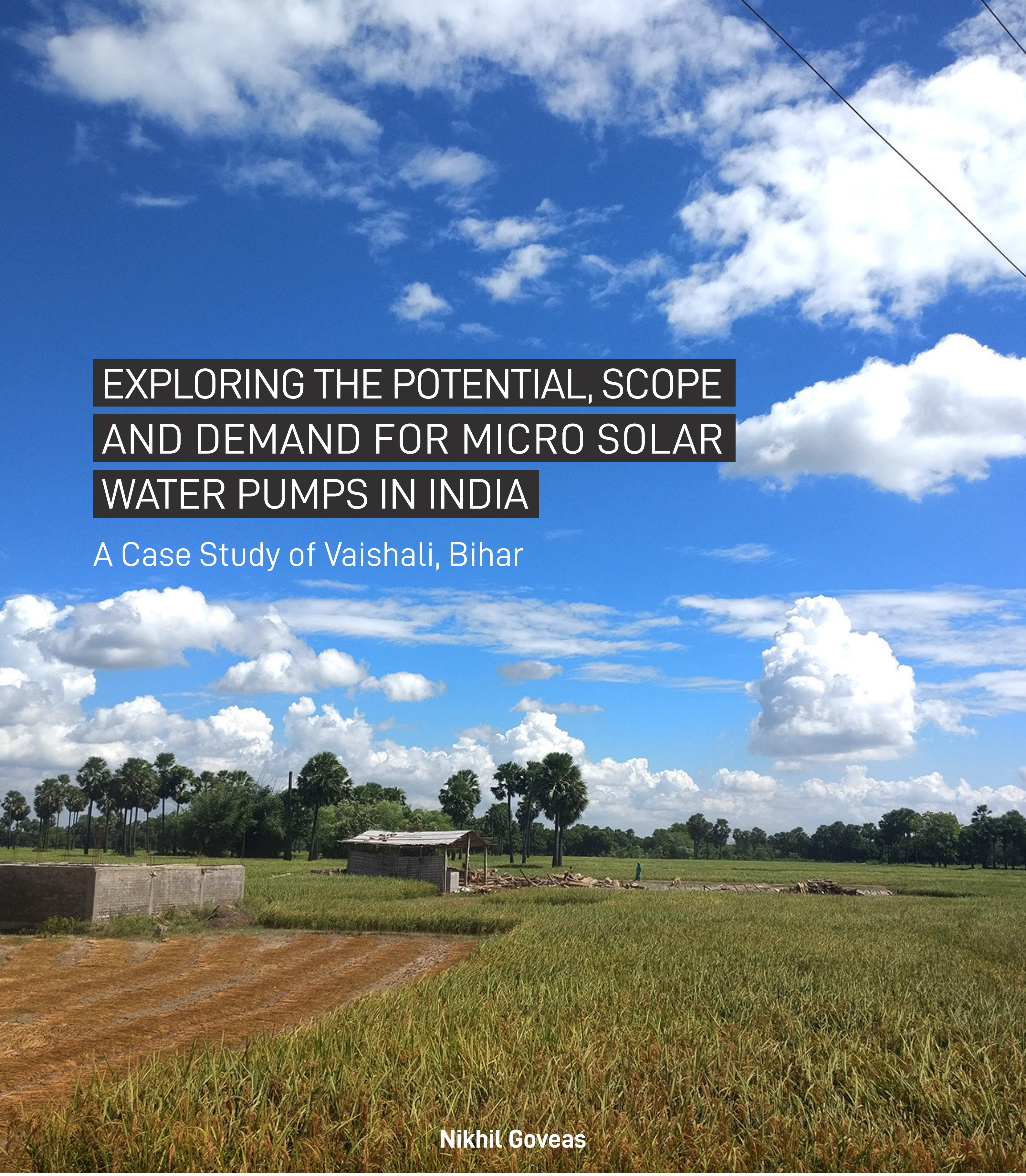

EXPLORING THE POTENTIAL, SCOPE AND DEMAND FOR MICRO SOLAR WATER PUMPS IN INDIA

A Case Study of Vaishali, Bihar

Nikhil Goveas

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giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Cover Image: Nikhil Goveas

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Koan Advisory
B6-1, Second Floor, DDA Commercial Complex
Safdarjung Enclave, New Delhi 110029
contactus@koanadvisory.com
www.koanadvisory.com

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Disclaimer:

The present document is an attempt to put together relevant information to stimulate thinking and raise basic knowledge on the scope, potential and demand for micro solar water pumps in India. Note that this document is neither exhaustive nor complete on the topic of micro solar water pumps. The information has been compiled from reliable documented and published references/ resources, as cited in the publication. Mention of any company, association or product in this document is for informational purposes only and does not constitute a recommendation of any sort by Koan Advisory or GIZ.

Executive Summary

India's agriculture continues to be dependent on the monsoon, with only 48 percent of the total net sown area in the county having access to irrigation resources. It is estimated that close to 30 million electric and diesel pumps are being used to draw groundwater to irrigate farms across the country. Of these, close to 70 percent of the pumps run on grid electricity, 29.5 percent are fuelled by diesel/kerosene and only 0.5 percent are powered by solar.

Electricity and fossil fuel powered irrigation have their respective limitations. Voltage fluctuations and limited hours of electricity supply continue to be chronic problems plaguing the farm sector. Applying for an electricity connection for the farmer is expensive and can take several months to become operational. This forces farmers to rely on diesel or kerosene powered pumps, which are expensive to operate and contribute significantly to greenhouse emissions. It is estimated that energy costs for irrigation average between 20-40 percent of production costs for farmers.

In comparison to the high costs and carbon emissions of diesel-fuelled irrigation, Solar Water Pump (SWP) supported irrigation has lower operating costs and a reduced environmental footprint. Even partial substitution of diesel pumps with solar offers significant opportunities for farmers to save on production costs.

In light of the opportunities for deployment of solar-based irrigation solutions, particularly through the recently launched Kisan Urja Surksha Utthan Mahaabhiyan (KUSUM), this report analyses the demand, requirements and potential for sub one metric horsepower solar water pumps in India. As part of this report, we also present the findings of a pilot project testing six submersible micro SWPs with 12 marginal farmers in Bihar aimed at generating primary feedback and assessing farmers' usage experiences, requirements, satisfaction levels, and challenges while operating micro SWPs.

Micro Solar Water Pumps: Technical Overview:

Micro SWP systems are categorized as pumps that are less than one metric horsepower (Hp) (less than 1kWp PV capacity and engines / motors with less than 0.746kWp capacity). In contrast to their larger counterparts, micro SWPs have limited discharge (litres/ per hour) and head (distance to which the water can be pumped). For the pilot in Bihar, only two capacity pumps were used – 0.1 Hp and 0.5 Hp. All of the six pumps used for the pilot were DC pumps, since they provide relatively better performance than AC pumps and do not need an inverter or variable frequency drive for operation.

Enabling Factors for Micro Solar Water Pump Deployment:

Theoretically, micro SWP can only pump limited volume of water through the day and are more suited to regions with a shallow depth to water level (2-5 metres). The states of Assam, Bihar, Jharkhand, Odisha, the upper regions of West Bengal, as well as the coastal regions in the country, particularly Kerala, Karnataka and Maharashtra could hold great promise for deployment of micro SWP supported irrigation solutions, on account of their shallow depth to water levels.

Studies indicate that solar powered irrigation solutions are economically viable to operate only when replacing diesel powered pumps, of for farmers who do not have access to electricity connections. (Aggarwal and Jain, 2018) Despite the high number of rural households electrified since 2009, there exist critical infrastructural gaps in expanding grid connectivity to farms in the states of Assam, Bihar, Jharkhand, Odisha, and West Bengal, forcing farmers in these regions to resort to diesel fuelled irrigation.

Since micro SWP can only pump limited volume of water, they are most suited for small plot sizes growing vegetables and less-water intensive crops. Deploying micro SWP can be the perfect solution to meet irrigation requirements for marginal and small farmers, who bear relatively higher energy costs on fuel.

Unlike their more powerful solar counterparts, micro SWPs are better suited for water efficient irrigation and are comparatively cheaper, thereby reducing the upfront cost borne by the farmer. Micro SWPs are also small and to a certain degree portable, making it easier for farmers to irrigate multiple plots.

Key Findings:

1. Submersible SWP Infrastructure and Eco-System

• Submersible pumps require borewells that are four inches in diameter and in good condition, without leakages and bends in the pipes.

• Deploying SWP systems require an eco-system of repair and maintenance technicians and easy availability of spare parts.

2. Farmers' Irrigation Requirements and Practices

• Marginal and small farmers need to grow at least one food crop a year for subsistence purposes. Option to shift cropping patterns is not easy for farmers.

• Farmers need better training and improved access to water saving irrigation solutions such as drip and sprinkler systems.

• Farmers want to complete irrigation operations as quickly as possible, while incurring the least expenditure, so that they can attend to other diverse livelihood activities.

• Marginal and small farmers use their water pumps for multiple functions not limited to irrigation alone.

3. Performance of Submersible Micro SWPs

• Micro SWP were easy to assemble and operate and took only five minutes to start up. They also made no sound during operations, which many farmers appreciated.

• Farmers took between 2-4 days to complete irrigation operations on one bigha (2500 m^2) through flood irrigation.

• Discharge from 0.1 Hp pumps was only 225 LPH and 1800 LPD and were ill-suited to meet farmers' irrigation requirements.

• Discharge from 0.5 Hp pumps was 1800 LPH and 14,400 LPD and display great promise for marginal and small farmers who grow water-intensive crops.

• Micro SWPs need to be deployed with efficient irrigation solutions to achieve optimum utilization and performance

4. Farmers' Incomes and Willingness to Adopt Solar Solutions

• Marginal and small farmers face significant challenges in raising large amounts for capital expenditure and would prefer staggered payment options for pumps.

• All farmers in the group were highly impressed with the performance of the SWP systems and wanted to shift to solar based irrigation solutions and were willing to pay up to Rs. 17,500 for a 1 HP Micro SWP.

• Farmers in the group were willing to pay INR 8,626-11,283 per annum over 3 years to buy a SWP system of 1 HP or above.

5. Incentivising Micro SWP Through Policy

• State governments should prioritize deployment of micro SWPs along with micro irrigation solutions for marginal and small farmers to enhance the efficiency and performance of the pumps.

• Incentivizing SWP usage for marginal and small farmers requires reflective subsidy and financing models to take into account the revenue and cost dynamics of different farmers and their ability to generate profits from agriculture.

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Glossary

AC - Alternating Current

CO2 - Carbon Dioxide

DC - Direct Current

FYM - Farm Yard Manure

GOI - Government of India

Ha - Hectare

Hp - Horse Power

INR - Indian Rupee

JNNSM - Jawaharlal Nehru National Solar Mission

KUSUM - Kisan Urja Surksha Utthan Mahaabhiyan

Kwp - Kilowatt-peak

LPH - Litres per Hour

LPD - Litres per Day

m^2 - Square Metre

MNRE - Ministry of New and Renewable Energy

mts - Metres

PMKSY - Pradhan Mantri Krishi Sinchaee Yojana

PV - Solar Photovoltaic Panel

SWP - Solar Water Pump

TDH - Total Dynamic Head

wp - Watt Peak Capacity

Land Size Categories and Area

CATEGORY	AREA (in m^2)
acre	4046.86
hectare	10000
katha	150
bigha	2500

1. Introduction

1.1 Background

Agriculture in India is at a crossroads. Despite 54 percent of the population earning their livelihood through agriculture, the sustainability of 'farming' as a livelihood option for farmers remains a constant struggle. A complex set of factors, mainly – increasing competition over land use, high costs of inputs, poor access to irrigation resources, non-remunerative returns from the market, and climate change vulnerabilities have created new challenges for farmers in India, of whom, 86 percent are marginal and small farmers operating an average land holding size of 1.41 Ha (14100 m2). (GOI, 2016)

India's agriculture continues to be dependent on the monsoon with only 48 percent of the total net sown area in the county having access to irrigation resources (GOI, 2017). The lack of access to irrigation resources and the over-reliance on erratic monsoon rains has significant implications on the profitability and productivity of marginal and small farmers, particularly in the eastern regions of the country. Close to 89 percent of groundwater extracted in the country is used for irrigation. Poor irrigation practices, choice of cultivating water intensive crops ill-suited to local aquifer conditions, incentives for irrigation equipment (pumps), and subsidised electricity supply have contributed significantly to groundwater depletion from Punjab all the way down to Tamil Nadu.

The major sources of irrigation are groundwater and surface irrigation (canals), with the former accounting for almost 70 percent of the total net irrigated area in 2015 (Gulati & Mohan, 2018). It is estimated that close to 30 million electric and diesel pumps are being used to irrigate farms across India, drawing water from underground sources. Of this, close to 70 percent run on grid electricity, 30 percent are fuelled by diesel/kerosene and only 0.5 percent are powered by solar (Shalu & Jain, 2015). The energy requirements for electric and diesel pumps account for more than 85 million tons of coal and 4 billion tons of diesel per annum (KPMG, 2014).

