PRODUCTIVE USE OF SOLAR WATER PUMPING SYSTEM WITH UNIVERSAL SOLAR PUMP CONTROLLER

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Abstract

This paper details the opportunity for additional productive uses of solar water pumping systems (SWPS) by replacing a normal controller with a Universal Solar Pump Controller (USPC). The USPC helps in fulfilling the need for power for running many loads in addition to powering SWPS. Owing to its potential, it is already part of the ongoing PM-KUSUM scheme of India, the largest in irrigation space. It also complements the fact that the utilization of off-grid SWPS is traditionally low. This study intends to assess the existing USPC ecosystem, identify gaps and challenges, and draw out possible strategies and mechanisms for increasing USPC acceptability and its deployment. The paper also entails the details on the assessment of key parameters impacting the adoption of USPC. A tool has been developed to quantify the potential of utilizing the available excess energy generated during non-irrigation hours of SWPs for other applications and analyzed them in 50 districts across different states in India.

Keywords: SWPS, USPC, PM-KUSUM, excess energy, irrigation

1. Introduction

Solar Water Pumps (SWPs) have now become an integral part of the agriculture and irrigation ecosystem in the country. Once a novelty, SWPs are emerging as an effective alternative to traditional options such as diesel and electric pumps. The growth in SWP deployment has seen a great push recently with support from the ambitious national scheme of India, the Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan (PM-KUSUM) scheme. Many research works have been conducted to estimate the performance of SWP along with optimum sizing (Cuadros et al., 2004; Glasnovic and Margeta, 2007; Hamidat and Benyoucef, 2009; Moulay-Idriss and Mohamed, 2013; Kassem, 2012). However, the SWPs deployed at a high upfront cost are currently being utilized only for half of the days in a year (around 150 days per year) on average, which varies to a great extent depending on many factors such as the number of cropping, land size, water table, lack of proper design, etc. As per the study of Anas and Abhishek, 2021 (www.ceew.in), only 27% of the energy generation potential of SWP is utilized in India whereas the remaining 73% of energy just remains unutilized but with a great potential for meeting the energy needs of livelihood applications. It has been observed that increasing utilization of SWPs leads to greater income generation for farmers thereby increasing the financial and commercial viability of the system. The utilization of the SWPs can be increased by broadly two ways: firstly, by aligning the cropping pattern and thus the irrigation requirement as per SWP operation, and secondly by utilizing the excess energy for other income-generating end-use applications. It is challenging to convince farmers to change/ align their cropping patterns since cropping patterns are associated with traditional farming practices passed on from one generation to another. Additionally, many a times, change in cropping is not feasible considering climate, temperature, type of soil, and crop water requirement considerations. A more sustainable method of increasing SWP utilization is thus to explore other applications which can be powered by electricity generated by SWP systems during non-irrigation hours.

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In the above context, the Ministry of New and Renewable Energy (MNRE), Govt of India has introduced technical specifications for Universal Solar Pump Controller (USPC), a controller with multiple outputs allowing farmers to utilize the excess energy generation during the non-irrigation hours for operating other applications such as Atta Chakki, Chaff Cutter, etc. It is a unique, multipurpose, variable speed motor controller that replaces a normal controller to run agrarian equipment in addition to a solar pumping system. It converts high voltage, direct current from a photovoltaic (PV) array into highly controlled, three-phase PWM (pulse width modulated) alternating current (VAC) to run standard AC water pump motors. It can also be used to run DC water pumps. As per the specification designed by MNRE, USPC must have at least four numbers of three-phase output cables to feed power to various uses as per the need of the farmer and the farmer should have the option to select the specific application at a time using a keypad or via mobile or remote control connectivity.

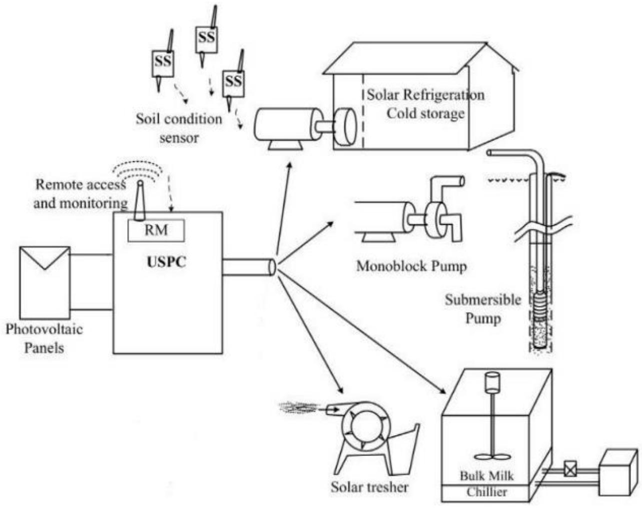

Fig. 1: USPC operation schematic diagram [7]

Even though USPC is part of a national scheme owing to its potential, there are some challenges in adoption and hence, despite encouragement from MNRE to use USPC (by including it in the PM-KUSUM scheme), to date, there are very few installations on the ground across the country. This study has made efforts through primary surveys and stakeholder consultations to understand different aspects of USPC that would aid in identifying the bottlenecks and identify probable solutions and directions for large-scale uptake of USPC.

2. Methodology

To understand the potential and challenges of USPC a two-way approach has been taken. First, the estimation of excess energy available for USPC to run is calculated and analyzed in different scenarios. Secondly, a detailed primary survey was conducted among firsthand users of USPC along with consultation with different stakeholders.

