,000, their fair share, for the PV pumping system. It was a common belief among our respondents that suppliers had set prices too high and were making supernormal profit at the cost of the farmers and the government.

(d) The Subsidy Went Mainly to Medium and Large Farmers: Out of 1,675 solar pumps, 1,277 (76.23%) were installed in the three canal-irrigated northern districts of Rajasthan (Sri Ganganagar, Hanumangarh and Bikaner) where the average holding size is much larger than the state average and horticulture is more popular. Even within these districts, where large landholdings are common, the average size of the land owned by farmers who bought subsidised solar pumps is higher than the district average (Table 4). Across all three districts, not a single solar pump owner in our sample was a small or a marginal farmer. The subsidy on solar pumps has benefited medium and large farmers disproportionately.

Table 4: Average Holding Size in Our Sample and the Districts

District*	Average Holding Size (Ha)**	Average Holding Size (Ha) in Our Sample
Bikaner (27)	9.41	13.18
Sri Ganganagar (72)	7.42	12.085
Jaipur (8)	2.58	18.67
Rajasthan	3.38	

*Numbers in parentheses in this column indicate the sample size.
** Data from Agriculture Census 2005-06 (GoI 2012).

There are three possible reasons for such high inequity in subsidy allocation. First, the technology is still new for this area and large farmers are often the first to adopt new technologies. Second, even after the 86% subsidy from the government, a farmer had to pay about Rs 80,000 for a 3,000 wp solar power system. Few small or marginal farmers can afford such an expensive asset. Third, a farmer must have a diggi in his land to qualify for subsidised solar pumps under the scheme. Diggis take up land and farmers in our survey told us that making one costs Rs 2-4 lakh. The GoR gives subsidy for construction of diggis, but the farmer's share of the cost after the subsidy is still considerably large (in our survey, Rs 1.4-2.18 lakh on an average). Further, a recent study shows that a diggi is financially viable in this area only if it irrigates more than four hectares of land (Amarasinghe et al 2008). Hence, small and marginal farmers do not build diggis and do not qualify for subsidised PV pumps. Recently, the GoR has increased the subsidy on diggis from 20% of cost of construction (ibid) to 50% or Rs 2 lakh, whichever is less. The increase in subsidy will reduce the minimum farm size needed to make a diggi financially viable, yet, it is unlikely that many smallholders will go for it.

The distribution of electric pumpsets is unequal too (Murgai and Howes 2003). Still, smallholders get some benefits of the power subsidy to farmers through water markets. None of the PV pump owners in our sample, however, sold water to other farmers. They are farmers with large landholdings of their own and not enough water to irrigate all their lands. So, the subsidy on solar pumps does not benefit small and marginal farmers even indirectly. Only large farmers have benefited from it.

(e) Solar Pumps Mainly Replaced Diesel Pumpsets and Tractors: Every farmer in our sample has at least one diggi and all PV pumps are installed to take water from diggis to fields. Before installation of PV pumps, farmers relied mainly on diesel pumpsets or tractors, and at times, just the force of gravity. Only 18 out of the 107 respondents used electric pumps to take water from the diggi to their fields. Farmers with electric pumps too had to use diesel pumps, tractors, or gravity irrigation because of restricted hours of power supply. Even now, solar pumps are not always the only pumping device used with diggis. Forty-seven out of the 107 farmers in our sample also use diesel pumpsets or tractors along with solar pumps.

Only 36 farmers in our sample have electric pumpsets, while 64 own diesel pumpsets, and seven had neither. Twenty-four respondents told us that they had applied for an electricity connection sometime in the past; 23 of them still want the electric pump, even when they have a solar pump now.

Thus, PV pumps have largely replaced diesel pumpsets or tractors, and not electric pumpsets, as pumping devices in Rajasthan. They save more diesel than they do electricity. Introduction of PV systems for irrigation may not make much of a dent in the long waiting line for new electric pump connections in the state either. Farmers want electric pumps for groundwater irrigation, while solar pumps are used mainly on diggis. There has been only a limited demand for PV pumps in areas where groundwater is the main source of irrigation in both the first and the second year of the programme. This is mainly because of the ceiling of 3,000 wp on the capacity of PV systems. Farmers need pumps of higher capacity to draw groundwater in most parts of Rajasthan. Higher capacity pumps, even if allowed in the scheme, will be proportionately more expensive and probably unaffordable for most of the 70,000 farmers still waiting for new electric connections in the state.

(f) Saving in Diesel Costs Is the Biggest Benefit of Solar Pumps: Saving in the cost of diesel is the biggest perceived benefit of solar pumps for 79 out of the 107 farmers we interviewed. On an average, a solar pump owner expected to save diesel worth Rs 60-65,000 in Jaipur and Sri Ganganagar and Rs 48,000 in Bikaner in one crop year. Diesel savings are lower in Bikaner because flood irrigation using gravity is more common in the district. Farmers in Bikaner grow mainly field crops and keep their lands fallow in the summer. Therefore, they do not have to store water in their diggis for irrigation in summer and they can afford less efficient flood irrigation.