Electricity and fossil fuel powered irrigation have their respective limitations. Electricity access for agriculture is heavily subsidized by state governments, thereby increasing financial stress on power utilities and distribution companies. Additionally, voltage fluctuation and limited hours of electricity supply continue to be chronic problems. Applying for an electricity connection for the farmer is expensive and can take several months to become operational. Regions suffering from gaps in grid connectivity routinely face the apathy of power distribution companies, who have little incentive to expand grid infrastructure to the farm-level. This forces farmers to rely on diesel or kerosene powered pumps, which are expensive to operate and contribute significantly to greenhouse emissions. It is estimated that energy costs for irrigation average between 20-40 percent of production costs for farmers. The high energy cost for irrigation is disproportionately higher for marginal and small farmers, further hurting their profitability and competitiveness.

In comparison to the high costs and carbon emissions of diesel-fuelled irrigation, Solar Water Pump (SWP) supported irrigation has lower operating costs and a reduced environmental footprint (GIZ, 2013). Research

indicates that farmers who completely substitute diesel powered irrigation with solar based solutions stand to save upwards of INR 20,000 annually on energy costs for irrigating one hectare (4 bighas or 10000 m2) of farm land (KPMG, 2014). Even partial substitution of diesel pumps with solar offers significant opportunities for farmers to save on production costs. Studies calculating carbon emissions from irrigation in India have estimated that CO2 emissions from diesel powered pumps range between 32-131 million tonnes annually (Sharma, 2018). Irrigation contributes only between 2 to 7 percent of total annual CO2 emissions from India, which is relatively low when compared to other sectors such as transport, industry, power and biomass burning. However, poor quality of fuel commonly used in irrigation pumps leads to an increase in emissions of toxic nitrogen oxides. Recent studies have concluded that pollution due to nitrogen oxides destroys 22 million tonnes (21%) of India's total wheat yield and 6.5 million tonnes (6%) of rice every year (Fernandes, 2019).

India's experience with solar based irrigation solutions began almost 25 years ago with the Ministry of New and Renewable Energy (MNRE - earlier called the Ministry for Non-Conventional Energy Sources or MNES) initiating a program to deploy 50,000 SWP systems for irrigation and drinking water across the country. The program suffered from many teething problems and by March 2012, had managed to install only 7,771 SWP systems against the proposed target of 50,000. Research on deployment of SWP-based irrigation solutions in India has identified several barriers to uptake among farmers, mainly, high capital costs, inadequate infrastructure for after sales service, credit and financing issues, and the development and deployment of standardized technology without taking the end users' (farmers) needs into consideration; as some of the primary reasons for the poor uptake of solar irrigation solutions.

Underscoring the importance of solar in India's energy mix, the Government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010 to promote the commercialization of SWP systems for irrigation and drinking water. The program included efforts to streamline financing schemes with the MNRE providing a front-ended 30 percent capital subsidy to farmers willing to purchase a SWP, in addition to further capital subsidies provided by state governments. The scheme set an ambitious target of financing and installing one million SWP systems by 2020. However, actual numbers have fallen well short of this target, with only an estimated 130,000 SWP systems installed between 2014-17 under this scheme (Raymond & Jain, 2018). In June 2017, the MNRE in a Directive to State governments recommended that states prioritize farmers who had no access to irrigation, used diesel powered pumps exclusively, and whose farms were located more than 300 metres away from the grid, for promoting SWP systems. The Directive also recommended that 50 percent of the sanctioned pumps were to be of size 3HP, with 30 percent capital subsidy on all capacity sized SWP systems (MNRE, 2017).

The Government of India in 2018 announced the launch of Kisan Urja Surksha Utthan Mahaabhiyan (KUSUM) to subsidize SWP for farmers. The scheme provides for the installation of grid-connected solar power plants, distribution of SWP to farmers not connected to the grid, and mechanisms to sell surplus power to distribution companies. It is estimated that the cost of KUSUM over 10 years would total INR 1.4 trillion, of which the Central Government will provide INR 480 billion. Through KUSUM, the MNRE plans to allocate INR 220 billion as front-ended capital subsidy to help install 1.75 million off-grid SWPs. Farmers willing to purchase SWP under KUSUM will only have to pay 10 percent of the total cost of the SWP pumps upfront and avail 30 percent through a bank loan. An equal subsidy provided by the central and respective state governments would cover 60 percent of the remaining cost (ET, 2018). Additional details of this scheme are yet to come out and there is considerable speculation with regards to the particular modalities that will become operational.

1.2 Objectives

In light of the opportunities for deployment of solar-based irrigation solutions, this report analyses the demand, requirements and potential for sub one metric horsepower solar water pumps in India. The research methodology for this report combines a literature review of existing studies on SWP supported irrigation solutions in India, as well as a pilot project deploying submersible micro SWPs with marginal farmers in Bihar aimed at generating primary feedback and assessing farmers' usage experiences, requirements, satisfaction levels, and challenges while operating SWP supported irrigation solutions. Besides analysing enabling features – hydrological, regulatory, and agricultural methods, the report also outlines the most promising deployment areas and deployment options for SWP supported irrigation solutions across India.

2. Micro Solar Water Pump System - Technical Overview

Micro SWP systems are categorized as pumps that are less than one metric horsepower (Hp) (less than 1kWp PV capacity and engines / motors with less than 0.746kWp capacity). In contrast to their larger counterparts, micro SWPs have limited discharge (litres/ per hour) and head (distance to which the water can be pumped). A brief comparison of different capacities of submersible micro SWP systems is detailed below:

Table 1: Technical Specifications of Micro SWP

DESCRIPTION	MODEL 1	MODEL 2	MODEL 3
Solar PV Array	100 Wp	500 Wp	1200 Wp
Motor Capacity	0.1 Hp	0.5 Hp	1 Hp
Max. TDH	20 mts.	30 mts.	70 mts.
Discharge	225 LPH*	1800 LPH*	4000 LPH*

Note:

Wp – Watt peak capacity; Hp – Horse power Max. TDH - Maximum total dynamic head; mts – metres; LPH - litres per hour

Source: *Discharge levels of the 0.1 Hp and 0.5 Hp pumps were calculated during operations. The discharge levels of the 1 Hp pump were provided by the manufacturer.

For the pilot in Bihar, only two capacity pumps were used – 0.1 Hp and 0.5 Hp. Theoretically, small pumps can provide sufficient water to irrigate vegetables and less water intensive crops through efficient micro irrigation, for marginal and small farmers in particular. The micro SWP system consisted of a PV solar panel, a controller to manage voltage fluctuations and the pump. Submersible pumps were used to compensate for the limited water discharge of the micro SWP and to accommodate the fluctuating depth to water level, which averaged 6.7 metres below the ground level. All of the six pumps used for the pilot were DC pumps, since they provide relatively better performance than AC pumps and do not need an inverter or variable frequency drive for operation. However, deploying DC pumps comes with its own challenges. Foremost is that the cost of DC pumps is relatively higher than AC pumps, and service and repair options for DC pumps is limited in rural areas. The decision to test pumps of a smaller capacity was made to empirically validate the performance of micro pumps with marginal farmers and map their experiences without changing their irrigation practices. Micro SWPs are small and to a certain degree portable, making it easier for farmers to irrigate multiple plots. Considering their dynamic use, small pumps could be an ideal solution to meet irrigation demands of marginal and small farmers. Unlike their more powerful solar counterparts, micro SWPs are better suited for water efficient irrigation and are comparatively cheaper, thereby reducing the upfront cost borne by the farmer. While certain economic (capital subsidies, financing schemes) and regulatory features (grid connectivity, operation and maintenance, after sales service) that enable the development of solar based irrigation solutions are the same across all pump sizes, it is the technological specifications and end-user's irrigation demands that add further complexity to the decision to deploy micro SWP systems.

3. Methodology

Stage 1: Scoping study to understand demand and potential of micro SWP supported irrigation solutions

A review of existing literature on solar powered irrigation solutions helped identify enabling features and challenges including – depth to water levels of ground water aquifer, grid connectivity, land size holding patterns, type of crops and irrigation practices, and government schemes and policies for SWP. The lessons learn from India's experience with SWPs have been distilled and contextualised to understand the policy architecture, financing, incentives, infrastructural requirements and farmer capabilities that can enable the successful deployment of micro SWP based irrigation solutions across geographies. Considering the limited water discharge capacity of the micro SWPs, the utilization and operational dynamics of the pumps differ greatly from large size capacity pumps. What would be the best possible utilisation scenarios for micro SWP deployment, which could include, deploying micro SWPs with improved irrigation practices, such as drip and sprinkler systems.

Stage 2: Pilot exercise to test performance of sub 1 Hp micro SWP systems with farmers in Vaishali, Bihar.

A group of 12 marginal farmers were selected to administer the pilot. The identification of the farmers was based on the following criteria:

1. Marginal and small farmers who own/operate less than one hectare of land.[1]

2. Farmers who have access to borewells and surface water and are currently reliant on diesel / kerosene-based water pumps.

3. Farmers who do not currently own diesel / kerosene-based water pumps and who lease pumps for irrigation.

A baseline survey of the group was undertaken to assess existing cropping patterns and irrigation demands and practices. Farmers were given two types of portable micro SWPs to be used for irrigation on a rotational basis over the course of the pilot. Six portable micro SWP pumps (0.1 Hp x 3 and 0.5 Hp x 3) were used for the pilot with farmers using both capacity pumps for a period of one week each. This process was repeated with both types (capacities) of micro SWPs till each farmer had used both pumps.

Farmers were assisted in setting up the solar photovoltaic panels (SPV) and the micro pumps and provided with on-ground training on operating and maintaining the pumps. During the irrigation cycle, information was collected through physical verification of micro SWPs in operation and through a perception study of farmers to map out the experiences of operating and comparative functioning of the two types of micro SWPs. Through the data collection exercise, several key data points were captured, including – user experience, water discharge of the pumps, satisfaction levels, and cost sensitivity and probability of farmers to adopt micro SWP solutions through loans, subsidies and external financing. Additionally, information on ground level challenges faced during usage of micro SWPs, capability gaps of the technology and users, local ecosystem for repairs and spare parts, portability of machinery, safety, user friendliness, etc. was also collected through the surveys.

3.1 Scope and Limitations of the Study

The study aims to understand the scope, demand and potential for micro SWP supported irrigation solutions in India. Despite an abundance of literature on the potential of SWP supported irrigation solutions for India's farmers, there are no insights to be found on the potential of micro SWP systems for irrigation. The lessons from India's experience with SWPs had to be contextualised to the technical specifications of micro pumps and the irrigation demands of marginal and small farmers. Considering the geo-hydrological and agricultural diversity in India, the study will only be able to provide a general overview of the enabling factors and barriers to the deployment of micro SWP supported irrigation solutions. The study is limited in the sense that it does not consider non-agricultural usage of micro SWP systems and retains focus only on irrigation.

The pilot exercise of testing six micro SWP systems with 12 marginal and small farmers only aims to understand the experiences and satisfaction of the farmers while using these systems without changing their irrigation pattern. The inferences gathered therein are limited owing to small sample size, limited number of pumps used, and the limited use of the micro SWP by farmers. The pilot was intended to

[1] One Hectare = 4 Bighas or 10000 m^2

commence in the months of October-November 2018, coinciding with the beginning of the Rabi (winter) cropping season. However, owing to technical difficulties in the installation of the submersible micro SWPs in the borewells, the pilot could only begin in February 2019. This delay meant that farmers were only able to use the pumps for two rounds of irrigation. Inferences of farmers' experiences using the micro SWPs can only be termed as preliminary, owing to the limited use of the micro SWPs by farmers.

Another major challenge that the pilot exercise faced was the perception bias of farmers with regards to the discharge levels of micro SWP systems. Most farmers in the region use kerosene powered surface water pumps that have a minimum capacity of 2 Hp. Differences in capacity of the pumps has a direct correlation to the levels of water discharge from the respective pumps. To shift from a higher power water pump to a sub 1 Hp submersible motor pump is likely to elicit negative perceptions with regards to the functioning of the micro SWP systems.

The choice and number of pumps in the sub 1 Hp submersible range was also a limiting factor. Only two (0.1 Hp and 0.5 Hp) capacity submersible micro SWPs were available for the pilot, whereas a pump with a capacity between 0.5 Hp to 1 Hp would have lent greater insights in terms of pump performance, water discharge levels and farmer experiences.