2.1. Excess energy calculation

The Excess Energy Computation Tool (EECT) is an Excel tool based on the Solar Irrigation Pump Sizing (SIPS) Tool developed by the Indian Council of Agricultural Research (ICAR), GIZ, Climate Change, Agriculture and Food Security (CCAFS) and IWMI to estimate the optimal solar pump capacity at a given location in India (https://pmkusum.mnre.gov.in/landing.html). The SIPS tool intends to increase the understanding of factors that drive farmers' irrigation demand, and pumping behavior, and ultimately recommends 'pump size' and monthly irrigation requirement based on various factors, such as location, climate data, irrigation data, etc. Further, an additional layer is added to the tool to estimate the excess energy not utilized by SWP across the selected states and districts. The excess energy is calculated by subtracting the energy consumed by solar water pumps for irrigation purposes from the energy generation by solar panels during a year. The tool aims to allow stakeholders, such as solar developers, policymakers, and financiers, to make informed decisions about SWP installations. The tool provides insights on monthly excess energy available by water pumps across shortlisted districts and can assist stakeholders in identifying areas for improvement and optimization, thereby contributing to the overall effectiveness and enhancing the financial viability of SWP projects.

Selection of states

Estimating excess generation is critical for getting the range of average SWP utilization across various states and districts across the country. Since the surplus energy needs to be estimated across various states and districts, ensuring uniform representation, a framework/methodology for the selection of states and districts based on various parameters/criteria has been created. The methodology for the selection of states and districts has been carried out in two modules (a) Selection of districts from the cluster combination as defined in the IWMI-Tata Policy Paper (https://www.iwmi.cgiar.org) based on high level of farm mechanization, (b) States with higher number of SWP Installations and demand as submitted for Component B of PM KUSUM scheme. The purpose of shortlisting selected districts and states is to ensure that the selected districts represent the varied geographical, geological, and climatic conditions across India. Accordingly, 50 districts in 15 states across the country were selected for the estimation of the excess energy available by SWPs across the country.

The following assumptions have been considered in the base case scenario while estimating the above levels of % of annual excess energy available across the districts:

- 3 times cropping in a year is considered for all the districts.
- Micro-sprinklers were chosen as the irrigation system due to their efficient water distribution, and tube wells were the primary water source employed due to their widespread availability in the studied districts.
- 25 days of irrigation is considered across months.
- The water table depth, crops, and planting months are chosen based on state-specific data available from the respective states' govt. agriculture and irrigation portals.
- Solar irradiation has been considered from the NASA portal for respective districts. (www.power.larc.nasa.gov)

2.2. Primary Survey of USPC users

Currently, the USPC technology is in the nascent phase with very few installations across India. At the time of conducting the survey, Himachal Pradesh is one of the very few states with a relatively higher number of USPC installations. In consultation with MNRE and the Agriculture Department of Himachal Pradesh, 54 farmers across 7 districts (as shown in Fig 2) have been shortlisted for the primary survey. The majority of the SWPs have a capacity of 5 HP. A thorough consultation procedure was designed to facilitate transparent and meaningful interaction with the farmers. During the preparatory phase of the survey, a questionnaire for the farmers was prepared to capture the farmers' motivation for use of USPC, their experience while applying for USPC and using USPC, information on subsidy availed by farmers for purchase of SWP with USPC, key issues (if any) faced while using USPC, typical equipment used with USPC, usage pattern of USPC, etc. The questionnaire was also designed to understand the USPC technology, its cost and benefits, and identify bottlenecks, if any, affecting the USPC adoption by farmers. The questionnaire has a mix of qualitative and quantitative questions to capture relevant information regarding the usage of USPC. The robust and comprehensive questionnaire was intended to capture technical, financial, social, and behavioral aspects related to USPC.

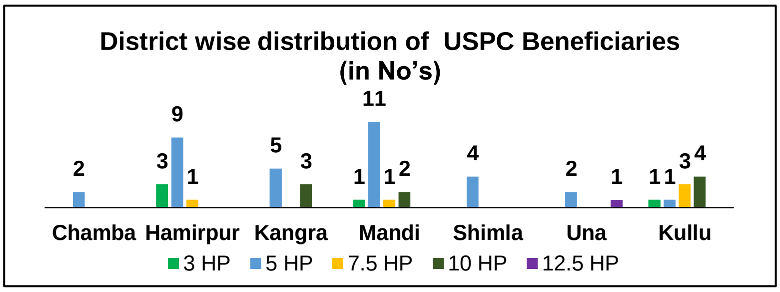

Fig. 2: District Wise USPC Installation to be considered for the primary survey

During the survey conducting phase, a detailed action plan encompassing a meeting agenda, a tentative schedule for consultations, and key points of the discussion were developed. The stakeholders were taken through their respective questionnaires and their responses were documented in a detailed manner.

During the documentation and reporting phase, all the responses from farmers were collected either in pen and paper mode in the local language or in the Survey CTO tool on Electronic Tablets. Both qualitative and quantitative information collected from farmers were analyzed for key insights on USPC penetration, usage, and issues. The responses provided by farmers were corroborated by responses from other farmers to ensure that the insights derived were accurate.

2.3. Stakeholder consultations

The project team conducted consultations with various SWP/USPC/Agri equipment manufacturers, researchers, technical institutes, and SIAs in the country. The discussions were focused on understanding the challenges vis-à-vis technical requirements of the equipment and excess energy produced from SWPs (e.g., electrical compatibility, O&M requirements, etc.) in promoting USPCs.