(g) Solar Pumps Save Labour Too: Besides saving diesel and electricity, solar pumps also result in labour saving because, unlike diesel pumpsets or tractors, they do not require an operator. Once started, a solar pump needs minimal attendance. Farmers perceive labour saving to be a significant logistical and financial benefit of solar pumps.

(h) Area Irrigated by PV Pumps: A solar pump is able to irrigate 2-4 ha of land in rabi and 2.25-6 ha in kharif seasons. In summer, it is a lifesaver for horticulture crops. Orchards need regular watering in hot summer months when solar pumps can work for up to 11 hours a day. Canal water is not available for three-four weeks in the summer as the system remains closed for repair and maintenance. Farmers use canal water stored in their diggis for irrigation. Water is scarce and valuable during this period, and fruit growers try to use it efficiently with drip systems. An average farmer in Sri Ganganagar irrigates about five hectares of his orchards from solar pumps in the summer season. In Jaipur, this area is about three hectares.

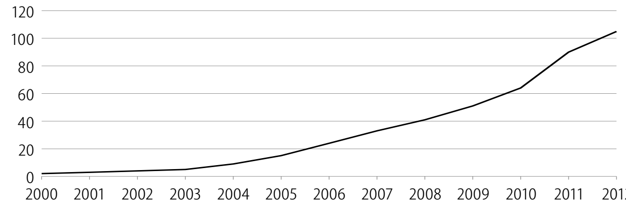
(i) Impact of PV Pumps on Adoption of Drip Irrigation: The solar programme in Rajasthan requires a farmer to have drip irrigation in at least 0.5 ha of his land to qualify for the subsidy. The policy is designed to encourage farmers to use solar pumps to irrigate high value crops (fruits and vegetables) with high water use efficiency. Coupling solar pumps with drip systems has been shown to have a large impact on farmers' income and productivity (Burney et al 2010).

All farmers in our sample have drip systems and most of them use solar pumps for drip irrigation. However, they use their solar pumps with sprinklers and mini-sprinklers, and for flood irrigation too. Sprinklers are common in Bikaner and Jaipur, where all farmers in our sample had them. Farmers use sprinklers to irrigate field crops like wheat and mustard, while drip systems are used for fruits and vegetables. A few farmers in our sample, all of them in Bikaner (five out of 27), owned a drip system, but did not use it. On prodding, they told us that they had bought the drip system mainly to qualify for subsidised solar pumps and considered the small amount of money spent on it as additional cost of owning the PV pumping system. It helps that the GoR provides a 90% subsidy on drip systems. Such non-serious purchase of drips would not have happened without this high subsidy.

We also asked our respondents what year they had bought their drip and sprinkler systems. Sixty-six farmers had purchased drip systems even before the solar subsidy programme was announced, while 41 bought them just around the time of the public announcement of the new subsidy policy on solar pumps with ownership of drip systems as an essential criterion.

Figure 1 shows cumulative growth in ownership of drip systems in our sample over the years. There seems to be a jump in ownership in recent years, but we cannot attribute it to the subsidy policy for solar pumps. In fact, only five farmers in our sample said that they purchased drip systems because they wanted to own a solar pump. Moreover, there has been a nearly tenfold increase in area under drip-irrigation in Rajasthan between 2006-07 and 2011-12, including in parts of the state where solar pumps are not much in demand.

Figure 1: Cumulative Growth in Number of Farmers Who Own Drip System in Our Sample from 2000 to 2012



Thus, making drip systems essential for the solar pump subsidy may encourage some farmers to buy and experiment with drip irrigation, who would have otherwise not done so, but it does not guarantee that farmers will use these systems. It is also not practically possible to force farmers to use drip systems.

(j) Solar Pumps Increase Water Productivity, But Do Not Save Water: Solar pumps do lead to higher water use efficiency. When farmers use diesel pumps or tractors, they irrigate their crops in bursts with relatively long intervals between two irrigations. With solar pumps, crops get water in smaller quantities at shorter intervals. Timeliness of irrigation improves and farmers do not hesitate to use the pump because it has zero operating costs. Eighty-four out of the 107 respondents listed improved timeliness of irrigation as a significant benefit of solar pumps. Improved timeliness and more frequent and adequate water application by solar pumps also resulted in increase in productivity of crops by 5%-10% and better product quality of fruits and vegetables.

We must add here that while a solar pump does lead to higher water use efficiency, it does not result in net water saving. Farmers continue to use up all the water stored in their diggis as they used to do before installing solar pumps. The irrigated area expands and crop productivity increases, but the total volume of water used for irrigation does not go down with solar pumps.

