Small-Scale Solar Pumping Systems in India

Analysis of Three Implementation Models

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Abstract—**The replacement of diesel- or grid-powered water pumps with solar energy offers environmental, economic, and social benefits via climate change mitigation, improved livelihoods, and greater quality of life. As a result, India's government is promoting solar pumping technologies via direct capital subsidies, financing schemes, and legal and regulatory development. Despite such attention, and while solar pump systems have shown significant promise, challenges in implementation continue to prevent the full realization of environmental, economic, and social gains. In this paper, we examine three small-scale system implementation models across India: grant-funded pay-it-forward systems for agricultural use in Uttar Pradesh, grid-tied irrigation systems in Karnataka, and direct-to-customer financed systems for salt farming in Gujarat. We explore the feasibility of these models through financial analysis coupled with knowledge gained from interviews with key stakeholders, including system users, manufacturers, installers, and system integrators. We find that institutional factors weigh heavily on whether systems are properly introduced, used, and maintained. Particularly, ensuring long-term project sustainability requires sound project economics, proper system sizing, and effective pre-/post-sales service. Greater understanding of the interdependency between hydrogeological context, technological specifications and financial realities among project implementers and system users will be essential in scaling up solar pump systems effectively.**

Keywords—India; agricultural technology; renewable solar energy; irrigation; water management; sustainable project implementation

I. Introduction

India faces numerous development challenges, particularly with respect to poverty alleviation, inequality, and sustainable environmental management. These challenges become greater when placed in the context of increasing stress due to population growth, climate change, and volatile political and economic processes. Further, those living in poverty are often caught in a vicious cycle whereby low risk-taking behavior persists due to an inability to invest in capital that would lead to improved output and greater cost recovery (see Fig. 1). Improved technologies have the potential to disrupt this cycle by not only promoting productivity and efficiency, thereby increasing returns on investment at the household level, but also by stimulating social and environmental benefits in service of broad gains in human development [1].

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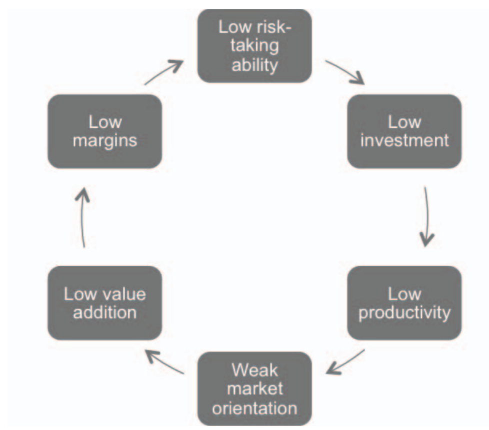

Fig. 1. The persistence of low risk-taking: a vicious cycle of poverty

The case of solar pumps is a useful and instructive example. In India, because reliable irrigation is so critical to farmers' livelihoods, approximately 25 million grid- and diesel-powered pump systems are installed [2]. Replacing these with solar-powered pumps will yield numerous benefits. First, it will mitigate air pollution and the release of greenhouse gas (GHG) emissions: A recent lifecycle analysis (LCA) reckons that SPV systems have an energy payback time (EPBT, the time it takes to generate an amount of energy equal to that used in its production) between 1 to 4 years [3]. Second, relative to manual systems (e.g., hand or treadle pump), solar pump systems are less labor- and time-intensive, freeing up energy and schedules so that other activities may be pursued. Third, pump users, primarily marginal and smallholder farmers (defined as those who grow crops on 2 hectares or less), who often live in rural areas where grid electricity is unreliable or non-existent, are able to close yield gaps through more reliable supply and increase output via additional harvests during the dry season. This leads to improved livelihoods and income generation from increased sales, as well as improved household health through enhanced nutrition and self-sufficiency.

When supported by sound policy and robust financing mechanisms, solar pump systems can address water, energy, and food security concomitantly (see Fig. 2). Hence, these systems prove important to the water-energy-food nexus, an area of research and practice gaining greater attention [4]. Yet, despite their clear advantages and their promotion by national and state governments in India, only 17,611 solar pumps for irrigation purposes have been installed in India as of January 2016 [5]. A noteworthy hindrance of greater uptake is not the technology itself, but rather challenges in implementation that continue to prevent the full realization of environmental, economic, and social gains [6].