3. Results and Discussion

3.1. Excess energy availability

As highlighted above, one of the objectives of the study is to estimate the energy available from the solar water pumping system, which can be utilized by farmers for non-irrigation purposes to meet their energy needs. The findings revealed significant variation in the selected 50 districts in the availability of excess energy among these districts as shown in Fig 3. In some districts, annual excess energy available is as high as 85% of the total solar energy highlighting low utilization of SWP for irrigation. In contrast, some of the districts showcased considerably higher utilization, with annual excess energy available as low as 38%. Importantly, this contrast in excess energy utilization is also impacted by optimal SWP capacities for respective locations, which ranged from 1 HP to 10 HP. It is to be noted the tool used for this estimation has the capacity to design a maximum upto 10 HP.

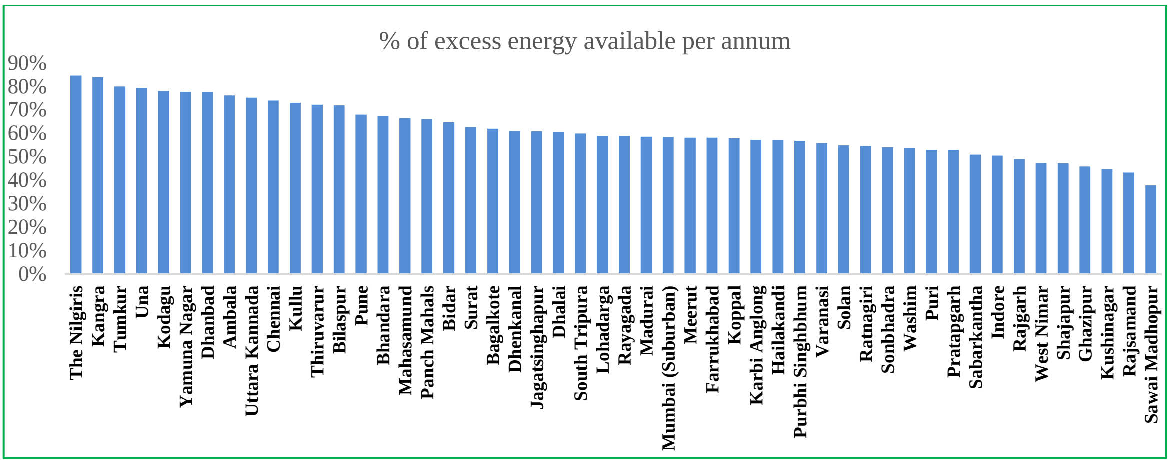

Fig. 3: % of excess energy available per annum across 50 districts

Further, the following sections detail the scenarios that highlight the impact of the number of crops, irrigation system, and water table depth on pump capacity and excess energy generation. The expected outcomes of each scenario, along with the rationale behind them, are discussed in Table 1.

Tab. 1: Expected outcome and rationale of various scenarios

Scenario	Expected Outcome	Rationale
Change in Cropping style	Decreased excess energy availability with a greater number of cropping	The decrease in crop counts within a specific district is likely to result in reduced water demand, subsequently leading to less frequent usage of SWPs. This reduction in usage increases the availability of excess solar energy, which can then be repurposed to meet various agricultural or non-agriculture activities.
Change in Irrigation Style	Shifting from Micro-Sprinklers to Surface irrigation results in higher energy consumption by pumps and may necessitate the need for higher-capacity SWP.	Switching from Micro-Sprinklers to less efficient Surface flooding requires higher capacity SWPs to meet the increased water demand. However, this shift may not correspond to a significant increase in energy unutilized,

Scenario	Expected Outcome	Rationale
		as the energy from added pump capacity is predominantly used for the increased irrigation demand.
Change in Water Table Depth	Increase in requirement of energy for pumping water with an increase in the water table depth.	Pumping water from deeper wells requires more energy, leading to a reduction in the surplus energy of Solar Water Pumps (SWPs) and making the use of higher-capacity pumps necessary for deeper water sources. In such a scenario, for a given amount of non-irrigation hours in a year, more energy will be available for other activities.

For these scenarios, representative districts among the 50 districts were chosen such that the various impacts of each of the parameters on pump capacity, excess energy generation, or both are highlighted clearly.

Scenario 1: Different cropping style

In this scenario, the focus is on assessing the variation of excess energy availability depending on the number of cropping practiced in a year. Keeping all other parameters unaltered i.e., the cropping per year has been reduced from triple to single. As shown in Fig 4, a decrease in cropping number count across districts has either resulted in the need for lesser SWP capacity or higher energy available or both. The graphs below highlight the same across 4 representative districts out of 50 districts.

Fig. 4 (a) illustrates the impact of varying crop patterns in Uttara Kannada, a district in Karnataka, on the percentage (%) of excess energy left unused. It can be observed that a decrease in the number of cropping has marginally decreased the SWP capacity from 2 HP to 1 HP. However, this has resulted in an increase in excess energy available from 75% to 87%. In the Mahasamund district of Chhattisgarh [Fig. 4 (b)], it can be observed that with the decrease in number of cropping from triple to single, the SWP capacity decreased from 10 HP to 2 HP. This has been accompanied by an increase in excess energy from 66% to 82%. Fig. 4 (c) shows the decrease in the number of cropping from triple to single resulting in an increase in SWP capacity from 10 HP to 2 HP and a drop in excess energy from 47% to 80% in the Shajapur district of Haryana. Lastly, in the Kushinagar district of Uttar Pradesh, as shown in Fig. 4 (d), the decrease in the number of cropping didn't alter the SWP capacity but has only resulted in an increase in excess energy (in %) available.