4. Groundwater scenario in India

The groundwater scenario in India is vastly complicated to analyse due to the vast diversity of geological formations and rainfall patterns across the country. Porous geological formations such as the alluvial plains in the Ganga-Yamuna and Brahmaputra river basins are the most important repositories of ground water aquifers. In peninsular India and in the hill tracts across the country, groundwater aquifers are limited and found only in the weathered and fractured portions of rocks. In major parts of eastern states – Bihar, Jharkhand, Chhattisgarh, Odisha; Himalayan states of Uttarakhand and Himachal; and the north-eastern states of India, depth to water level generally varies between 2-5 metres below the ground level. In Andhra Pradesh, Maharashtra, Karnataka, Telangana, Tamil Nadu, Kerala, north western parts of Uttar Pradesh and West Bengal, depth to water level generally varies from varies from 5-10 m with small patches showing depth to water level between 2-5 m. In major parts of north-west India and the south – Punjab, Haryana, Delhi, Gujarat, Rajasthan, Tamil Nadu, and parts of Maharashtra and Uttar Pradesh, depth to water level is significantly deeper between 20-40 metres below ground level. Rainfall contributes more than 67 percent of the total water replenishment of ground water reservoirs in the country. However, the impact of climate change and unseasonal rainfall in the past decades has meant that replenishment of ground water reserves is lower than the rate of groundwater development. Table 1 below outlines the different aquifer systems in India, their coverage and potential for groundwater development.[2]

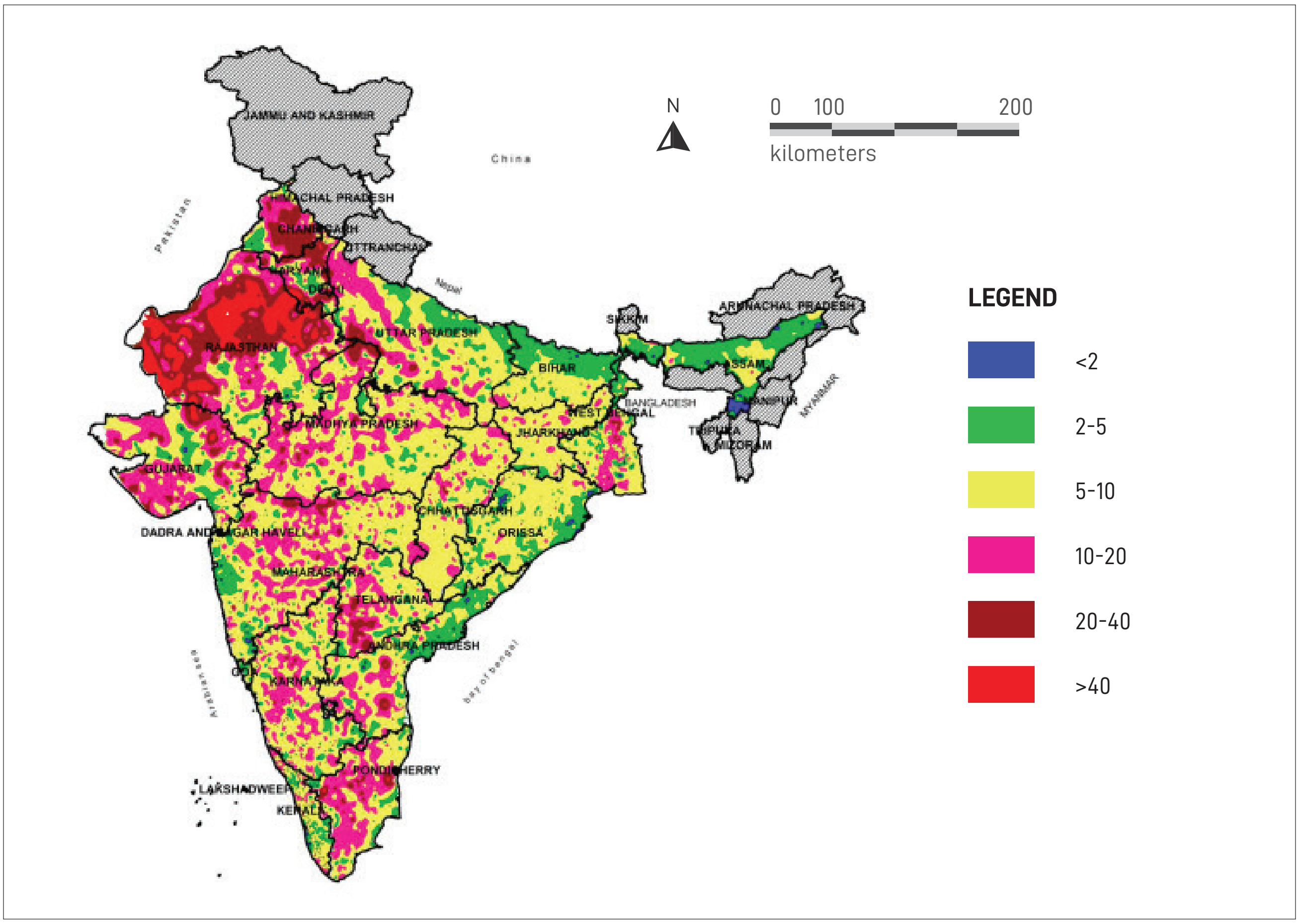
Table 2: Aquifer Systems and Groundwater Potential in India.

SYSTEM	COVERAGE	GROUNDWATER POTENTIAL
Unconsolidated formations - alluvial	Indo-Gangetic, Brahmaputra plains	Enormous reserves down to 600 m depth. Higher rain-fall and hence ensures adequate recharge of groundwater.
	Coastal Areas	Reasonably extensive aquifers but risk of saline water intrusion
	Part of Desert areas – Rajasthan and Gujarat	Scanty rainfall. Negligible recharge. Salinity hazards. Ground water availability at great depths.
Consolidated/semi-consolidated formations (sedimentaries, basalts and crystalline rocks)	Peninsular Areas	Availability depends on secondary porosity developed due to weathering, fracturing etc. Scope for groundwater availability at shallow depths (20-40 m) in some areas and deeper depths (100-200 m) in other areas.
Hilly	Hilly states	Low storage capacity due to quick runoff

Source: (CGWB, 2017)

[2] Groundwater development refers to the extent of water extraction vis-a-vis existing levels of water in aquifer.

Figure 1: Depth to Water Level Pre-Monsoon 2017, India

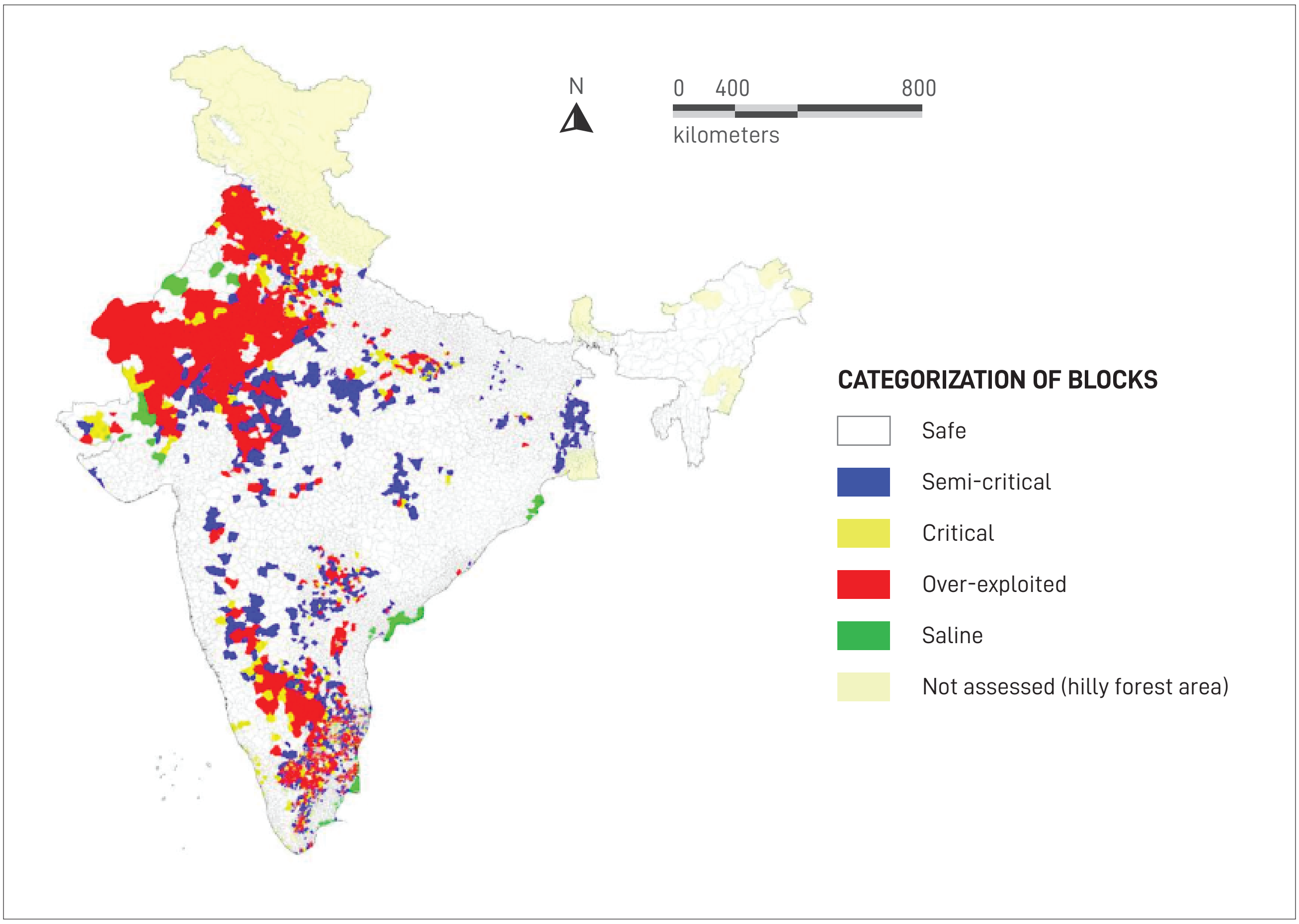


Source: (CGWB, 2017)

The depth and magnitude of groundwater aquifers has seen considerable change owing to the ubiquity of ground water extraction for irrigation, drinking water and other purposes. It is estimated that in the preceding four decades, the area brought under groundwater supported irrigation increased at a rate of 2.87 percent per annum, in contrast to surface irrigation which only increased at 0.54 percent per annum (Gulati & Mohan, 2018). India pumps more than twice the amount of groundwater per annum as compared to China or the United States of America (Shah, 2008). Unfettered groundwater extraction and usage has led to an overall 13 percent decline in the water table over the past 30 years (GOI, 2018). In the states of Uttar Pradesh, Punjab, Haryana, Delhi and Rajasthan, annual groundwater extraction exceeds the annual groundwater recharge (CGWB, 2017). In 2013, the Central Ground Water Board (CGWB) conducted an exercise to map the extent of groundwater development in India by assessing over 6584 units across all states in India. In its findings, the CGWB reported that over 15 percent of assessment units were over-exploited and that these numbers would increase over the years. The number of over-exploited and critical groundwater units are significantly higher in Delhi, Haryana, Himachal Pradesh, Karnataka, Punjab, Rajasthan and Tamil Nadu and Uttar Pradesh. The same assessment also highlighted that groundwater resources in the eastern states of Bihar, Jharkhand, Odisha, and the coastal regions of Andhra Pradesh, Karnataka and Maharashtra were safe for development (CGWB, 2017). More recent analysis of groundwater development in India indicates that groundwater recharge levels in Maharashtra and Gujarat have been rising the past couple of years, however injudicious extraction, ill-suited crop selection, and inefficient irrigation practices could potentially reverse this change (Srivastava, 2018).

Groundwater depletion is a challenge everywhere and the need of the hour is to find sustainable solutions to stem the volume of water that is being pumped to meet irrigation requirements. Theoretically, micro SWP can only pump limited volume of water through the day and have a greater potential to ensure that excessive groundwater is not pumped to meet

Figure 2: Categorization of Assessment Units (as on 21-3-2013)



irrigation requirements. Also, considering their limited pumping capacity, micro SWPs are more suited to regions with a shallow depth to water level. Data shows that the prevalence of enabling geological formations, shallow depth to water levels between 2-5 metres, positive groundwater development, and faster groundwater recharge levels are mainly evident in the Ganga-Yamuna and Brahmaputra river basins. The states of Assam, Bihar, Jharkhand, Odisha, the upper regions of West Bengal, as well as the coastal regions in the country, particularly Kerala, Karnataka and Maharashtra could hold great promise for deployment of micro SWP supported irrigation solutions. However, further studies need to be conducted in these states to determine regional variations in depth of water levels and prevalence of groundwater contamination.

The continuing paradox of groundwater-dependant irrigation in India is that on one hand, there is a grave danger of groundwater depletion due to injudicious usage and on the other hand, the Government of India has proposed an ambitious plan to double farmers' incomes by 2022 by enabling farmers to grow a minimum of three crops every season (Bera, 2018). Intensive cultivation could accelerate the stress on groundwater aquifers if current extraction patterns, crop choices and irrigation practices continue. The need of the hour is to design and deploy sustainable solutions that could address and mitigate the capability, financial, technological, and infrastructural gaps that plague the irrigation sector.