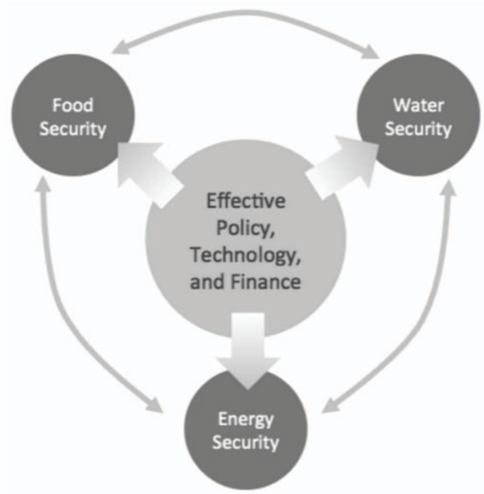

Fig. 2. Water-energy-food nexus: enabled by policy, technology, and finance

Our research aims to understand the different ways solar pump systems have been promoted in order to identify barriers to, and therefore opportunities for, greater scale. In particular, we examine three small-scale system implementation models across India: grant-funded pay-it-forward systems for agricultural use in Uttar Pradesh, grid-tied irrigation systems in Karnataka, direct-to-customer financed systems for salt farming in Gujarat. This approach allows for a comparative analysis that reveals implementation challenges both unique and common across the three case study areas.

II. METHODS

A. Study Design

We employ a mixed methods research strategy drawing primarily on the case study approach [7]. This approach, drawing on both qualitative and quantitative data, allows us to capture the interactions between higher-level structural dynamics and the agency and opinions of individuals [8].

Primary data collection consisted of semi-structured interviews that covered 6 topics: technical performance, affordability, availability, ease of use, demand generation, and environmental and health issues. Demographic information, farming practices, and knowledge and attitudes about solar pump system operation and maintenance were also collected to understand the social and economic systems in which technologies are embedded. Though not presented in this paper, empirical data such as flow rate and power input/output were gathered to get a broad sense of systems' performance under field conditions.

This research was undertaken as part of the Comprehensive Initiative on Technology Evaluation (CITE) at the Massachusetts Institute of Technology (MIT) and was approved by the university's internal review board.

B. Data Collection

Based on a scoping study, which included prior field visits to India, and consultations with our Indian partner organizations, we elected to visit three states in India: Uttar Pradesh (Jhansi district), Karnataka (Bangalore district), and Gujarat (Surendranagar district). While perhaps not representative of all Indian solar pump users, these regions exhibit significant environmental, economic, and socio-political heterogeneity. In Uttar Pradesh, 6 solar pumps have been deployed via our partner organization; we interviewed 4 of those users. In Karnataka, our partner organization expects to install 200 pump systems by the end of this year; thus, we interviewed 20 users, or 10% of expected users. In Gujarat, approximately 250 salt farmers use solar pumps, with plans to distribute 200 more by 2017. Therefore, we interviewed 25 users, or 10% of current users.

Semi-structured interviews with solar pump system users were the main source of data collection. Because the number of pump users is relatively small, our sampling method was purposive rather than random. Our partners—Development Alternatives (DA) in Uttar Pradesh, SunEdison in Karnataka, and the Self-Employed Women's Association (SEWA) in Gujarat—assisted in identifying appropriate households that would provide a reasonably representative sample. Key informant interviews with 21 manufacturers, system integrators, installers, and project implementers were also conducted to complement the perspectives of system users and to learn more about opportunities and challenges throughout the supply and value chains.

III. IMPLEMENTATION MODEL DETAILS

Throughout India, the needs of solar pump users vary greatly, even within the agriculture sector. These demands are shaped not only by technical and environmental requirements—e.g., water table level, geology, soil type, annual rainfall, and crops' differing water requirements—but also by the needs and desires of the communities involved. While several implementation models exist, from large-scale subsidized government projects to (albeit limited) direct-to-customer market channels, the three case studies in this paper highlight one of the most common approaches, wherein an institution in collaboration with local farmers finds an appropriate solar pump system solution. This lends itself to a community-focused lens: a user is not a stand-alone purchaser or investor in a solar pumping system.