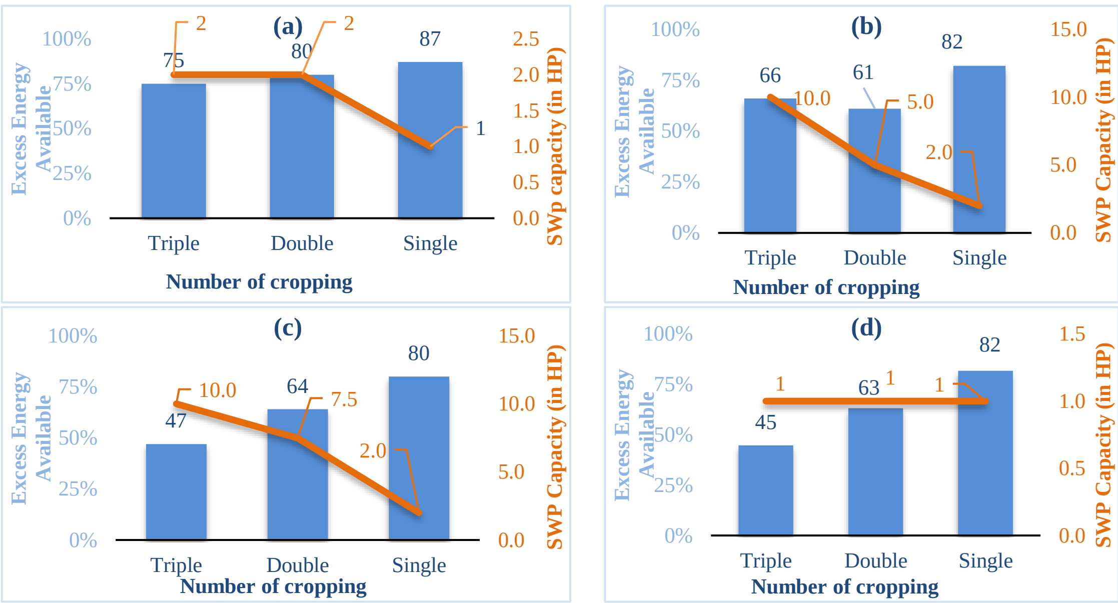

Fig. 4: Impact of Annual Crop Count Change on SWP Capacity and Energy Available (a) - Uttara Kannada District, Karnataka; (b) - Mahasamund district, Chhattisgarh; (c) - Shajapur district, Haryana; (d) - Kushinagar district, Uttar Pradesh

Scenario 2: Different irrigation style

In this scenario, the focus is to understand how the selection of different irrigation systems, viz. Micro-sprinklers, Sprinklers, Drips, or trickle, and Surface/flood can change pump capacity requirements and its utilization time. Fig. 5 shows the impact of change in the irrigation system in 4 representative districts viz. Uttara Kannada District of Karnataka, Kangra District, Himachal Pradesh, Dhanbad District, Jharkhand, and Kushinagar District of Uttar Pradesh.