5. Grid Connectivity in India

Despite the high number of rural households electrified since 2009, there exist critical infrastructural gaps in expanding grid connectivity to farms in the states of Assam, Bihar, Jharkhand, Rajasthan, Uttar Pradesh, and West Bengal (CEA, 2018). Estimates indicate that the farm sector uses around 24 percent of electricity generated in the country, however, recovery rates for service providers are only around 3 percent (CEA, 2018).

Studies have found that SWP supported irrigation systems are economically viable to operate only when replacing diesel/kerosene pumps, or for farmers who do not have access to irrigation services (Verma, 2014). However, when compared to electrically operated water pumps, SWPs are not particularly viable, given the high subsidies that governments provide on agricultural electricity consumption (Agrawal & Jain, 2016). In areas that are connected to the grid, electric pumps are the primary choice for farmers, despite intermittent supply, voltage fluctuations, and high costs for electricity connections for the farm. Applying for electricity connections are expensive and time consuming for farmers, where a basic connection can take many months to become operational. Realising the full potential of micro SWP systems would require deployment in regions which have poor access to grid connectivity and irrigation is fuelled primarily using fossil fuels. Micro SWPs could also potentially be deployed in areas with grid connectivity, by small and marginal farmers who do not have access to electric pumps and are completely reliant on rain-fed and diesel/kerosene powered irrigation or have to pay for water services.

A recent survey of the performance of solar pumps in four states – Bihar, Rajasthan, Tamil Nadu and Uttar Pradesh found that farmers practised stacking SWP systems with either electric or diesel pumps to fulfil their irrigation requirement. Energy stacking refers to the dual usage of distinct sources of energy to perform similar activities. In the above cases, farmers were recorded as stacking SWP systems with either diesel pumps or electric pumps as a means to reduce expense on fuel and electricity respectively (also referred to as hybrid pumping). It was also reported that deployment of SWP systems has marginally reduced usage of electric and diesel pumps (Agarwal & Jain, 2018). However, as more and more state governments opt for separating feeder lines for agriculture and household consumption, there is a chance that electricity rates for agriculture will go up, particularly for farmers who have metered connections. In this scenario, deploying micro SWP systems could offer replacement options for marginal and small farmers who, because of their meagre resources and assets, find it expensive to apply for electricity connections for their farms, and would be more sensitive to increases in input costs of grid power.

6. Crop Choice, Irrigation Patterns and Potential for Solar

Water intensive crops such as rice and sugarcane account for 25 percent of the net sown area in the country. In contrast to other food crops (wheat, cereals, pulses), oilseeds, horticulture, floriculture, and other cash crops, water requirements for rice and sugarcane are three to four times higher. Crop selection and cropping patterns not suited to local hydrological conditions can pose several environmental challenges, particularly excessive groundwater extractions and contamination. In cases such as paddy cultivation in Punjab and sugarcane cultivation in Maharashtra, Haryana and Western Uttar Pradesh, the choice of crops cultivated has been identified as a major cause of depleting groundwater availability and increasing groundwater contamination in the region (Gulati & Mohan, 2018). Despite the overwhelming evidence which suggests that cultivating water intensive crops in water scarce regions has severely impacted groundwater levels, the issue is deeply contested due to political economy factors. Engendering solutions to the challenge of cultivating water intensive crops in water scarce regions is as much political as it is economic and technological.

Farmers in groundwater-scarce regions need to be incentivized to switch to less water intensive crops. Switching cultivation and irrigation practices for small and marginal farmers is made more difficult by the vulnerability and uncertainty of smaller farmer production and their limited financial capacity and threshold for risk. However, such incentives could work better with simultaneous reforms in input markets, cold storage, skills and knowledge training and forward linkages at mandis.

Solar irrigation solutions are generally crop agnostic, however, new evidence on SWP usage has helped shed some light on farmers being able to deploy additional rounds of irrigation for their crops (sugarcane in Bihar) and in certain cases has helped farmers achieve greater diversification gains by shifting towards vegetable cultivation (in Rajasthan and Uttar Pradesh) (Agarwal & Jain, 2018).

Inefficiency of irrigation practices is another significant barrier to sustainable groundwater development in India. Farmers continue deploying flood irrigation to water their crops, which is inefficient, leads to excessive weed growth, and can also lead to increased pest and virus attacks on crops. The recently launched Pradhan Mantri Krishi Sinchaee Yojana (PMKSY) has placed deployment of micro/mini irrigation solutions – mainly drip and sprinkler systems – as the centrepiece of the scheme, with a financial outlay of INR 50,000 crores to guarantee 'more crop per drop' for farmers. However, progress on this scheme has been slow with only 13 percent of the total net irrigated area having been converted to micro irrigation systems. It is important to note that replacing fossil fuel powered pumps with SWPs in water scarce regions may not be able to stem the problem of groundwater depletion, since SWPs can operate for up to eight hours a day, and are thus likely to be used to pump more water, unlike barriers to continuous extraction posed by irregular electricity supply or the high cost of hydrocarbon fuels. However, deploying appropriate capacity SWPs to meet irrigation requirements along with micro irrigation technologies could potentially mitigate the challenge of indiscriminate groundwater extraction.

The choice of crops, irrigation practices, cropping patterns and types of SWP systems that need to be deployed should only be determined after a rigorous analysis of local agro-ecological conditions.

7. Potential for micro SWPs in India

Besides the current study, there has been only one exercise to study the potential of micro SWPs for irrigation (Chamola, 2018). This goes to show how under-researched micro pumps are in the context of providing irrigation solutions for marginal and small farmers. The earlier exercise to test micro pumps was conducted in Bissamcuttack and Muniguda blocks of Rayagada district, Odisha. SWPs with a capacity below 1 Hp were tested with 45 marginal farmers who cultivated vegetables. All the farmers in the test group cultivated lands that were entirely dependent on rainfall and were irrigating their crops for the first time. Each SWP system comprised of two 75 Wp panels and one submersible motor. The pumps were provided to the farmers through a combination of subsidy and loans, and the total cost borne by a farmer was INR 20,000. The average size of the farm irrigated by the SWP was 0.6 acres (2400 m2). Farmers were trained in efficient irrigation practices by a local NGO who helped farmers deploy overhead water tanks and gravity drip lines. Farmers were also trained in using irrigation canals instead of flooding their farms. The results of this exercise found that even though some farmers complained of the poor discharge levels of the small pumps, the volume of water pumped was adequate for their vegetable crops. The portability of the pumps was also an added advantage for farmers who could use the pumps to irrigate multiple plots. The lessons from this pilot indicate that there is significant potential for micro SWPs when combined with efficient irrigation practices to meet irrigation demands of marginal and small farmers.

Further analysis of the literature on solar-based irrigation solutions points toward four challenges for SWP deployment in India – economic, regulatory, technological and capability gaps (KPMG, 2014; Agrawal & Jain, 2016, 2018; Raymond & Jain, 2018).

• **Economic challenges:** There is a pervasive lack of awareness and knowledge about SWP use and potential benefits, thereby limiting demand amongst farmers for this new technology. Moreover, considering that farmers operate with asymmetric information on inputs, better management practices and market dynamics, it becomes extremely difficult for farmers to want to shift away from traditional and current agricultural practices. An analysis of the deployment of SWP systems across farmer groups also shows a deep imbalance, with large and medium sized farmers owning more than 5 ha of land being the primary beneficiaries of capital subsidy schemes for purchasing SWP systems. A major reason for this is the fact that SWP systems have a higher upfront capital cost which is not affordable for marginal and small farmers.

• **Regulatory challenges:** SWP deployment policies have generally adopted a one size fits all paradigm when dealing with beneficiaries. Intended users (marginal and small farmers) get squeezed out due to lack of financing solutions and as an unintended consequence, benefits of capital subsidies generally accrue to medium and large farmers. Additionally, most states have yet to develop friendlier financing solutions for marginal and small farmers (soft loans, grant, etc.) to access funds to purchase SWP systems, and neither has commercial finance (rural banks, microfinance) evolved disbursal guidelines catering to the needs of small farmers for purchase of such equipment.

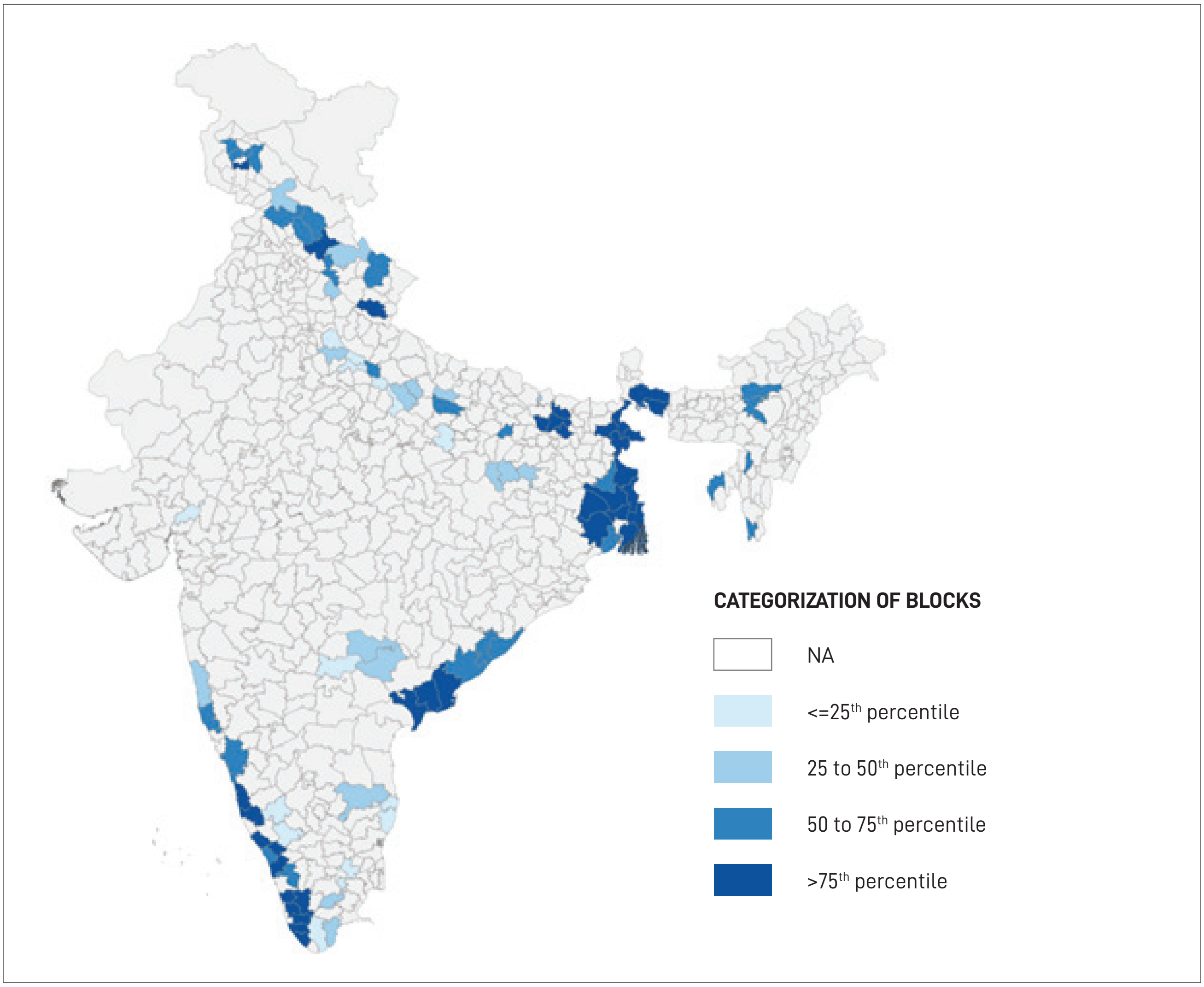
• **Technological challenges:** Incorporating SWP-supported irrigation solutions is often done without acknowledging local agro-ecological conditions as well as needs and demands of end users (farmers). Pump size and capacity (Hp), type (surface, submersible), addition of micro irrigation systems (drip and sprinkle) need to be assessed before deploying solar based solutions to ensure not just maximum utilization amongst intended beneficiaries, and the overall success of any scheme promoting such solutions.

• **Capability challenges:** Perhaps one of the most important challenges preventing wider solar uptake is the behaviour, threshold for risk and operating conditions of farmers in India. Farmers, particularly marginal and small farmers, are unwilling to undertake high capital expenditure and take on financial risks. Farmers require demonstration of new technologies and in this context, peer networks are an important driver for technology adoption. Another important capability challenge is the lack of a local eco-system for maintaining and repairing SWPs, particularly DC pumps, which increases costs for farmers who have to cope with poor after-sales service.