TABLE I. SALIENT CASE STUDY FEATURES

	Case #1: Uttar Pradesh	**Case #2: Karnataka**	**Case #3: Gujarat**
Financial model	Revolving fund	Grid-connected	Consumer finance
Usage	Irrigation	Irrigation	Salt Extraction
Installed systems	6	46 (200 planned)	250
Sample size	4 (66%)	20 (43%)	25 (10%)
Scale-up potential	1,000	500	40,000
Average Cost per system [a,b]	Rs. 2.5 lakhs ($3,731)	Rs. 5.5-7.5 lakhs ($8,209-$11,194)	Rs. 1.7-1.9 lakhs ($2,537-$2,836)
Initial cost to user	Rs. 0	Rs. 5,000 ($66)	Rs. 0
Monthly cost to user	Rs. 3,000 ($45)	Rs. 7.20/kWh [c] ($0.11/kWh)	Rs. 5,000 ($66)
Average pay-back period	5 years	9 years	5 years

a. A lakh is a common numerical unit In India, equivalent to 100,000 (10^5).

b. A currency conversion of 67 Indian rupees (Rs.) per dollar is used for comparison purposes only.

c. Farmers in Karnataka are paid for feeding electricity into the grid, a portion of which goes to paying back the initial loan (see Section III.B.3 for more details).

Indeed, a community-level approach is necessary in these cases due to the high capital investment cost of such solar pump systems when compared to the available funds of the families and farmers involved. For instance, a 1.5 hp solar pump costs approximately 10 times more than a diesel pump of the same size: Rs. 350,000 ($5,200) versus Rs. 30,000 ($450) upfront plus an additional Rs. 35,000 ($500) annually for diesel. This results in: 1) a high break-even period of between 8 to 15 years, dependent upon whether or not crop yield improvements are assumed [2]; and 2) a farmer's inability to purchase solar pump systems without significant assistance from a community organization or funding partner.

Below, we discuss the unique and common factors of all three small-scale implementation models studied. As shown in Table I, they are designated as: revolving fund, grid-connected, and consumer finance to differentiate based on their financing sources.

A. Uttar Pradesh: Grant-Funded Pay-It-Forward

1) Use Case

Each of the 4 solar pump systems the team visited in Uttar Pradesh are used by 1 to 4 farmer families in rural areas for irrigation of a range of revolving crops, including both horticulture and cash crops. The solar pump systems operate in open wells and replace diesel pumps. Flood irrigation dominates, as depicted in Fig. 3, though one farmer who was interviewed also had a sprinkler system that was used occasionally.

Fig. 3. Solar-powered flood irrigation in Uttar Pradesh

According to our partner in the area, this particular belt of central India has been hit hard by drought in the last several years, resulting in very low water levels in the wells in which the pumps are installed. We visited before monsoon during the summer, a time when water levels would ordinarily be low, but in years of normal rainfall, wells are still operational. Because of the drought one of the wells was completely dry, and two others were only marginally functional.

2) Technical Specifications

The solar pumping systems implemented in this model were identical to each other and installed en masse one year prior to our field visit. Each system consisted of a 3 hp, AC submersible water pump connected to a 3 kW (16 x 190 W) solar array via an electronic controller and inverter. The water level varied from 30 to 60 feet and the water was used for crop irrigation purposes with an average usage rate of 3 hours per day. Due to the ongoing drought in the region, 2 of the 4 wells were at significantly lower levels. As a result, farmers were limited in the time they were able to pump: one such farm was only able to pump for 6 minutes before shutting off the system due to lack of water.

3) Financial Model: Revolving Fund

The pumps belong to the local farmer federation and are financed using a revolving fund model. This model relies on initial grant funding from the Coca-Cola Foundation to catalyze the project. The grant funding was used to purchase the first four systems for farmers within the federation. Farmers then make payments on the solar pump systems to the federation, which in turn will be used to purchase future solar pumps for other members of the federation. Despite the availability of government subsidies for solar pumps, Development Alternatives chose not to access government money because of delays and complications associated with the application and funds dispersal process.

When assessing the financial viability of solar pumps, it is necessary to also assess what they are replacing, in this case diesel pumps. Diesel pumps have a low initial fixed cost, and a relatively high variable marginal cost of fuel. Solar pumps have a high initial fixed cost, but no fuel cost and very low maintenance cost. As with many high priced assets, the farmers pay monthly installments on the pumps. Assuming that the water well is functioning properly, these payments are equal to or less than the equivalent cost of diesel for the same number of irrigation hours.