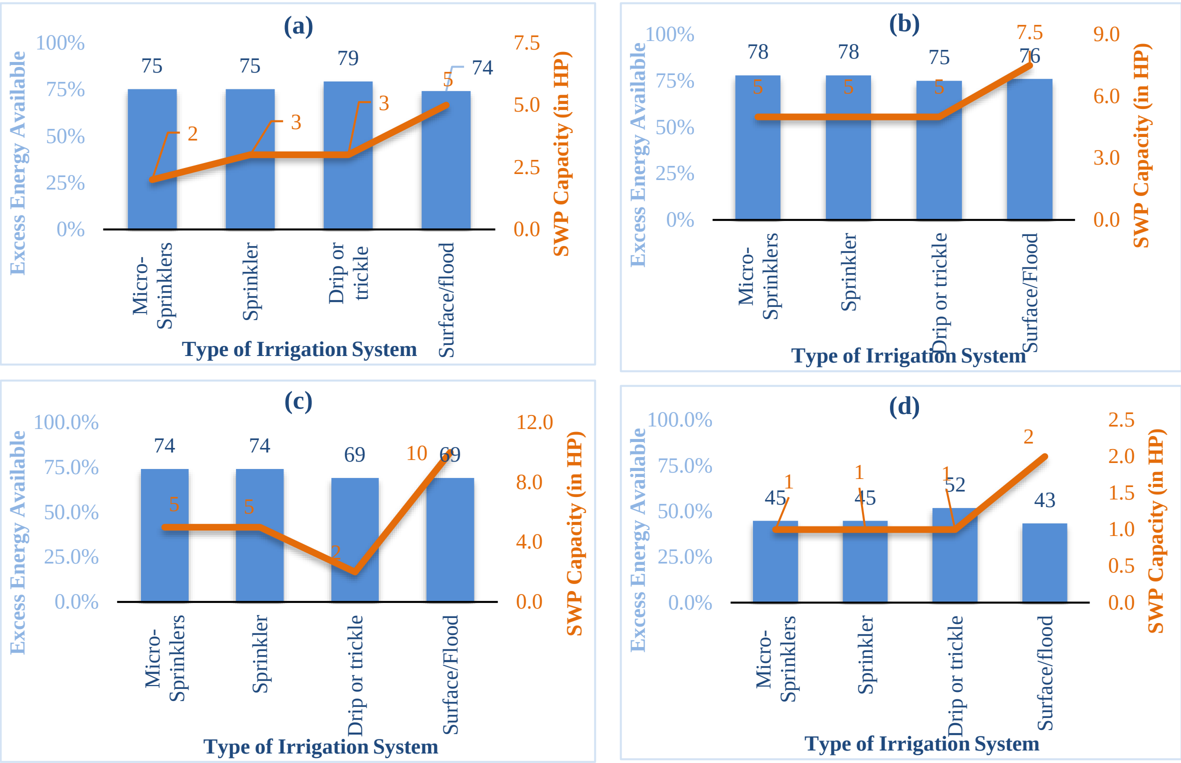

Fig. 5: Impact of change in irrigation system on SWP Capacity and Excess Energy Available (a) - Uttara Kannada, Karnataka; (b) - Kangra district, Himachal Pradesh; (c) - Dhanbad district, Jharkhand; (d) - Kushinagar, Uttar Pradesh

Fig. 5 (a) illustrates the impact of changing irrigation methods employed by farmers in Uttara Kannada district of Karnataka on the SWP capacity (in HP) and the annual percentage of excess energy available. It was observed that transitioning from Micro-Sprinklers to Surface/flood increased the SWP capacity from 2 to 5HP without significant change in excess energy available. Fig. 5 (b) highlights the impact of irrigation systems in the district of Kangra, Himachal Pradesh. With the change in irrigation system from Micro-sprinkler to Surface the SWP capacity increased from 5 to 7.5 HP without significant change in excess energy available. Fig. (c) illustrates the impact of changing irrigation methods in the district of Dhanbad, Jharkhand. With the change in irrigation system from Micro-sprinkler to Surface the SWP capacity increased from 5 to 10 HP and further decrease in excess energy available. As shown in Fig. 5 (d), in Kushinagar district of Uttar Pradesh, transitioning from Micro-Sprinklers to Surface floods increased the SWP capacity from 1 to 2 HP without significant change in excess energy available. It is evident that a significant amount of excess energy is available for all the different irrigation methods across all the locations which concludes the potential of USPC for productive use irrespective of irrigation method preferred by farmers.

Scenario 3: Different water table depth

In this scenario, to understand the impact of changing water table depths, an analysis of the range across 50 districts was conducted, which spanned from 3 m to 40 m. For ease of representation, the analysis was divided into two primary categories: water table depth under 20 m, and water table depth ranging from over 20 m up to 40 m. Further, the impact of water table depth on SWP capacity and % of excess energy available is represented for 5 districts in each of the above-mentioned categories.