The Council on Energy, Environment and Water (CEEW) in collaboration with GIZ, has created a solar pump tool that has mapped over 600 districts in the country profiling various factors, including, agro-ecological conditions, cropping patterns, land holding size, access to irrigation sources, groundwater depth, presence of banking and financial institutions, enabling features and bottlenecks, and suitability of deployment approaches to identify the most promising deployment areas for micro SWP-supported irrigation solutions (CEEW & GIZ, 2017). This tool provides policy makers, development and finance professionals, government officials, and farmers, with actionable inputs for SWP deployment that are empirically validated. Vaishali district where the pilot is carried out is in the 99th percentile for micro SWP deployment demonstrating enabling features such as – high number of marginal and small farmers with limited access to irrigation resources, high fossil fuel usage for irrigation, poor grid connectivity, greater crop diversification, high depth to water level, and a well-functioning banking system that caters to financial needs of farmers.

According to the figure above, districts in the states of Assam, Andhra Pradesh, Bihar, Jharkhand, Kerala, Odisha, Tamil Nadu and West Bengal are best suited for micro SWP deployment. These states demonstrate a relatively shallow depth to water level (2-10m), high number of marginal and small farmers without access to electricity grids, and poor irrigation resources. Combined, these factors demonstrate a matrix of the highest suitability for micro SWP deployment. However, deployment potential needs to match farmers' requirements and capacity for expenditure. Other criteria for micro SWP deployment are the choice of crops grown and irrigation practices employed by farmers. Results of the current pilot exercise indicate that micro SWPs are not suited for water intensive crops that rely on flood irrigation, however, there is potential for farmers growing vegetables in combination with micro irrigation technologies.

Figure 3: Most Promising Deployment Areas for Micro SWP



Source: (CEEW & GIZ, 2017)

8. Demand for micro SWP in India

Mapping the demand for SWP solutions in India is a complex process which needs to consider the purchasing power and risk appetite of farmers. It is estimated that over 51 percent of farmer households in the country are indebted with an average outstanding debt amounting to INR 104,602. Additionally, over 55 percent of marginal and small farmers are in debt, placing significant barriers on their ability to seek fresh loans and make high capital investments on their farms (NABARD, 2018). Alarming levels of indebtedness amongst India's farmers has precipitated a growing trend of farmers wanting to quit agriculture as a livelihood option. An estimated 40 percent of farmers disliked farming and were dissatisfied to the extent that they did not want to continue farming according to one survey (Agarwal & Agrawal, 2016). The same survey estimated that over 80 percent of farmers' children in the ages of 15-24 expressed their disapproval to continue farming. The only positive outcome of this trend is that more land would be freed up for expanding land holding sizes and thereby increasing farm output. However, in the absence of alternate employment and livelihood opportunities in rural areas, many farmers are forced to continue farming, even when returns are poor. Considering the growing disillusionment with agriculture as a livelihood option amongst farmers, there is an urgent need to de-risk agricultural production, by reducing costs and enhancing profitability, reliability and sustainability of returns to farmers.

To boost the demand for micro SWP based irrigation solutions would require wider dissemination of knowledge and awareness of the potential benefits of solar energy amongst marginal and small farmers. The potential of SWPs needs to be seen beyond the more immediate requirement of cutting energy costs for farmers, but more holistically as an irrigation system that can enhance productivity and manage water resources more efficiently. Governments, both at the centre and state levels, and banks and lending institutions need to work to streamline financing options for SWP systems by adjusting collateral demands and creating fixed interest rates for loans. There is growing evidence to indicate that banks are getting more comfortable with providing loans to farmers for purchasing SWPs since there is considerable evidence of the potential of these systems to enhance returns from agriculture (Agarwal & Jain, 2018).

One of the biggest challenges to widespread deployment of SWP supported irrigation are high costs. On average, a 1 Hp SWP system costs approximately INR 65,000 (ten times more expensive than a diesel pump of the same capacity.) However, with innovative financing solutions, staggered repayment options and lower upfront costs borne by the farmer, micro SWP systems could be a cheaper alternative to existing diesel-powered pumps in a lifecycle cost analysis. Deployment of micro SWP systems needs to be tailored to meet irrigation demands of marginal and small farmers and local agro-climatic conditions and possible alternate uses of SWP systems for lighting and domestic usage. Best practices in economic and regulatory policies in SWP deployment need to scale-up and be replicated across geographies to help unleash the maximum potential of solar-based irrigation solutions.

It is hoped that the findings of the pilot exercise conducted in Vaishali, Bihar, will provide important lessons that will shape future deployment designs for micro SWPs and shed light on enabling factors that will promote higher utilization of solar-based irrigation solutions.

9. Piloting Submersible Micro SWPs in Patepur, Vaishali District, Bihar

Patepur is located in Vaishali district, 70 kilometres north of Patna, the capital of Bihar. The main crops grown here are rice, wheat, maize, tobacco and vegetables. Rice and wheat constitute the main food crops and farmers alternate between tobacco and vegetables (particularly chili, tomatoes, cauliflower and aubergine) every year. Despite its proximity to the state capital and a relatively high-water table (5-8 metres), agriculture in Patepur, and in large parts of Vaishali district, is underdeveloped with marginal farmers owning/operating less than one hectare of land constituting 90 percent of all farmers in the block.

Bihar scrapped the Agriculture Produce Market Committee (APMC) Act in 2006, following which, small, unregulated markets have mushroomed in almost all major agricultural pockets in the State. While these markets are located close enough for farmers to take small lots of produce to sell and has reduced transportation costs, farmers end up earning non-remunerative prices for their produce. To be able to sell in these private mandis, farmers have to pay commission charges ranging from 2 – 11 percent of the total value of their produce to sales agents. Commission charges are arbitrary since there is negligible value addition to the produce, and neither are there any provisions for cold storage and warehousing. Prices of produce are determined through an allotment system; wherein wholesale buyers determine maximum prices for produce which is used as a benchmark by other buyers. The allotment of prices is undertaken without physical verification of the produce and does not take into account variations in quality and size of the produce. Once prices are allotted, farmers are unable to get better rates for produce even if the produce is of a higher quality. This denies any possible gains that might accrue to farmers through an open auction system.

Groundwater is the main source of irrigation in the region and most farmers use kerosene powered water pumps, except for a handful of large farmers who use electric water pumps for irrigation. Electricity supply in Patepur is erratic and is plagued with voltage fluctuations, thereby limiting the options for farmers to deploy electricity-based irrigation solutions. Additionally, the cost of applying for an electricity connection is expensive and time consuming. A basic single-phase connection for agriculture costs INR 4500 and can take many months to become operational.[3] The single-phase connection can only handle smaller electricity loads, up to 230V, whereas triple-phase supply can handle close to 415V. This limitation also means that farmers have to spend more on a single-phase compatible electric pump, which are approximately 40 percent more expensive than triple-phase compatible pumps of the same horse power (Hp) capacity.

The pilot exercise was conducted in February 2019 with a select group of small and marginal farmers residing in two villages – Kwahi and Saidpur Dumra, located in Patepur block, Vaishali district, Bihar. Twelve farmers were identified and invited to participate in the pilot exercise. The land size owned/operated by farmers ranges from 1.6-2.8 bighas (4000 m^2 – 7000 m^2).[4] The selected farmers are not wholly reliant on agriculture income alone, and income accruing from cultivation for all members of the group has been less than INR 1 lakh per annum in the preceding three years. All farmers have diversified their productive activities to include dairy, goat rearing and other small businesses. Family income is also routinely supplemented by remittances made by family members and relatives who work mostly outside Bihar.

A striking feature of the group was its age composition. Only three members of the group were below the age of 40, with the average age of the other farmers in the mid-fifties. The group members were unanimous in the belief that their children would probably not continue in agriculture because of further division of the land holding of the family, and a general disinterest in agriculture. Informal interactions with the children of the farmers aged between 15-25 years revealed a general feeling that the labour and investment required for farming did not provide adequate returns and that any other 'job' would provide better monetary gains.

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[3] Based on interactions with farmers in Patepur block who have electricity connections on their farms. Of the total cost - Rs. 4500 for a single-phase connection, Rs. 3500 is a deposit and Rs. 1000 is the cost of the meter and wires.

[4] One acre = 4000 m^2. In local terminology, land size measurement categories used are katha and bigha. One katha = 125 m^2; one bigha = 2500 m^2

The submersible micro solar water pumps (SWPs) used in the pilot were procured through an open tendering process for 0.1 Hp, 0.25 Hp and 0.5 Hp SWPs, inviting some of India's leading solar pump manufacturers. However, no quotation was received for 0.25 Hp SWP, therefore only 0.1 Hp and 0.5 Hp SWPs were procured and tested. The different quotations received during the tendering process were as follows:

Table 3: Price Quotations for Different Capacity Micro SWP

PUMP CAPACITY	ELECTRICAL POWER	MANUFACTURER[5]	PRICE (IN INR)	PARTS COVERED IN WARRANTY	WARRANTY PERIOD
0.1 Hp DC	100 Wp	1	30,000	SPV	1 year
0.5 Hp DC	500 Wp		80,000	Pump & controller	1 year
0.5 Hp AC	500 Wp	2	75,000	SPV	NA
				Pump & controller	5 years
0.5 Hp AC	500 Wp	3	96,000	SPV	5 years
0.75 Hp AC	750 Wp		126,000	Pump & controller	5 years

Note: DC – Direct Current; AC – Alternate Current; Wp – Watt Peak Capacity; SPV – solar photovoltaic panel

During the installation process it was found that the submersible pumps were getting stuck inside the pipes at a depth of 4.5 meters. This could be for many reasons, but most likely due to existing borewell pipes getting corroded or bent, thereby reducing their circumference, and so preventing lowering of the submersible pumps. Borewells and tube wells dug by farmers are often in bad condition, with broken pipes, rust and poor discharge limiting the extent of water that can be drawn from borewells.

To overcome this challenge, the only option to complete the project was to dig six new borewells that would accommodate the submersible SWPs. The new boring process was completed in January 2019, by which time farmers were mid-way through their rabi cultivation. Significant time delays meant that the pilot exercise had to be curtailed, allowing farmers usage of pumps only once. Usage of micro SWPs proved challenging for farmers as they did not have enough time to get comfortable with the pumps, and they required significant handholding in setting up and operations. Farmers also had to be assisted in dismantling the pumps, particularly the 0.5 Hp SWP, which weighed over 30 kgs, so that they could be rotated between other farmers in the group.

[5] Manufacturers are: 1 – Nimbus Irrigation; 2 – Shakti Pumps; 3 – Rotomag Motors and Controls

10. Understanding Kerosene Powered Irrigation Practices

All 12 farmers in the study group used kerosene-powered surface water pumps, however, three farmers also resorted to purchasing irrigation services from another farmer's electric pump at times. Only one farmer had access to a drip system and all practiced flood irrigation for their crops. The kerosene powered pumps that the farmers use have an average capacity of 2 Hp, while three farmers (brothers in a joint household) use a 4 Hp capacity pump. All farmers in the group owned a pump and shared it with other farmers of their household as per their needs. Pumps were not only used for irrigation purposes, but also to aid other productive activities such as providing drinking water for livestock and bathing animals, cleaning cow-sheds, and at times providing water for construction activities. All of the kerosene pumps in use were purchased over four years ago, with one farmer using a pump that was over seven years old. There was no evidence of a rental market for kerosene powered water pumps for irrigation in Patepur, however, fuel costs are borne by the farmer using the pump, irrespective of ownership.

There is a strong network of pump repair and maintenance shops in the area and mistris (technicians) also make farm visits to fix damaged pumps. Expenses incurred by farmers on repair and maintenance of kerosene pumps averages INR 880 per year. However, when major parts of the pump – rings, gaskets and valves have to be replaced, costs can average from INR 2100-4300 for repairs. Even though kerosene powered pumps get damaged often, costs incurred by farmers to repair pumps are staggered through the year. Farmers prolong necessary maintenance by running pumps for shorter periods and with less power, and even by mixing additional motor oil to improve the lubrication of kerosene and reduce wear and tear.

Farmers in the group travel to Patepur block to purchase kerosene for their pumps. All farmers use a motor cycle to cover the 3 km distance from their homes to the kerosene store and return to their farms. Usually, farmers spend around 45 minutes per trip to procure kerosene. The origin of the kerosene supply is illicit and does not come through government public distribution (PDS) shops. There are only four shops selling kerosene in Patepur and supply can be erratic. At such times, farmers travel to a nearby town, Malpur, located 8 kms away, to buy kerosene. Price of kerosene averages INR 60 per litre with small spikes of INR 2-3 depending on supply.

Farmers also mix 50 ml of motor oil with every litre of kerosene to improve lubrication of the fuel.