However, in drought conditions, water is not available in high enough volume for substantial irrigation. In summer months, this means that a great deal of a farmer's land is not cultivated at all. In this scenario, farmers using diesel pumps would have substantially lower diesel expenses because they are pumping for a shorter period of time. But those using solar pumps still have the same monthly payments to make on their solar pump systems. For those unable to cultivate, they are also unable to make consistent, on-time payments. This has implications for the revolving structure, effectively curtailing the federation's ability to plan for new pump systems because of the diminished ability of farmers to repay.

4) Stakeholders

The major financial stakeholder is Coca-Cola Foundation, which provided the catalyzing grant to start the project to provide farmers with solar pumps. However, since awarding the initial grant 2 years ago, the funding agency has taken a backseat. While Coca-Cola provided basic parameters for the technology, such as system size, Development Alternatives chose Punchline Energy, a local energy installation company, to work out the finer details of the system and to take care of installation and servicing requirements.

5) *Community Engagement*

As facilitators of a pilot project, Development Alternatives prioritized engaging with community leaders and influencers. While these hand picked farmers were not involved in the technology selection, they were able to give feedback about the operation of the systems. The farmers took good care of the panels and understood their value. Their only complaint was a lack of water in the wells because of the drought. The farmers reported that they were given very basic training on systems and noted that they were so easy to use that even small children could flip the on/off switch to run them. They were not, however, trained on the more intricate workings of the inverter, which remains closed and locked for the duration of the project, unless a representative of the installer company is servicing the system.

B. *Karnataka: Grid-Connected Systems*

1) *Use Case*

Rather than replacing diesel pumps, the farmers interviewed in Karnataka are replacing pumps powered by grid electricity. These farmers cultivate a single crop throughout the year: mulberry bushes for silk production. The farmers generally have one pump per family and cultivate 2 to 4 acres. These pumps are also much larger in size because they pump from a deep borehole well instead of an open well.

2) *Technical Specifications*

The solar pumping systems implemented in this model were specified and sized by the implementing organization, SunEdison, a global for-profit renewable energy development company. The program was in the middle of installing the systems at the time of the fieldwork and thus the systems were only 2 to 4 weeks old. Each system consisted of a 5 or 7.5 hp, AC borehole water pump connected to a 7.2 kW (24 x 300 W) solar array via an electronic controller. The solar arrays were intentionally oversized to facilitate the financial model by maintaining a continuous baseline feed-in to the electricity grid, as shown in Fig. 4. As a result, these systems were the most expensive of the 3 case studies examined. The water level varied from 240 to 600 feet and the water was used for crop irrigation purposes with an average usage rate of 6.5 hours per day for 138 days during the year.

3) *Financial Model: Grid-Connected*

The grid-connected model for solar pumps relies on a key piece of policy called net metering, which allows the electricity distribution company to pay farmers for excess electricity generated by the panels. It brings together the local electricity distribution company, the farmers, the project implementer, and debt financing. Government subsidies were also used in this case. The farmers pay a minimal part of the initial cost, approximately Rs. 5,000 ($75). Government subsidies cover 40% of the cost and debt financing covers the rest.

The intentional oversizing of the solar panels helped ensure that there is always extra electricity being fed into the grid. They are paid Rs. 7.2 ($0.107) per kWh, of which Rs. 6 ($0.09) go toward debt servicing, Rs. 0.2 ($0.003) go to the farmer federation for operation and maintenance costs, and Rs. 1 ($0.015) goes directly to the farmer. Once the debt is fully repaid, the farmer will receive Rs. 7 ($0.104) per kWh. This incentivizes efficient use of the pumps, including drip and sprinkler irrigation, to ensure that the maximum number of hours of solar production can be fed into the grid.

Fig. 4. Over-sized panels with grid connection in Karnataka

4) *Stakeholders*

The stakeholder ecosystem for the Karnataka project is more complex than the other use cases we examined. The policy environment was extremely important in this case, as the project is essentially government-sponsored. The United States Agency for International Development (USAID) played an important role in the development of the net-metering policy for the payment of power fed back into the grid. Additionally, the Power Ministry was instrumental in engaging with the project to ensure its success. The local distribution company, Bangalore Electric Supply Company (BESCOM), put out a tender for the development of a solar pumping project for the catchment area around one particular electricity substation. SunEdison won the bid and was in charge of carrying out the implementation of the project, which included engaging heavily with panel and pump manufacturers. Solar Electric Company (SELCO), a for-profit sustainable energy solutions social enterprise, was recruited to implement local community development and capacity building in service of building awareness about the project.