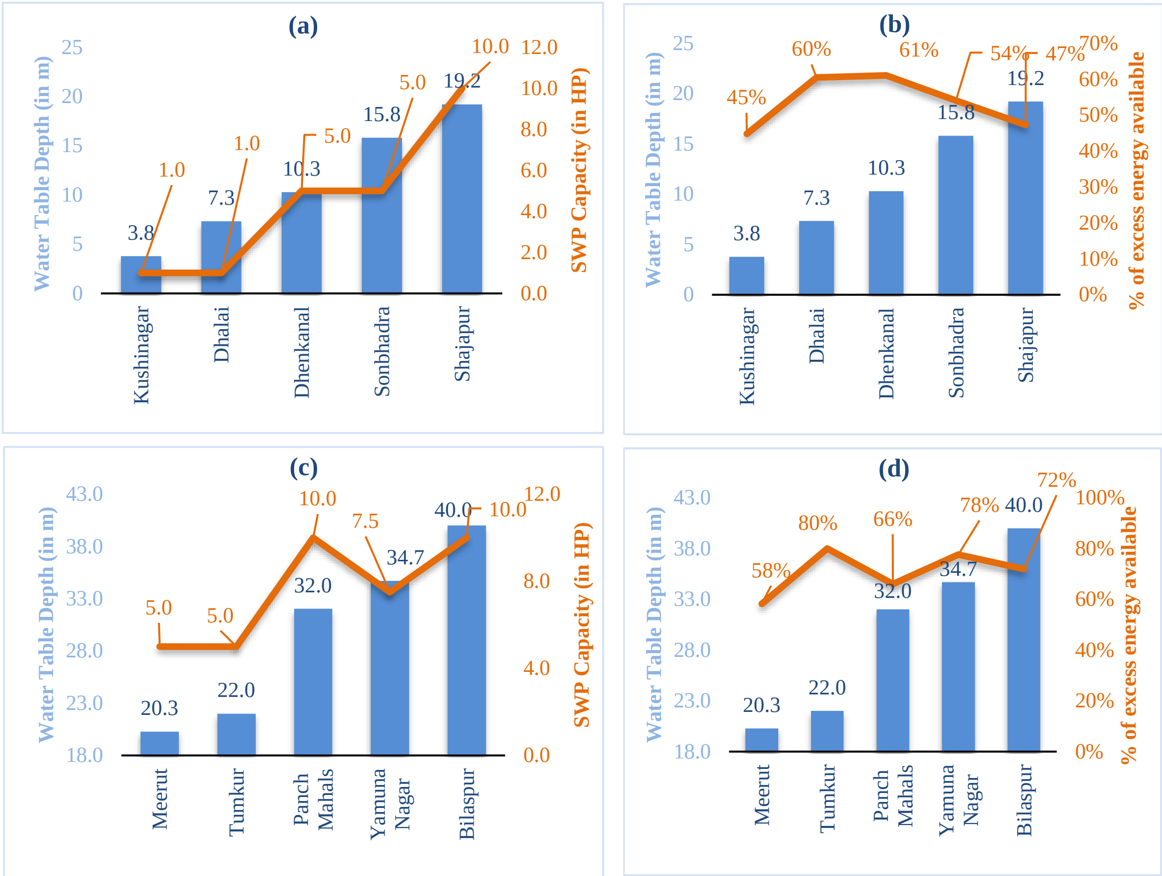

Fig. 6: Impact of change in the water table depth (in m) on SWP Capacity and Excess Energy Available (a) - Water table depth less than 20 m- Change in SWP capacity; (b) - Water table depth less than 20 m- excess energy available (%); (c) - Water table depth 20 to 40 m- Change in SWP capacity; (d) - Water table depth 20 to 40 m- excess energy available (%)

Fig. 6 illustrates the influence of water table depth changes (in m) on SWP Capacity (in HP) and the annual percentage of excess energy that remains unused. This is represented across 10 districts- 5 with a water table depth of less than 20 m and 5 with a water table depth from 20-40 m: As highlighted in the above figures, water table depth is not directly correlated with SWP capacity and % excess energy available. This is attributed to varying rainfall and cropping patterns across different districts of India. Fig. 6(a) illustrates the impact of changes in water table depth (in m) in the districts mentioned above that have a water table depth of less than 20m. It can be observed that as the water table depth increases from ~4 m to ~19 m, the SWP capacity required also increased from 1 HP to 10 HP. Whereas in Fig. 6 (c), while assessing the impact on a district having a water table depth greater than 20 m, it is observed with an increase in water table depth from ~20 m to ~40 m, the SWP capacity increased from 5 HP to 10 HP. However, in all these cases, the absolute value of excess energy available (in kWh) increases with increase in the water table depth.

3.2. Primary Survey

Out of the 54 farmers with whom consultations have been conducted, it was identified that 3 of the farmers were using the normal controller and the rest 51 of the farmers were using USPC. However, based on consultations with 51 USPC beneficiaries, it was revealed that only 1 out of those were utilizing USPC for operating Agri equipment (Chaff Cutter) apart from operating SWP, while the rest of the 50 were utilizing USPC only for SWP operation. Some of the key observations during the survey were highlighted below:

- 15 farmers did not have any agri equipment or any other energy needs to be fulfilled.
- 9 farmers were interested in purchasing the additional Agri equipment for operating it with USPC.
- 8 farmers had stated that the USPC is installed far away from their homes (where agri equipment is installed).
- 8 farmers were interested in connecting the SWP/USPC system with the grid.

- 5 farmers were found to be having single-phase equipment which were incompatible with USPC and 24 had shown interest for single-phase instruments to be connected if possible.
- 10 farmers had witnessed the visual operation of SWP/USPC prior to purchasing the system.

3.3. Key issues and potential solutions

Based on the learning during the primary survey as mentioned above and consultations with different stakeholders, key issues deterring the USPC penetration were identified as shown in Fig 7. The stakeholders include manufacturers of USPC, solar water pumps, agri/food-processing equipment, State Implementation Agencies (SIAs) of the PM-KUSUM scheme, researchers, and testing laboratories. Figure 11 illustrates broad categories of issues identified.

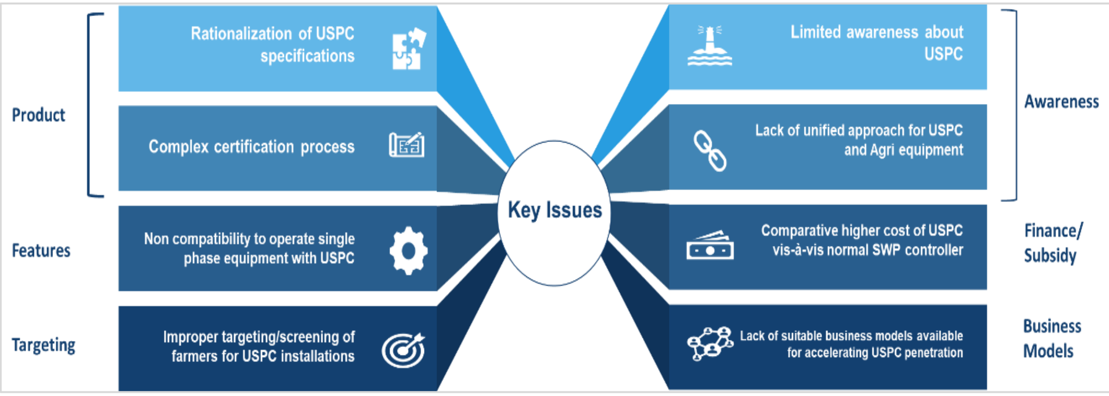

Fig. 7: Key Issues identified for USPC adoption

The following section will explain the different issues under the broad categories mentioned in detail.

- The cost differential between the price of regular controller and USPC is one of the major reasons affecting the USPC adoption. As shown in Fig 8, the cost difference ranges from 8% to 13%. (https://www.hindiyojana.in/wp-content/uploads/2021/02/2021122685-compressed.pdf).