(k) Farmers Are Very Happy with the Solar Pump's Performance: PV pumps are easy to use and require little maintenance (Burney et al 2010). Most farmers in our sample did not experience any inconvenience or hassles in using them. Eighteen out of 107 farmers complained about shoddy civil works in installing the system where suppliers had left loose wires, etc. The other 89 farmers did not experience any trouble whatsoever.

We asked our respondents if they would recommend PV pumps to other farmers. Every one of our respondents said they would. When asked to list reasons for doing so, they cited saving of diesel and labour, easy operation and maintenance, and improvement in productivity and product quality as key factors.

All, but seven of them, said they wanted a second solar pump from the government and were planning to apply for it again in the name of a different family member. One farmer already had two pumps – both installed on the same diggi.

(l) Farmers Want Multiple Use of Solar Panels: When asked about additional features they would want in their solar pumps, most farmers said they wanted pumps of higher capacity. In Jaipur and Bikaner, all but two farmers want the second solar pump to be of five hp, while in Sri Ganganagar, 39 farmers want the new pump to be of 5 hp, 19 want the new pump to be of 7.5 hp or more, and eight farmers were not sure of the size of the new pumping system. Three farmers in Sri Ganganagar and one each in Bikaner and Jaipur want to go for another 3 hp solar pump.

All our respondents also want to use solar panels for home lighting. Households in rural Rajasthan get 18-20 hours of daily power supply. Farmers want to use solar panels to save on their household electricity bill and to use it as a power backup when the grid supply is not there.

Auto-tracker, an automatic device that tilts the panel in the changing direction of the sunlight and, hence, improves the system's performance, was another feature many farmers wanted.

3 Conclusions and Policy Implications

Our interaction with the first adopters of solar pumps in Rajasthan during the fieldwork and the primary survey shows that this technology works. Solar pumps are convenient to use, require minimal attendance and have few maintenance problems. Each 3,000 wp system saves its owner Rs 45-65,000 worth of diesel, besides increasing land and water productivity and crop quality. It also saves him labour and exposure to noise and air pollution. All owners we talked to were very happy with their PV pumps. They hoped to recover their share of the system's cost in less than two years. Each one of them thought other farmers should get solar pumps. The popularity of the technology is evident from the sharp increase in the number of applications, from around 2,500 in the first year of the programme to 6,500 in the second year.

The RHDS has implemented the programme well. Every farmer in the government's list had installed a solar pump. The qualifying criteria for getting the subsidy were universally met without any exception. All pumps were installed on diggis as mandated by the policy, and in a large number of cases, pumps were being used with drip systems as mandated by state policy.

While farmers are happy with the PV pumps they received and the government bureaucrats did a decent job of implementing the programme, the design of the subsidy policy itself needs to change for better and more equitable impact.

3.1 High Subsidies

The GOR offers 86% subsidy on solar pumps. The subsidy should be much lower. Solar pumps offer high returns to their owners and have low risks, if any. Therefore, the technology should be promoted more with attractive financing through banks and other lending institutions and not so much with high subsidies. The high subsidy is hard to justify also because it goes mostly to already well-off medium and large farmers. Small and marginal farmers have got almost no direct or indirect benefits from subsidy on PV pumps in Rajasthan.

Positive externalities of a technology may justify subsidising it. If we look at solar pumps, there are two big positive externalities associated with their use. First, it saves diesel and, hence, the subsidy on diesel that is paid by the GoI. Second, it reduces air pollution (carbon and non-carbon) caused by diesel pumps or tractors that it replaces. Among our respondents, a 3,000 wp system saved about 900-1,200 litres of diesel per year. If we assume 1,000 litres to be the average annual reduction in use of diesel due to a solar pump, it implies lowering of CO_2 emission by 2.65 tonnes per year and savings of Rs 6,520 per year in diesel subsidy.[10] Contrary to the hopes of the state government, solar pumps have not reduced the demand for new electricity connections and consumption of subsidised electricity for irrigation. Nor have they lead to reduced use of water even as water productivity increased. Altogether, private benefits of a solar pump exceed public gains from it by an order of magnitude. This is yet another reason that the technology should not be so highly subsidised.

Further, such high subsidy is creating problems of its own. One, it limits the number of solar pumps that can be installed with the state's support. Two, high subsidy is resulting in gold-plating and it is discouraging cost-cutting innovations. Three, the subsidy is crowding out autonomous adoption of this technology and emergence of an open market for solar pumps. Four, continued high subsidy could lead to diversion of solar panels from agriculture to other usage, where the subsidy is much lower and marginal value of electricity generated by solar panels is much higher.