5) Community Engagement

The farmers in Karnataka had the least amount of choice in project and system design among the use cases we observed. The project was awarded by tender to SunEdison, who designed the system according to, *inter alia*, well depth, plot size, and type and amount of crop(s) under cultivation. Because the pumps were installed in boreholes, the entire system was closed and not open to customization by the farmer. All farmers within the catchment area of the electricity distribution substation were enrolled in the project, suggesting either that it was an irresistible opportunity or that they were under at least minor pressure to join. At the time of our field visit, SELCO's capacity building efforts was either minor or incomplete because many of farmers did not have a full understanding of the intricate financial arrangements in place for the payback of these expensive systems. It is also important to note that the farmers in this sample group were more educated and in better financial situations than other farmers we interacted with during our project.

C. Gujarat: Direct-To-Customer Financing

1) Use Case

This final model we consider is unique because the pumps are used not for agricultural irrigation, but for salt production. There are 40,000 salt farmers in the Little Rann of Kutch in Gujarat, of which 250 are working with the local non-governmental organization (NGO) to purchase solar pumping systems. The salt farmers pump underground brine into saltpans, which evaporate to produce rock salt. A saltpan can be seen in the background of Fig. 5. The salt farmers seek to maximize the amount of salt they can produce, so they run pumps anywhere from 12 to 24 hours per day, pumping briny water into the pans. The solar pumps they are using replace diesel-powered generators and greatly reduce the cost of fuel for the farmers during the salt season.

2) Technical Specifications

The solar pumping systems implemented in this model were sized and the specifications were chosen by the implementing organization. The program was in its second year at the time of the fieldwork and the systems were between 1 month and 2 years old. Each system consisted of either a 1 or 1.5 hp, AC water pump connected to a 1.8 kW (6 x 300 W) solar array via an electronic controller; however, some farmers had added an additional 1 hp pump to their systems. The water level varied from 40 to 69 feet and systems were used for brine extraction with an average usage rate of 8 hours per day (i.e., all available sunlight hours) for 180 days during the year.

3) Financial Model

The financing model for the salt farmers is debt financing facilitated through a local NGO. This model is very similar to a consumer finance model, where the farmer takes possession of the solar pump system and makes monthly payments for a specific period of time in order to pay off their system, after which they own it in full. This model works well for the salt farmers because, unlike agricultural irrigation, they are pumping as much water as possible, ensuring that the solar power generated is used in full.

Fig. 5. Solar pumping for salt production in Gujarat

4) Stakeholders

The Self-Employed Women's Association (SEWA), an organization whose membership consists of poor women and whose mission is to ensure their rights, is the driving force behind the solar pump project for the salt farmers in the Little Rann of Kutch. They have secured loans from commercial banks for the salt farmers and negotiated the purchasing of the solar water pumping systems. Additionally, SEWA has taken an active role to date in relation to maintenance and after-sales support. This is motivated by a desire to continue the project and encourage more farmers to adopt the technology.

5) Community Engagement

The desires and concerns of the users were strong driving factors on the technology choice in Gujarat. In particular, SEWA advocates for gender empowerment, and saw solar pump systems as an opportunity to advance women's energy and financial inclusion. Toward this end, each female head of household legally owns the solar pump system. SEWA has an extensive presence in the community and is trusted by the members to make decisions in their best interest. Additionally, this group of users was introduced to the technology from alternative acquisition channels, such as salt merchants that purchase their harvests. These users rely heavily on their pump systems, both diesel and solar, for their primary income generation activity, brine extraction. As a result, they are much more dependent upon and invested in the technology. Consequently, they devote time to learn about and tinker with the systems to improve performance, and to suit their individual needs.

D. Sucessful Implementation: Key Factors

1) User Satisfaction with the Technology

Across all use cases, a significant perception of solar pumping systems as an improved technology was observed. Specifically, when farmers in Karnataka were asked if they would recommend the systems to others, all but one user indicated "very likely." The remaining farmer was more cautious and wished to spend more time with the system before deciding to recommend or not. In Karnataka, when asked what advantages they saw over their previous systems, a clear perception that it will remove grid-related issues, such as unreliable power supply, was evident. Similarly in Gujarat, users of the system with higher solar capacity were very likely to recommend, whereas the users of the reduced capacity were only somewhat likely to recommend on average. This was due to their awareness of the ability of the alternative system to run more than one pump at one time. When directly questioned about the payback-time and full cost of the systems, the majority of end-users were unaware of both and unable to estimate with any degree of confidence. All but one respondent indicated that they would not have purchased the systems if their corresponding program did not exist.