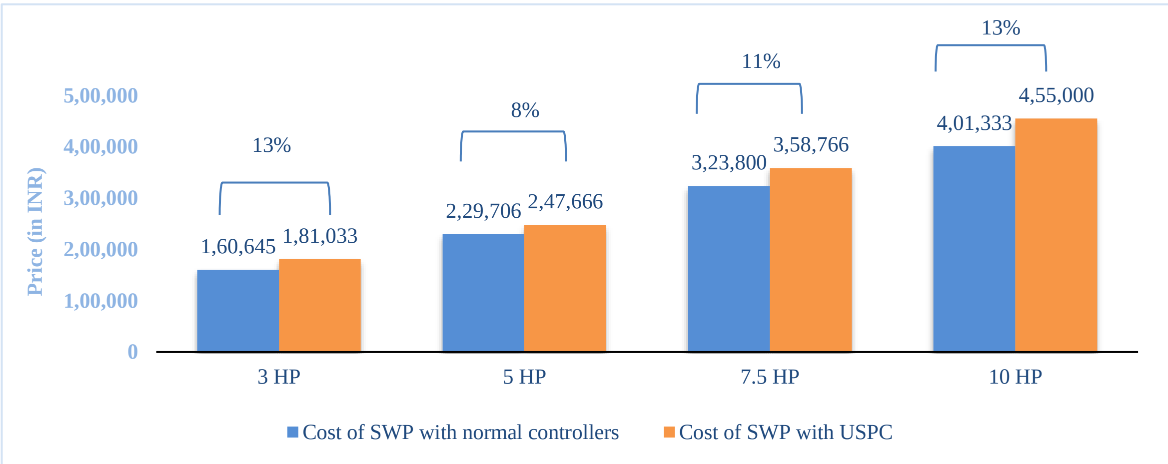

Fig. 8: Cost of USPC Vis-à-vis normal controller

- The current technical specifications of USPC are quite stringent and complex in nature resulting in increasing the cost of USPC. For example, the input voltage range as defined in the specifications may need to be revised based on suitable scientific methodology, since such a surge is not achievable, a change in total harmonics distortion (THD) levels in the range of 3-5% is not practically possible to manage all the time.
- Testing norms of USPC are not standardized by the certification labs across the country. In addition, the current testing procedure requires performing the functional test analysis of USPC by using actual

defined three-phase farm equipment such as Atta Chakki, Chaff Cutter, Bulk Milk Chiller, etc. However, it makes it difficult for vendors to carry the actual farm equipment to the testing centers. Considering the variety of farm equipment, including models and brands, it is impossible to achieve any degree of consistency in results either in the test center or in the field. Further, it would also be logistically difficult for manufacturers to bring the required equipment to the testing centers. In addition, the current technical specifications are detailed about intermediate conditions such as Maximum Power Point Tracker (MPPT) efficiency, number of ports, etc. but are unclear about the 'real' output of the core performance test. Hence, there is a need to simplify the certification process, where the number of equipment to be tested and the testing procedure to be streamlined.

- The current technical specifications permit only the use of three-phase agri equipment with USPC and not single-phase equipment. Primary consultation with USPC beneficiaries across HP revealed that 45% of the farmers had shown interest in using single-phase equipment for their daily needs and indicates an inclination/demand to operate both single-phase and three-phase equipment using USPC. Also, many farmers cited that single-phase agri equipment are easily accessible in the local market in contrast to the three-phase agri equipment, which were stated to be available only in far-off big cities. Further, there might be a high probability of damage/tampering with the equipment/USPC by farmers as farmers due to lack of technical knowledge might connect the single-phase equipment with USPC.
- There is a need for criteria to be adopted for allocating the USPC to farmers (under government-supported programs) to improve the targeting and enhance utilization. It is to be checked in advance whether the USPC can be used for the specific farmer's benefit.
- There is a need for steps to be taken to increase awareness among farmers regarding USPC benefits and the potential list of equipment that can be operated with USPC.
- There is a need to develop suitable business models for both individuals/groups of farmers for better utilization of USPC, better payback period, and maximization of revenue. A suitable delivery model should closely resemble local conditions, often requiring multiple approaches to cater to the needs of the farmers.

In view of the issues highlighted by stakeholders during consultations, the following solutions have been proposed.

- Simplification of specifications and testing procedures: USPC is currently in the nascent stage, hence an adaptive approach is suggested involving gradual simplification/easing up of the testing process, resulting in making the testing procedure more simplified, and streamlined. appropriate feedback may be sought from the various vendors, testing labs, and willing consumers during the process so that a variety of new issues can be identified, recorded, and analyzed to minimize their impact.
- Awareness Campaigns: A comprehensive approach to disseminating information to all stakeholders through awareness campaigns, pilot demonstrations, communication materials, capacity building, and engagement with farmers to educate and address their concerns is required. This would aid in enhancing USPC demand among farmers and would ensure in dissemination of the benefits and applications of USPC among end users and accelerate the adoption of USPC at scale.
- Customized solution: Offering customized solutions to farmers rather than a 'one-size-fits-all' approach will help farmers optimally utilize the excess energy generated for meeting their needs for operating agri equipment using USPC.
- 'Single Window' Information and Support Mechanism (SWISM): Based on the survey conducted with farmers in HP, it was found that the majority of farmers were not aware of the potential list of equipment that can be operated with USPC and also not aware of any financial assistance being provided on purchase of Agri/irrigation equipment. Hence, SWISM can help in providing information for all aspects related to agricultural equipment, solar water pumping systems, and USPC, which shall be beneficial for all the concerned stakeholders.

In addition to these, there is a need for specific criteria for the identification of farmers for USPC installations, so that it can be allocated to the right people in the right way. Some of the criteria suggested for allocating USPC are defined in Table 2.