3.2 Need for Alternate Subsidy Designs

Not only do we think that the subsidy on solar pumps should be reduced from its current levels, but the subsidy design should also change. The government should move from the current pro rata subsidy to a lump sum subsidy to foster competition and to remain more nimble to exploit rapidly falling prices of solar panels.

Currently, solar pumps are popular mainly in canal irrigated areas of Rajasthan, partly because there is a restriction on pump size and a requirement to use it only with diggis. Eventually, in Rajasthan and in other states of India, farmers will begin using solar pumps for groundwater irrigation too. Use of solar pumps for groundwater irrigation could lead to wasteful use of water and over-exploitation of aquifers because of the cost structure of solar technology – with high fixed costs and negligible variable costs – which creates incentives for farmers to use it as much as possible. Solar pumps are very much like electric pumps that pay flat tariff for electricity.

Rajasthan and other states like Punjab require farmers to use drip irrigation with solar pumps to ensure high water use efficiency. However, high water use efficiency does not guarantee reduced use of water.

Such problems can be minimised by replacing capital cost subsidy on solar pumps by smarter subsidy design and administration, where power utilities would guarantee buy-back of surplus electricity at an attractive price from grid-connected farmers. This is the strategy used by the National Solar Mission to incentivise large-scale solar power generation (Kandhari 2011). A farmer would be more willing to invest borrowed funds in a solar pump if he was offered a guarantee of buy-back of surplus power at a remunerative price. The Government of Gujarat has offered guaranteed buy-back of solar power at Rs 15/kWh for the first 13 years (GEDA nd). The National Solar Mission invited bids from private power producers who whittled the price down to around Rs 7.60/kWh (Kandhari 2011). A 5,000 wp solar panel can produce about 8,400 kWh electricity in a year in the Indian plains,[11] enough to run a 5 hp pumpset for more than 2,100 hours. A guarantee to purchase surplus solar power at, say, Rs 10/kWh would assure maximum revenue of Rs 84,000/year, if he sells all the electricity generated to the utility. This guarantee will create a high opportunity cost of using electricity for irrigation. Every unit of electricity that he uses for irrigating his crops will cost him Rs 10 in lost revenue. Such high incentive would lead to significant energy and water savings in agriculture.

With rapidly falling prices of PV cells, rising diesel prices, and dwindling hours and quality of farm power supply, solar pumps are likely to open a new chapter in India's irrigation economy in the years to come. However, using high levels of pro rata subsidy on capital cost of solar pumps, like in Rajasthan and many other states, e g, Bihar (90% subsidy), Tamil Nadu (80% subsidy), Madhya Pradesh (80% subsidy), Punjab (70% subsidy) and Karnataka (50%-60% subsidy), could slow down the adoption and diffusion of this technology, as it did in case of micro-irrigation systems (Shah and Keller nd). On the other hand, with appropriate promotional strategy and incentives, solar pumps can attack India's invidious nexus between energy and groundwater irrigation and change it for the better. Aggressive promotion of solar pumps in groundwater-abundant eastern India has the potential to catalyse an evergreen revolution there. The same strategy in western and southern India, however, can increase the stress on depleted groundwater resources because solar pump owners face near-zero marginal costs of groundwater. In water-abundant eastern India and in canal commands, subsidising capital cost of solar pumps with a lump sum subsidy can be part of a sound promotional strategy. Elsewhere, it may be appropriate instead to connect farmers as micro-level independent power producers to the grid and offer an attractive price for buying surplus power from them.

NOTES

1 Average module price/wp was Rs 38 in October 2012 and was predicted to go down to Rs 33 in 2013 (Naam 2011).
2 Electricity from solar panels supplied to the grid has fallen to just Rs 8.78 per kilowatt-hour compared with Rs 17 for diesel (Pearson 2012).
3 This saving assumes that each 5 hp solar water pump will save 25 units of electricity per day. So, 25*10,000*360 = 9,00,00,000 kWh.
4 The programme was expanded to all 33 districts of the state in 2012-13.
5 Bikesh Jha of Sun Edison, personal communication, 28 November 2012.
6 A DC pump costs Rs 1.2-1.5 lakh more than an AC pump of similar capacity.
7 We cannot ascertain if the quality of components used are similar in both cases. However, it is hard to imagine that the difference in quality of components alone could explain a nearly 300% difference in prices.
8 Allegedly, some dealers and manufacturers are unofficially offering discounts up to Rs 30-40,000 to farmers to lure them to buy their product. If true, these stories suggest that some of this cost reduction will be passed on to farmers directly or indirectly. We could not validate these stories in our surveys. Not one respondent reported receiving any discount or refund on their initial deposit.
9 Ideally, this subsidy should be indexed to the price of solar panels in the Indian market.
10 Calculated using price build-up of Diesel data given by PPAC (nd).
11 Amit Magnani, Rotomag, personal communication, 28 November 2012.

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