2) Customer Engagement

Because the solar pump systems are quite technologically complex, we were surprised to find that all users considered the solar systems very easy to use. Respondents reported that compared to diesel pumps, which can be difficult to start and require the procurement of fuel from sometimes remote locations, and electric pumps, which often require nighttime operation and sometimes dangerous travel to agricultural fields away from the farmer's home, the solar pumps are turned on and off with a simple flick of a switch. Some farmers had their children operate the pumps. This demonstrates, that in addition to the financial benefits of solar pumps, the solar systems provide additional benefits in terms of increased safety, ease of use, and comfort.

We also found that farmers have a high capacity to accept increases in monthly payments up to and maybe just slightly more than their current payments for diesel. It follows that the farmers are not at all sensitive to the total cost of the system, as long as their monthly payments are manageable. However, inasmuch as they have a choice in technology, the farmers are highly sensitive to the technology type and deployment in a particular project. The lesson learned is that involving farmers in the technology choice is an important element in the ongoing success of solar pump projects.

3) System Sizing

The other key element of technology choice is the correct sizing of the solar pump system. Solar panels are an expensive asset, so the pump size should be chosen carefully. If the system is undersized, the pump will not work well, but if the system is oversized (something that farmers often requested), the panel cost increases accordingly and the overall cost of the system may become unnecessarily costly. This is particularly important when considering that for agriculture, the capacity utilization factor (CUF)—the ratio of real output to maximum output under ideal conditions—is relatively low.

While the pump is able to operate during all daylight hours, it is rarely used more than a few hours per day and sometimes not at all. As all of the systems considered in this paper were designed to work without batteries to store energy, this means all the power the panels could produce during that time is wasted, resulting in a prolonged payback period. Similarly, such waste also translates to a longer energy payback time. Greater productive use of the asset could be addressed by using the solar panels for other applications beyond agriculture, such as home lighting or small machine operation (e.g., milling cutter), though this adds system complexity, requiring greater training and local technical support. Systems with these capabilities are currently in use around the world but were considered out of scope for this initial study.

Overall, the message is clear: proper system sizing is essential to both the financial and environmental sustainability of a project.

4) Water Availability

Our observations in the field suggest that efficient irrigation systems could potentially have a larger impact for a smaller cost than solar-powered irrigation systems. The current drought conditions in Uttar Pradesh underscored this point: because farmers have a limited amount of water at their disposal, efficient irrigation can help them cultivate more land with the same total amount of water.

For example, in a tribal area we visited in Uttar Pradesh, the farmer was able to irrigate for only 20 minutes at a time because the water level in his well had dropped so low. This amount of water could only irrigate a small, 350-square-foot patch of tomatoes. With a storage tank and drip irrigation system, he may be have been able to irrigate more land and see more income with the same amount of water, for a minimal cost.

When considering technology applications for irrigation, it would behoove project implementers and funder to first consider the suitability of efficient irrigation systems, then consider solar energy to power the pump. Drip irrigation systems are lower cost than solar, so as an initial investment for a farmer, the financial burden will be less of a barrier. If the farmer later chooses to purchase a solar array to power the pump, the pump will also be of the right size and the solar system overall will cost less.

5) Technical Capacity and Local Servicing

The knowledge, ability, and capability of farmers to interact with and operate their systems beyond simply flipping a switch varied greatly from location to location. In Gujarat, the representatives from SEWA understood the operation of the pumps in detail and were on hand for repairs and maintenance on a weekly basis. Conversely, the farmers in Uttar Pradesh and Karnataka were not only discouraged to service the solar panels and inverter, but were effectively unable to do so. At most, users were able to clean their pumps and wells of debris.

However, in places where the farmers received less training, they were also provided support from installers. Yet, in these cases it is less the lack of technical training and instead the understanding of the business model that needs to be better conveyed, especially in complicated financing arrangements like those we saw in Karnataka. This lack of understanding is unfair to the farmer, but is also a risk to the ongoing viability of the project.