Operating a kerosene powered pump requires two people to set up the 15 kg motor and connect it to the borewell. Average time to set up the pump takes around 25-35 minutes depending on the distance and condition of the different borewells that farmers need to use to irrigate their plots. Setting up the kerosene pumps is a laborious process where farmers have to connect a suction pipe from the head of the borewell to the inlet of the motor. After this, a hand lever is used to pump the water up the borewell pipe to surface level so that water can be drawn. Farmers need to stick wet mud to the suction pipes to prevent any air from leaking out as this would reduce the air pressure and increase the time taken to raise the water level up to the surface. Once started, the kerosene pumps bellow a thick cloud of black soot. Kerosene pumps are noisy and based on the sound emanating from the system, farmers can tell if the motor is overheating or requires maintenance. Pumps need to be checked every hour to ensure that any leaks in the suction pipe are fixed and that the motor does not over-heat. After the end of operations for the day, pumps are disconnected from the borewells and transported back home. This process has to be repeated every time the kerosene-powered pumps are used.

Differences in borewell capacity and damage to the mouth of the borewell can limit the water discharge, thereby increasing the time that the pumps need to be used, which means higher kerosene use. Borewells in the region are in an extremely poor shape. Most of the old borings are only at a depth of 9 meters. But increased groundwater extraction has meant that the water level has lowered causing many of the borewells to run dry. Generally, four to five farmers need to pool their resources together to dig new wells which cost approximately INR 50,000 for a three-inch borewell up to a depth of 30 metres. Many farmers have used these collective measures to dig new borewells for their farms, but some farmers are still forced to draw water from borewells that are more than 50 metres away from their farms.

The crops being cultivated by the group in the current rabi season are wheat, mustard, tobacco, maize, green peas, and potato. Six farmers in the group rotate their crops with vegetables every alternate year. All farmers in the group use family labour while irrigating their crops, particularly to set up the pumps, move the water pipes and build canals on the farm. At times, however, farmers resort to hiring workers on a daily wage basis to assist on their farms.

The average irrigation requirements and kerosene consumed for irrigating crops grown on one bigha for the past year (2018) are as follows:

Table 4: Irrigation Requirements and Diesel Usage in Patepur

SR NO.	CROP	MONTHS GROWN	NO. OF HOURS TO IRRIGATE ONE BIGHA*	QUANTITY OF KEROSENE USED PER CYCLE OF IRRIGATION (IN LITRES)	NO. OF IRRIGATION CYCLES REQUIRED	TOTAL QUANTITY OF KEROSENE REQUIRED TO IRRIGATE ONE BIGHA PER SEASON (IN LITRES)
1	Rice	July – November	12	13	8	104
2	Wheat	November - April	10	9	4	36
3	Mustard	November - April	8	6	2	12
4	Tobacco	November - April	10	10.5	9	90.5
5	Potato	November - April	8	7	4	28
6	Maize	February - June	10	9	6	54
7	Chili	February - October	1.5	1	12	12
8	Cauliflower/ Cabbage/ Green Peas	October – December; January – March	3	1.5	4	6
9	Bitter Gourd/ Gourds	February – October	1.5	1	8	8
10	Aubergine	August- March	1.5	1	8	8

Note:

(i) *One bigha = 2500 m2

(ii) All irrigation requirements and water usage estimates have been averaged for the group and are conditional to farmer's irrigation practices, discharge of diesel/ kerosene pump sets and perceived irrigation requirements for one bigha of cultivation. These estimates are not static and change according to local climatic conditions. For instance, up to three years ago, farmers only had to irrigate their rice crops thrice, since they were mostly rain fed. But three years of successive drought like conditions has meant that farmers need to water the rice crop up to eight times per season.

Calculating water usage estimates in terms of litres per day proved to be difficult considering the variable water discharge of kerosene pumps used, condition of the borewells, and different irrigation practices deployed by farmers. Farmers felt that the local soil, which has a higher clay content, requires more water since the composition of the top soil prevented greater moisture accumulation. To distil these subjective practices deployed by farmers, the pilot implementation team thought it would be more illustrative to map the number of hours that the pumps were used, and kerosene consumed by the pumps, to understand the irrigation requirements and practices, perception of soil and moisture conditions, and expenditure on energy incurred by farmers.

Water requirements for the main food crops - rice, wheat, maize, and tobacco are the highest. In contrast, water requirement for vegetable cultivation is far lower. Higher water requirements directly correspond to higher usage of kerosene and correspondingly, higher costs to farmers. For instance, if farmers chose to grow three water intensive crops (rice, tobacco and maize) for the year, 248.5 litres of kerosene would be required to irrigate one bigha. If farmers could substitute one of the three water intensive crops with a less water intensive crop, total kerosene requirement could reduce by approximately 100 litres per bigha. The challenge with growing water intensive crops in regions such as Bihar with a shallow depth to water level is not so much a problem of increased groundwater extraction, but rather of high costs incurred on inefficient kerosene powered pumps. Substituting existing kerosene pumps with solar based irrigation solutions, such as a micro SWP, could provide solutions for irrigating water intensive crops since they can run for longer periods of time and provide greater savings on energy costs.

Choosing what crops to grow is not always a straightforward decision for marginal farmers. Crop choice is based on several factors, including knowledge and past experience of growing the crop,[6] expected returns, available capital resources and expenditure on the crop, soil condition,[7] subsistence requirements, marketing facilities, and market linkages, among others. Farmers in the group reported an acute necessity to grow at least one food crop per annum (either rice or wheat) to help meet subsistence requirements for their families. However, returns on food crop cultivation are negligible, with most farmers reporting losses during the season, owing to higher input costs (additional kerosene requirements for rice) and poor market linkages. The choice of the second and third crop (grain, vegetables, tobacco or cereal) depends on the capital resources available with farmers and the returns expected from cultivation. Tobacco is the only crop that has given profits to farmers in the past three years, contributing over 80 percent of their total income from agriculture. Even though farmers cultivated vegetables every alternate year, either during the summer or winter seasons, the returns from vegetable cultivation fluctuated considerably. Farmers in the group were able to break even on vegetable cultivation costs only if they began sowing operations a minimum of two weeks before the start of the season. This ensured that produce would be able to attract the best per-season rates during sales. This also meant that farmers had to germinate seeds and raise saplings on nursery beds on their farms prior to harvesting the preceding crop. This proved difficult for farmers who often had to seek external credit or divert capital from other livelihood activities to purchase inputs, such as seeds, fungicides and farm yard manure (FYM).

Another key insight discovered during the baseline surveys was the time spent by farmers performing irrigation activities. Irrigation requirements for water intensive crops, particularly rice and tobacco, were higher and pumps had to be operated for longer periods to flood the farm. On average, kerosene powered pumps had to be operated four times longer to irrigate water intensive crops than for less water intensive crops. This posed a challenge for farmers who often have to irrigate multiple plots within a short period of time and running the kerosene motors for a long time at a stretch (more than 90 minutes) led to frequent breakdown of the motors. Operating the kerosene powered pumps for a long time (setting up the pumps, digging canals and moving the pipes) was also physically taxing for farmers in the group who were above the age of fifty. These farmers would often resort to hiring labour to assist in irrigation operations and handle the more physical tasks of digging canals on the farm.

[6] Knowledge and experience of growing different crops entails two separate functions – first, a working knowledge of the plant's growth cycle, nutritional needs, disease management techniques, and inputs required. Second, the experience function relates to the returns from past seasons of cultivation that have accrued to the farmer. This provides a benchmark as to what the farmer expects with each continuing round of cultivating the crop.

[7] Certain types of soils and location of the farm (prone to flooding) could act as natural barriers preventing farmers from taking up certain crops for cultivation. For instance, only two farmers in the group cultivated tubers and root crops on account of the soil being lighter on their farms. A heavier top soil restricts the growth of tubers and root crops.

Table 5: Expenditure Incurred by Farmers on Kerosene to Irrigate One Bigha for Different Crops

SR NO.	CROP	NO. OF IRRIGATION CYCLES REQUIRED	VOLUME OF KEROSENE USED PER CYCLE OF IRRIGATION PER BIGHA (IN LITRES)	EXPENDITURE ON KEROSENE AND OIL FOR ONE CYCLE OF RRIGATION PER BIGHA (IN INR)	TOTAL EXPENDITURE ON ENERGY FOR IRRIGATION PER BIGHA (IN INR)
1	Rice	8	13	880	7040
2	Wheat	4	9	590	2360
3	Mustard	2	6	410	820
4	Tobacco	9	10.5	705	6345
5	Potato	4	7	470	1880
6	Maize	6	9	590	3540
7	Chili	12	1	80	960
8	Cauliflower/ Cabbage/ Green Peas	4	1.5	110	440
9	Bitter Gourd/ Gourds	8	1	80	560
10	Aubergine	8	1	80	560

Note:

(i) All costs have been averaged for the group covering the past three years.
(ii) Total expenditure on energy includes costs of motor oil lubricant.
(iii) Price of kerosene is estimated at INR 60.

Expenditure on energy requirements for irrigating water intensive crops is almost 10 times more than expenditure incurred for irrigating vegetables and less water intensive crops. If a farmer cultivates three water intensive crops through the year, expenditure on kerosene for one bigha of farm land alone would average between INR 12,940-16,925 per year.[8] Including maintenance and repair costs for kerosene pumps, the total expenditure by farmers on energy for irrigating one bigha amounts to upwards of INR 18,000 annually.

However, if farmers choose to grow only one water intensive crop per year and alternate with vegetables cultivation, then expenditure on kerosene would total less than INR 8,500 per bigha annually.

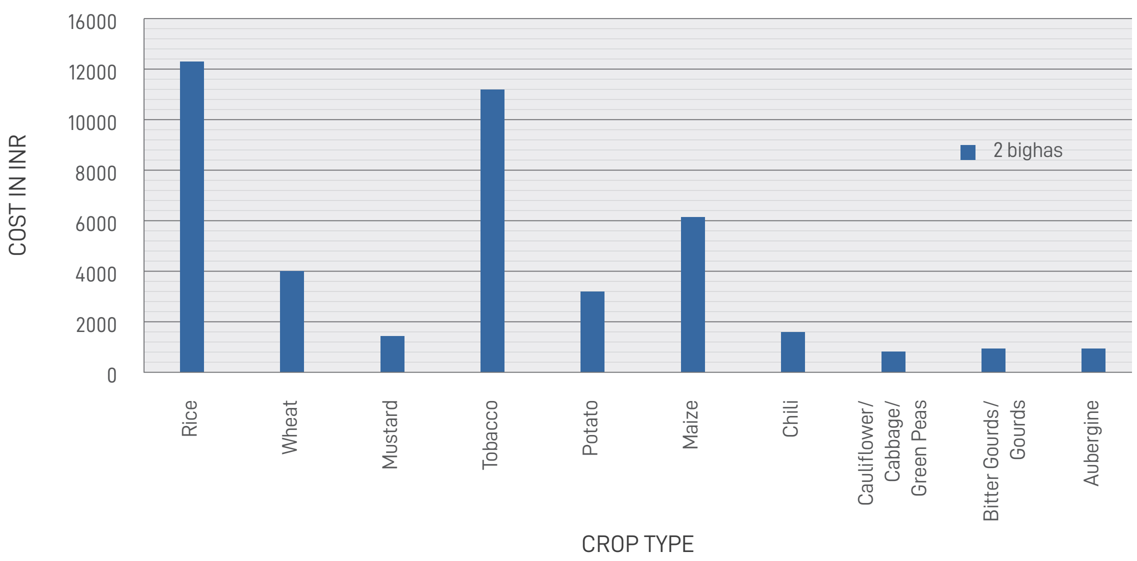
[8] If farmers grew paddy, tobacco and maize crops through the year.

Table 6: Kerosene Costs Incurred by Farmers According to Landholding Size

SR NO.	CROP	TOTAL ANNUAL EXPENDITURE ON ENERGY FOR IRRIGATION PER BIGHA (IN INR)	TOTAL ANNUAL EXPENDITURE ON ENERGY FOR SMALLEST LANDHOLDING SIZE OF 1.6 BIGHA (IN INR)	TOTAL ANNUAL EXPENDITURE ON ENERGY FOR LARGEST LANDHOLDING SIZE OF 2.8 BIGHA (IN INR)	TOTAL ANNUAL EXPENDITURE ON ENERGY FOR AVERAGE LANDHOLDING SIZE OF 2 BIGHA (IN INR)
1	Rice	7040	11264	19712	14080
2	Wheat	2360	3776	6608	4720
3	Mustard	820	1312	2296	1640
4	Tobacco	6345	10152	17766	12690
5	Potato	1880	3008	5264	3760
6	Maize	3540	5664	9912	7080
7	Chili	960	1536	2688	1920
8	Cauliflower/ Cabbage/ Green Peas	440	704	1232	880
9	Bitter Gourd/ Gourds	560	896	1568	1120
10	Aubergine	560	896	1568	1120

Note: 1 bigha = 2500 m^2

Figure 4: Cost Incurred on Kerosene Powered Irrigation for Two Bighas (5000 m^2)



In the pilot group, the smallest landholding that a farmer operated was 1.6 bighas (4000 m^2), and the largest was 2.8 bighas (7000 m^2). The average landholding size of farmers in the group was 2 bighas (5000 m^2).