Tab. 2: Criteria proposed for allocating USPC

Criteria	Details
Availability of diesel pumps	Clear guidelines may be formulated to prioritize farmers using diesel pumps and without agricultural power connections for allocating USPC, with an intention to de-dieselize the farm sector. The absence of such criteria can result in grid-connected farmers cornering subsidy benefits.
Intend/availability to operate Agri equipment:	Implementation agencies of states prioritize farmers having three-phase agri equipment to be operated with USPC or having intentions to operate three-phase agri equipment in the near future, for allocating USPC.
Proximity of Agri equipment with USPC	USPC should be located close to the farm where agri equipment are installed else it is difficult to operate the equipment with USPC
Geographical Location	Farmer is residing in locations where the grid extension is not feasible, or power supply is erratic.

Hence, for allocating USPC to farmers appropriate weightage may be assigned to each parameter discussed above, and depending upon their relative importance, a passing/selection score can be determined for selection of farmers for allocating USPC.

3.4. Case study analysis

While installations of USPC across India are limited in number, they are instrumental in tackling the specific hurdles that two individual farmers from Chikmagalur district of Karnataka and Daulatpura village of Rajasthan are facing.

The first farmer oversees an 8.5-acre organic farm, cultivating a rich array of crops including Robusta coffee, Areca nut, Coconut, and various spices such as Pepper, Ginger, Turmeric, and Cinnamon. However, he does not have a grid power supply which means dependence on manual and diesel-powered solutions for tasks like irrigation and farming.

The second farmer owns a vast 70-acre farm and despite having advanced equipment like a 12.5 HP electric pump and various three-phase equipment that uses Cow Dung as raw material for producing various items such as a Flowerpot-making Machine, he faces challenges due to long-lasting power outages.

Both the farmers resorted to SWP with USPC to meet their irrigation as well as other agricultural needs such as shredding, manuring the crops, etc. The first farmer installed 5 HP SWP with a solar panel capacity of 6.5 kW, USPC, a Battery bank with an inverter, Battery operated spraying machines, and a 5HP shredder to eliminate his dependency on costly diesel fuel and use it for meeting his irrigation needs and operating other Agri equipment. The set of equipment was funded by a combination of a grant and his own equity.

In the case of the second farmer, he initially installed SWP with the normal controller to be independent of unreliable grid power. He also owned multiple agri equipment such as flowerpot making machine, powder machine, sambrani cup-making machine that primarily uses cow dung as its input. This equipment plays a crucial role in recycling animal waste, transforming it into valuable products. In 2021, he contributed approximately INR 21,230, which amounted to 40% of the total cost for the 5 HP USPC installation. The government subsidized the remaining 60% of the capital cost.

We tried to conduct a cost-benefit analysis for both the farmers with usage of USPC as shown in Table 3. For the first farmer, the savings accrued are due to avoided manure costs that were earlier procured from the market and a reduction in labor costs for spraying the pesticides. The equity contribution is apportioned for shredder and battery-operated spraying machines and associated benefits are considered for cost-benefit analysis. For the second farmer, the equity contribution for USPC is apportioned over five agri equipment that he already possesses. The cost-benefit analysis is conducted for one piece of equipment viz. flowerpot making machine.

Tab. 3: Cost-Benefit analysis for USPC

S. No	Parameter	Farmer 1	Farmer 2
A.	SWP capacity (HP)	5	5
B.	USPC capacity (HP)	5	5
C.	Total proportionate equity contribution by farmer (INR)	63,627	4,246
D.	Average annual savings due to USPC (INR)	27,000	4,023
E.	Payback period (Yrs.)	Less than 3	Less than 2

The two cases represented above clearly demonstrate that utilizing their agri equipment is profitable for farmers with a reasonably short payback period. This approach makes sense not only for these farmers but also for similar farmers or agri entrepreneurs who can utilize this excess energy for operating equipment with similar loads/capacity. Despite its advantages, the discussed applications perse have not been widely adopted among many farmers, who often use other comparable equipment for various farming activities. A common example is the ownership of atta chakki machines of similar horsepower that are commonly used by farmers. USPC technology is relatively new and hence its adoption in the agricultural community has been limited. Our study, however, reveals a significant potential for the extensive application of the USPC technology to efficiently harness this energy.

4. Conclusion

SWP remains unused for a considerable period after irrigation demands are met. USPC is a controller with multiple outputs giving farmers the opportunity to utilize the excess energy generation for other applications. The study suggests that the various barriers that contribute to low USPC penetration are majorly due to the high cost of USPC, limited knowledge of the benefits, few technical limitations of USPC, improper targeting and screening of farmers, and lack of supporting ecosystem constraining the demand and thus income generation potential for other end-use applications. As USPC is a relatively new technology compared to SWPs, most stakeholders lack a complete understanding of the technology including its functionality. Focused promotional campaigns may act as a medium to build confidence. It is equally crucial to set up live demonstrations for potential beneficiaries and arrange for exposure visits to view successful USPC systems installed across the districts, which can play a major role in changing their mindsets.

Further, it was revealed that the cost differential between the price of a normal standalone controller and USPC is substantially high from the farmer's perspective. Thus, bridging the price between the two is the need of the hour. Gradually with the increase in demand for USPC, through a targeted program, the production volume will be increased, resulting in a lowering of the cost of USPC. Along with that, USPC technical specifications and testing procedures also need to be evaluated which will aid in bringing down its cost.

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