6) Financing Availability

In 2010, the central Government of India (GoI) launched the Jawaharlal Nehru National Solar Mission (JNNSM), whose aim is to make India a global leader in the development and deployment of solar energy technologies [9]. One scheme under JNNSM offers a capital subsidy to support the expansion of solar pumping for irrigation, at a desired rate of 30,000 systems annually. The Ministry of New and Renewable Energy (MNRE) is responsible for administering JNSSM, while the National Bank for Agriculture and Rural Development (NABARD) serves as the subsidy channelizing agency [10].

Despite the scheme's existence, subsidies prove difficult and time-consuming to avail of, with larger-scale, government-tendered projects (like the one in Karnataka) being the primary beneficiaries. This limits the scheme's ability to reach farmers in more remote areas, where low population densities do not warrant large-scale projects. Further, such government tenders often offer little flexibility to size systems appropriately for the context, which may lead to the financing of projects that would otherwise be unviable. Mismatches in agricultural timelines and financial regulations also present a real obstacle: farmers' incomes are seasonal, while banks often require monthly payments.

Financial mechanisms beyond capital subsidies are needed. For individual farmers, readily available low-cost debt for the purchase of solar pumps and larger-scale debt financing programs would be beneficial. Even as significant potential for agricultural loans exists in India, the solar pump system market is relatively under-developed, such that commercial banks show little interest in offering financing. Indeed, mature financial products and infusions of venture capital funds in this sector remain low.

IV. Conclusion

As a sustainable and scalable technology, solar water pumps reside at the water-energy-food nexus. Their implementation in regions heavily reliant on fossil fuels or grid electricity (powered primarily by coal) is often hailed as a vital step in battling climate change and increasing food security. In order to determine barriers and opportunities to scale in these contexts, three small-scale implementation models for solar pumping in India were examined.

All three use cases studied were approached from a programmatic standpoint and revolved around community integration. Through a research approach that included case study development, direct end-users surveys, and stakeholder interviews, 6 key factors to consider before implementation were identified: end-user satisfaction with the technology, customer engagement, system sizing, water availability, technical capacity and local servicing, and financing availability. They are listed as a formative first stage checklist when choosing to implement an agricultural-based, community-wide solar water pumping program. Though the factors listed arise specifically from the introduction of solar pumping systems, they may offer lessons germane to alternative technologies more broadly. Beyond the checklist, topics such as supply chain mapping in rural areas and alternative asset productivity uses for the solar panels, are highlighted as of interest to those procuring solar pumping systems at scale but beyond the scope of this initial investigation.

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References

[1] United Nations Development Program (UNDP), Making Technologies Work for Human Development, Human Development Report, New York: Oxford University Press, 2001.

[2] Fthenakis, V.M., H.C. Kim, and E. Alsema, "Emissions from photovoltaic life cycles," Environmental Science and Technology 42: 2168-2174, 2008.

[3] KPMG, "Feasibility analysis for solar agricultural water pumps in India," 2014.

[4] Food and Agricultural Organization (FAO), "The water-food-energy nexus: a new approach in support of food security and sustainable agriculture," Rome: FAO, June 2014.

[5] Ministry of New and Renewable Resources (MNRE), "Status of solar pumps for irrigation installed by various state nodal agencies," http://mnre.gov.in/file-manager/UserFiles/progress-report-of-solar-pumps-for-irrigation-implemented.pdf, accessed May 11, 2016.

[6] Food and Agricultural Organization (FAO), "Final report," International workshop: prospects for solar-powered irrigation systems (SPIS) in developing countries," Rome, Italy, May 27-29, 2015.

[7] Yin, R.K., Case Study Research: Design and Methods, Los Angeles: SAGE Publications, 4th ed., 2009.

[8] J.W. Creswell and V.L.P. Clark, Designing and Conducting Mixed Methods Research, 2nd ed., Los Angeles: SAGE Publications, 2010.

[9] Ministry of Renewable Energy and Environment (MNRE), "Jawaharlal Nehru National Solar Mission: Towards building solar India," November 2010.

[10] National Bank for Agriculture and Rural Development (NABARD), "Guidelines for capital subsidy scheme of Government of India for promoting solar photovoltaic (SPV) water pumping systems for irrigation purpose," Department of Refinance, December 2014.