If annual expenditure on kerosene is calculated for the average landholding size of the group of two bighas, the total cost borne by the farmer on kerosene for cultivating three water intensive crops per year would average between INR 25,880-33,850.[9] Correspondingly, the total cost of kerosene for cultivating a mix of water intensive crops and vegetables would amount to INR 19,760.[10]

Expenditure incurred by farmers on kerosene is also aided by routine subsidy disbursements by the state government of Bihar under the 'Bihar Diesel Anudan Yojana'. A maximum amount of INR 400 per acre is transferred directly to the bank account of farmers every season, if a farmer applies for the scheme by filing an online application form. All farmers in the group have availed of this subsidy and have received amounts averaging between INR 1,320-2,376 in the past year.

Production conditions of marginal and small farmers is precarious as input costs rise and reliability of remunerative prices in the markets is uncertain. An analysis of the yields, costs and revenue of the average landholding size of two bighas (5000 m^2) reaffirms this uncertainty.

Table 7: Average Yield, Costs and Revenue for Average Landholding Size of Two Bighas.

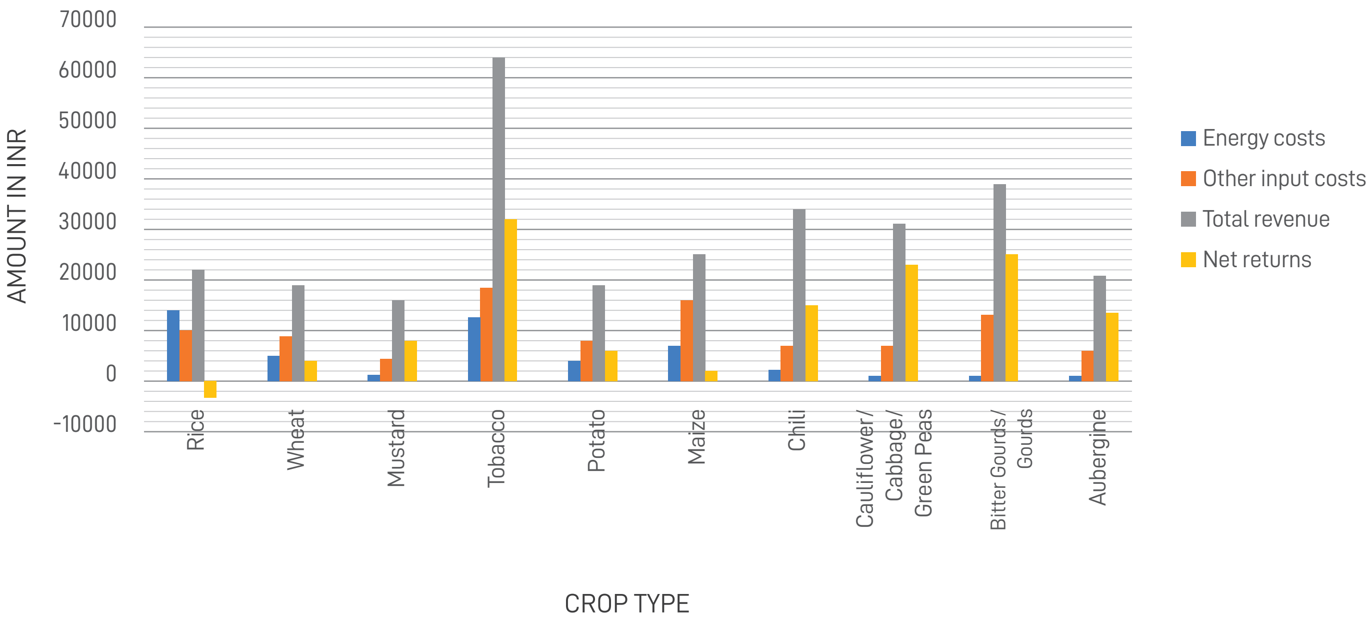
SR NO.	CROP	YIELD PER SEASON (TON / 2 BIGHAS)	TOTAL EXPENDITURE ON ENERGY PER SEASON (IN INR)	OTHER INPUT COSTS - TRACTOR, FERTILIZER, PESTICIDE, LABOUR, ETC. (IN INR)	TOTAL INPUT COSTS (IN INR)	TOTAL REVENUE PER SEASON (IN INR)	NET RETURNS (IN INR)
1	Rice	1.3	14080	10409	24489	21190	-3299
2	Wheat	1.1	4720	8968	13688	19360	5672
3	Mustard	0.5	1640	5200	6840	17040	10200
4	Tobacco	0.8	12690	18900	31590	64080	32490
5	Potato	12	3760	9024	12784	19200	6416
6	Maize	1.9	7080	16284	23365	25270	1906
7	Chili	1.1	1920	7100	9020	34100	25080
8	Cauliflower/ Cabbage/ Green Peas	10.3	880	6950	7830	30900	23070
9	Bitter Gourd/ Gourds	7.2	1120	13040	14160	39200	25040
10	Aubergine	6.9	1120	6135	7255	20700	13445

Note:

(i) Yield estimates are averaged for the average land holding size of the group – 2 bighas (5000 m^2). In reality, farmers grew vegetables only on approximately 30 percent area of their farm lands.
(ii) Total revenue per season has been averaged for the past three years for all farmers. Revenues reported are based on what farmers would have earned selling their entire produce in the market. However, actual revenues are much lower considering up to 30 percent of food crops are retained for self-consumption, barter or payments in kind to labour.
(iii) All of the figures are based on estimates reported by farmers.

[9] If farmers grew a mix of rice, tobacco and maize crops through the year.
[10] If farmers grew a mix of rice, potato and vegetables through the year.

Figure 5: Input Costs, Revenue and Returns from Agriculture for Two Bighas (5000 m²)



Farmers reported that expenditure on kerosene for irrigation of rice crop was 1.4 times the cost of other inputs taken as a whole, and for wheat, tobacco and maize, kerosene costs constitute almost 50 percent of total production costs. Whereas energy costs for less water intensive crops such as mustard, potatoes and vegetables were lower than 30 percent of other input costs. The self-reporting of costs and revenue by the farmers could be prone to errors since there has been poor rainfall in the recent past, with the entire district being declared drought hit for the past three years consecutively. From the table above we can clearly see that incomes from agriculture for marginal farmers are extremely low due to poor yields and particularly high energy costs.

Expenses incurred on kerosene are staggered through the seasons and farmers usually purchase 10 litres of kerosene in one go, costing INR 600. This staggered expenditure suited farmers who were more comfortable paying smaller amounts over time than paying a large amount upfront. This is a clear indication that a more sustainable solution to mitigating rising energy costs for irrigation would be to focus on growing less water-intensive crops and limiting the cultivation of water-intensive crops to a minimum of two crop cycles.

11. Findings and Results

Farmers were familiar with how solar-based appliances worked, since nine farmers owned and used solar lighting solutions in their homes. However, farmers were unaware that solar-based irrigation solutions could be deployed for agriculture. During the installation process of the pumps, a meeting was conducted to help farmers understand how the submersible micro SWPs worked and how to position and maintain solar panels. Six micro SWPs were used for the project – 3 x 0.1 Hp and 3 x 0.5 Hp. The six pumps were rotated with the twelve farmers in the group to undertake one cycle for irrigation with both pumps. The submersible micro SWPs were tested on the following crops - wheat, tobacco, mustard, potato and green peas. To assist the farmers in setting up the micro SWPs, the controller for the pumps was modified with a plug-in switch to make it easier for the farmers to operate the SWPs.

i. Performance of the 0.1 Hp submersible SWP

The 0.1 Hp submersible SWP has a 100 Wp solar photovoltaic panel (SPV) with a head of 20 metres. The solar panels have a surface area of 0.5 m2 and weigh only 1.5 kgs. Combined with the SWP, the total weight of the appliance is less than 5 kgs. Due to their light weight and mobility, farmers could easily transport both the panel and the pump by hand from their homes to the farms. Farmers were reluctant to leave the solar panels and pumps on their farms overnight for fear of theft. To set up the submersible pumps, farmers only had to lower the pumps 7.5 meters into the borewells and connect the switch, and the pump would start automatically. Installing the 0.1 Hp pumps was fairly intuitive for farmers and took less than five minutes to complete.

Water discharge from the 0.1 Hp pump averaged 225 litres per hour (LPH) and when used for the entire day (average of eight hours) pumped approximately 1800 litres. While testing the pumps using flood irrigation, farmers found the performance of the 0.1 Hp submersible SWP to be poor. Farmers with wheat, mustard, tobacco and potato managed to water less than 10 percent of their plots using the 0.1 Hp pumps in a day. A single farmer who was cultivating green peas managed to irrigate only 60 percent of his 0.7 bigha (1750 m2) plot using the 0.1 Hp pump in one day. In total, it took the farmer close to 14.5 hours to irrigate the green peas crop over 0.7 bighas. This activity would otherwise take the farmer less than one hour to complete had they been using a kerosene powered pump!

All farmers felt that despite its ease of use, the poor discharge levels of the 0.1 Hp submersible SWP and the extent of time taken to irrigate even small plots with lower water requirement made the pumps ill-suited for their irrigation needs. If deployed with active pump drip irrigation systems, the 0.1 Hp SWP would not be able to generate necessary water pressure and discharge for the irrigation system to work efficiently. On the other hand, with a dormant drip irrigation system (gravity tanks) where the water is first pumped to a raised water tank and then supplied to the drip pipes, the 0.1 Hp SWP could demonstrate potential utility. It would take less than two hours to fill an average 400 litre water tank. However, none of the farmers in the region had this apparatus and as such, this proposition could not be tested.

All farmers however managed to find alternative uses for the 0.1 Hp SWP, with some using them to draw drinking water from open wells to fill overhead tanks, while others used the solar panels to power household lighting appliances. Because the pumps were submersible and could only be used in four-inch borewells, the pumps could not be used in existing borewells owned by farmers and could only be used in either the new borewells dug for this exercise or in open wells. The overall performance and negative perception of the utility of the pumps indicate to the improbability of deployment of the 0.1 Hp capacity pump to meet farmers' irrigation requirements in Vaishali.

ii. Performance of the 0.5 Hp submersible SWP

The 0.5 Hp submersible SWP has 2 x 250Wp (total 500Wp) solar photovoltaic panels with a head of 25 metres. The two solar panels have a surface area of 1.8 m2 each and weigh a total of 16 kgs. The submersible SWP is also quite heavy, and along with 25 feet of the outlet head pipe, weighs close to 18 kgs. The total weight of the 0.5 Hp SWP system was 36 kgs. The entire system was difficult to manoeuvre, especially the SPV panels, and required a minimum of two people to transport and install the pumps. In comparison, a 2 Hp kerosene powered pump weighs only 22 kgs and can be easily transported on a bicycle. Only three farmers managed to transport the system on two bicycles, while the rest had to source a cycle-rikshaw to transport the system. Setting up the submersible pumps required two people, one to lower the pump and another to lower the outlet head pipe. Because the pumps had to be rotated among different farmers in the group and across different borewells, the panels were not permanently fixed on a stand. The immobility of the 0.5 Hp submersible SWP became evident when pumps had to be relocated to different borewells, with the entire process taking more than two hours. After lowering the pumps 25 feet into borewells, both the panels had to be connected to each other and the main switch of the controller had to be turned on. Modifying the controller panels to add a single switch helped make starting the pumps easier for farmers and took less than five minutes to set-up. Due to their weight and immobility, farmers found it difficult to transport both the panel and pump and resorted to leaving the pumps overnight on the farms.

Water discharge from the 0.5 Hp pumps averaged 1800 LPH and when used for the entire day (average of eight hours during the test period in February 2019), pumped approximately 14,400 litres per day. During testing, three farmers reported that the performance and discharge of the pumps was poor, seven farmers reported that the performance of the pumps was sufficient, while the remaining two farmers found the performance of the pumps to be good. The 0.5 Hp pumps demonstrated variable performance during irrigation operations across crops.

Table 8: Performance of 0.5 Hp SWP Supported Irrigation

SR NO.	CROP	AREA IRRIGATED IN ONE DAY (IN m^2)*	TOTAL NUMBER OF DAYS TAKEN TO IRRIGATE ONE BIGHA (2500 m^2)[11]
1	Wheat	675	3.5
2	Tobacco	850	4
3	Mustard	675	3.5
4	Potato	625	3.5
5	Green Peas	1750	1

Note:

i. *The SWPs were operated for an average of eight hours every day.

ii. Area and number of days taken to complete irrigation operations has been averaged for the entire group.

iii. Farmers had subjective preferences of the volume of water required for each crop. Hence, even though a relatively larger area of tobacco was irrigated per day, it took longer to completely irrigate one bigha in comparison to wheat, mustard and potato crops.

Using the 0.5 Hp submersible micro SWP, farmers were able to irrigate wheat, mustard and potato crops at an average rate of 0.25 bighas (625 m2) per day when the pumps were used for eight hours. For tobacco and green peas, farmers were able to irrigate 0.34 bighas (850 m2) and 0.7 bighas (1750 m2) respectively. Farmers reported that it took them more than three days to irrigate a plot measuring one bigha for their wheat, tobacco, mustard, and potato crops, whereas the green peas crop could be irrigated in a single day. In comparison, farmers could irrigate a full bigha of wheat, mustard, tobacco or potato using a kerosene powered pump in 8-10 hours, and a vegetable crop in less than 90 minutes.

When asked to compare the performance of the submersible micro SWP with kerosene-powered pumps, farmers reported that the performance and discharge of the solar pumps was sufficient, but less than half of what they currently managed with kerosene pumps. Farmers cultivating more water intensive crops - wheat, mustard, tobacco, and potato, through flood irrigation, felt that the micro SWPs

[11] Considering the small size of the pumps and the limited water discharge, a standard unit of one bigha = 2500 m^2 was considered as the benchmark for testing the performance of the pumps.

needed to pump more water. However, farmers also noted that the 0.5 Hp micro SWP pumped a good volume of water for vegetable crops. Relatively lower discharge of the pumps also corresponded to farmers having to spend a considerably longer time to complete irrigation operations. This was a critical requirement for farmers since they equated higher water discharge with lesser time spent in completing irrigation operations. Quicker pace of operations helped farmers free their time to focus on their other livelihood activities. Another challenge with spending a relatively longer time performing irrigation operations was reflected by five farmers in the group who hired labour services to help them irrigate their farms. Farmers reported that if irrigation activities would take more than one day, then expenses on labour would increase, thereby mitigating any possible gains that could accrue from lower fuel consumption.

However, while comparing the performance of the micro SWP with kerosene pumps based on ease of use and time taken to set up the pump, farmers responded positively in favour of the solar pumps. Although the pumps required some external assistance during installation, farmers reported that the pumps were excellent in terms of ease of use and took less than five minutes to set-up and begin operations. In comparison, the kerosene powered pumps took anywhere between 25-35 minutes to set up. Another feature that farmers appreciated was the extended duration for which the SWPs could be operated. Farmers set-up the SWP and left them on while conducting other activities and the pumps were unsupervised for hours at a stretch. This was not possible to do with kerosene powered pumps, which required hourly monitoring to fix leakages and prevent over-heating of the motor. Farmers also appreciated the fact that the micro SWP made significantly lower noise and were almost inaudible during operations, in comparison to the loud kerosene powered pumps.

After irrigating their farms with both pumps, farmers were asked to list features that they liked and disliked about each set of micro SWP system.

Table 9: Qualitative Assessment of Micro SWPs

MICRO SWP PUMP CAPACITY	POSITIVE FEATURES	NEGATIVE FEATURES
0.1 Hp	• The pumps showed potential for non-agriculture water use, such as pumping drinking water and water for household activities. • Pumps were mobile, easy to assemble, set-up, and operate.	• All farmers reported that the pumps demonstrated poor performance and water discharge and were ill-suited to meet their flood irrigation requirements.
0.5 Hp	• The pumps showed potential to meet irrigation requirements for vegetable and less water intensive crop cultivation. • Pumps were easy to assemble, set-up and operate. • SWP systems could be used in combination with kerosene powered pumps to reduce expenditure on kerosene. • Once operational, solar pumps could operate for a longer time and required little supervision from farmers. This freed up their time to adjust the water pipes and dig channels to direct the flow of water.	• Pumps did not provide good discharge for irrigating water intensive crops using flood irrigation methods. • Irrigation operations took more than three days to complete. • If labour resources were hired by farmers for the longer period to complete irrigation, then labour expenses would increase. • Solar panels would be easier to install and operate if they were permanently fixed on a stand. However, this increased the chance of theft and would require some type of anti-theft measures.

The purpose of the pilot exercise was to also elicit the price sensitivity of farmers and their willingness to invest in solar-based irrigation solutions. During the final perception survey, farmers in the group were asked how much money they would be willing to spend on the micro SWP. All farmers in the group replied that they would not be inclined to purchase the 0.1 Hp SWP, since it did not meet any of their irrigation requirements. For the 0.5 Hp SWP, the nine farmers who found the pumps to be satisfactory and good were willing to spend an average total of INR 14,500 for the pump. This set of farmers was most inclined to purchase a micro SWP if sufficient subsidies were provided by the government. However, farmers perceived external financing solutions, such as loans from banks and financial institutions, as being too risky. Three farmers who felt that the pump performance was poor were willing to spend an average total of INR 7,500 for the pump. After the actual prices of the 0.5 Hp SWP (INR 85,000) were revealed to the farmers, they were still not inclined to change their estimates on prices they would be willing to pay to buy the micro SWP. In comparison to these estimates, all farmers in the group were willing to spend an average total of INR 17,000 for a SWP with a minimum capacity of 1 HP. Based on discussions with farmers, we found that farmers would be willing to pay up to one-third of their current expenditure on kerosene (INR 8,626-11,283) per annum over 3 years to be able to buy a SWP system with a capacity of 1 HP or more.

When probed further on the extent of subsidy they would like the government to provide for such investments, most farmers replied that they would prefer the highest percentage of subsidy possible for purchasing the pumps. However, farmers did not appreciate fixed limits to subsidies that lowered the percentage of capital cost the subsidy covered. Subsidies for various farm inputs such as electric/diesel motors are usually capped at a maximum amount, while subsidies for drip irrigation systems and mulching is provided at a 50 percent discount to farmers. Farmers were generally wary of subsidy models that had expenditure caps or where they would have to pay the total upfront cost for inputs and receive a cash-back after a stipulated time period. Farmers were much more comfortable with a front-ended subsidy where they would pay a percentage of the total cost upfront and repay small instalments every season post-harvest. Interest, among nine farmers in the group, for adopting solar based irrigation solutions was significantly high when informed about their expenditure on energy for irrigating each crop. However, farmers demonstrated greater interest in solar pumps that had a minimum capacity of 1 Hp. Importantly, younger farmers in the group were more inclined towards adopting solar-based irrigation solutions than older farmers in the group, for whom repayment concerns were of paramount importance. At the end of the pilot, two farmers in the group decided to buy a 1 Hp micro DC SWP to substitute their kerosene powered pumps.12.

12. Conclusion

The pilot exercise was conducted to test the demand, scope and potential of micro SWPs and identify the utility and potential for different capacities of solar pumps to meet marginal farmers' irrigation demands. Limited range of different micro SWP capacities available and the constrained timelines to run the pilot proved significant challenges to conducting an extensive pilot exercise. However, there are several inflections which emerged from the current exercise which can deepen our understanding of the potential of solar powered irrigation solutions, particularly micro SWPs, to meet requirements for marginal and small farmers:

1. Submersible SWP infrastructure and eco-system:

a. Submersible SWPs perform relatively better than surface water pumps, especially when the depth to water level is more than 7.5-10m. However, submersible pumps require borewells that are in good condition, without leakages and bends in the pipes. Since the micro SWPs had a diameter of 3.8 inches, they could only be used in borewells that were 4 inches wide, which are rare in the region. In regions where water levels are relatively high and where farmers are completely reliant on diesel/kerosene powered pumps, width of borewells tend to be smaller to put less stress on pump motors.

b. Deploying SWP systems require a necessary eco-system of repair and maintenance technicians and easy availability of spare parts. In this case, DC pumps are simpler with less components and more efficient, but more difficult to repair, with fewer servicing opportunities in rural areas. With scaling up of technology and increased utilization of e-rickshaws (also operating using DC motors), and solar-based energy solutions, this might not remain a challenge in future. During the course of the pilot, farmers did not encounter any technical problems with the pumps. However, in case the pumps were to breakdown, the pumps would have to be taken to Patna, or even further to Kolkata, for repairs. The time limit for such repairs and maintenance could take a minimum of two weeks.

2. Farmers' irrigation requirements and practices:

a. Marginal and small farmers need to grow at least one food crop a year for subsistence purposes. In Bihar, this usually means that farmers will grow paddy during the monsoon. The opportunity to shift to less water intensive crops like vegetables, may not always be available to farmers. Poor monsoons, cultivating a water intensive crop and inefficient flood irrigation practices, forces farmers to rely on higher capacity pumps to meet their irrigation requirements.

b. Farmers are self-aware of the dangers of excessive groundwater extraction and usage as evident in the drop in the water table and potential damage to crops due to over watering. Farmers need better training and improved access to water saving irrigation solutions such as drip and sprinkler systems.

c. Time taken for performing irrigation operations is an important consideration for farmers. Farmers want to complete the task as quickly as possible, while incurring the least expenditure. This enables them to divert time to other livelihood activities and make minimal expenditure on labour services. Shifting towards any technology that extends time taken to perform an activity beyond what farmers would consider reasonable would prove challenging.

d. Marginal and small farmers use their water pumps for multiple functions not limited to irrigation alone. Limiting capacity and functionality of renewable based energy solutions could pose a challenge to emerging energy demands from diversified livelihood and household activities.

e. Farmers need sustainable solutions to meet their irrigation challenges and high energy costs. SWPs could offer solutions that go beyond just an alternate solution to diesel usage and could signal a shift towards the growing intersection of water, food and energy for rural households.

3. Performance of Submersible Micro SWPs:

a. Micro SWPs have the potential to provide sustainable irrigation solutions for marginal and small farmers in regions with a relatively higher water table, poor grid connectivity and absolute reliance on diesel/kerosene powered irrigation.

b. SWPs with a capacity below 0.5 Hp will not be able to meet irrigation requirements of marginal and small farmers who need to grow at least one food crop. For farmers who cultivate only vegetables, pumps with a capacity below 0.5 Hp could have utility if operated with a gravity drip system attached to a water tank.

c. SWPs with a capacity of 0.5 Hp to 1 Hp display great promise for marginal and small farmers who grow water-intensive crops. However, farmers' crop selection, depth to water level, and time constrains of farmers need to be factored in before identifying the capacity of the pump best suited to irrigation needs.

d. Micro SWPs have lower water discharge in comparison to large sized pumps. To mitigate this limitation, micro SWPs need to be deployed with efficient irrigation solutions to achieve optimum utilization and performance.

4. Farmers' need for cheaper and sustainable irrigation solutions:

a. Farmers are aware and deeply concerned about rising energy costs for irrigation and are looking for cheaper and sustainable solutions.

b. Despite the limited time using the micro SWPs in this pilot, farmers, who prior to this pilot had no knowledge of SWPs, were very inclined to make the transition towards solar-based irrigation solutions on account of the possible savings on fuel.

5. Farmers' incomes and risk:

a. Income from agriculture for marginal and small farmers has reduced on account of growing input costs, lower volumes and poor returns in the market. In case of adverse natural calamities and poor market conditions, marginal and small farmer households need additional security from uncertainty.

b. Marginal and small farmers face significant challenges in raising lumpsum amounts for capital expenditure, particularly since a large majority are already indebted. Farmers are more comfortable with staggered payments post the harvest period.

c. Marginal and small farmers are risk averse. Any capital expenditure that they incur, either by adopting SWPs, or using improved irrigation solutions, or shifting to horticulture, or all of the above, would have to be funded through improved outcomes on yields, productivity and market prices, apart from possible savings gained from lower energy costs.

6. Incentivizing Micro SWP through policy:

a. State governments should prioritize deployment of micro SWPs along with micro irrigation solutions for marginal and small farmers to enhance the efficiency and performance of the pumps, and also promote better irrigation practices and water recharge measures.

b. Incentivizing SWP usage for marginal and small farmers requires reflective subsidy and financing models to take into account the revenue and cost dynamics of different farmers and their ability to generate profits from agriculture.

c. Development professionals, government, non-governmental organizations, SWP manufacturers and other stakeholders in the renewable energy sector need to anchor their policy and technical designs around the need and requirements of farmers.

Over the course of this exercise, several additional research ideas cropped up which would help widen our understanding of the scope, potential and demand for micro SWPs. First, micro SWPs requires more testing across different geographies, using different micro SWP sizes, with different types of farmers, along with combinatorial technological solutions such as drip irrigation to improve outcomes. This would help identify best practices and best deployment scenarios for micro SWPs. Second, further research is required on financial models and incentives that would promote micro SWP usage among marginal and small farmers. And finally, research on policy architecture that enables utilization of SWPs and is reflective to farmers' irrigation requirements needs to be undertaken through a wider engagement with relevant stakeholders.

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Koan Advisory

B6-1, Second Floor,
DDA Commercial Complex,
Safdarjung Enclave,
New Delhi 110029

contactus@koanadvisory.com
www.koanadvisory.com