Report On

SOLAR PHOTOVOLTAIC PUMPS FOR IRRIGATION IN MAHARASHTRA – APPROPRIATE SIZING

By

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INDEX

CHAPTER 1:

EXECUTIVE SUMMARY

SPV pumps are being promoted to reduce fossil fuel usage through reduction in diesel consumption and the attendant reduction in greenhouse gas emissions, to address the shortfall in grid connectivity, and, to provide improved livelihood opportunities for poor farmers.

Several states in India have introduced various schemes for promotion of solar PV pumps. Maharashtra had a scheme which targeted farmers of up to 10 acres with a subsidy of 85% - 95% for pumps of 3 HP to 7.5 HP, promoted mostly in the Vidarbha region. The pumps were distributed starting from about mid-2016, and continued for about a year. Since the subsidy requirement per pump is quite high, ~Rs. 3 to 7 lakhs, it is important to target the pumps well, ensuring that small and marginal farmers benefit from the scheme, and misuse is minimized.

This work develops a framework for solar PV pump size requirement for small and marginal farmers in a district. This is something that could be used for any state of India. The framework has been applied to the districts of Akola and Buldhana. Surveys were conducted among solar PV as well as grid and diesel based farmers to determine the efficacy of the framework, and its applicability to the scheme.

Framework

Secondary datasets from Agricultural census, Department of Agriculture crop production data were used to find the crops grown and distribution of landholdings. Crop factor and evapotranspiration data from FAO and IMDB paper were used to find the theoretical water requirement of crops. Rainfall data from MahaRain, water sources and groundwater depth from Minor Irrigation census and Groundwater Survey and Development Agency (GSDA), were used to find the net water requirement and the pump size required. For Akola and Buldhana, it was found that farmers mostly grew soyabean, cotton, maize, tur and gram. Water depth in wells ranged from 20m to 40m. Small and marginal farmers (up to 2 ha or 5 acres) comprised 70% of the population, with another 20% being semi-medium (up to 4 ha or 10 acres). For a land holding of 1 ha, pumps ranging from 1 HP to 3 HP would suffice, and for 2 ha it increased to 3HP to 5 HP.

Scheme survey and analysis with respect to the framework in Akola and Buldhana

Surveys were conducted with 24 solar PV beneficiary farmers in 10 villages of the northern parts of Akola and Buldhana in December 2016. The profile of the farmers matched up with the framework – except for landholding. Farmers were not growing maize this year because wild animals are known to destroy the crop. Many beneficiaries, in fact, had large plots of land but showed small plots to benefit from the scheme. Of the farmers who actually had less than 10 acres of land, most were underutilizing their pumps (sized 3 HP to 5 HP) and using it for less than 5 hours a day in the peak irrigation period of December.

Additionally, a survey of grid connected and diesel farmers in the region showed that most farmers are water constrained and could not water their crops as per the theoretical requirements. Diesel farmers owning 1.5 to 3.5 acres of land, would only require solar PV pumps of 1.5 to 2 HP for theoretical water requirement and could do with even a 1 HP pump for their current levels of water usage. The cost of a subsidized pump of this size could be covered by one to two seasons of diesel spend.

Main Outcomes

As already mentioned above, smaller pumps, between 1 and 3 HP, could be more useful to the target group, and ensure a better response to the scheme. In fact, not having large pumps may discourage richer farmers from applying for the scheme.

The beneficiary farmers were happy with the scheme because of daytime supply. There were no breakdown issues, but that may have been because the pumps were quite new. The scheme received a poor response for a few reasons:

- The stipulation of giving up the right to a grid connection for ten years
- Even the subsidized cost was too high for poor farmers
- Farmers feared for the physical safety of the solar PV system in the fields
- Maintenance requirements and performance after the 5-year contract were unknowns

Also, Maharashtra has good grid penetration with 3.8 million cultivators using electricity for irrigation, out of a total of 11 million cultivators. Hence the requirement for an alternative technology may not be high enough.

CHAPTER 1: INTRODUCTION

1.1. Introduction:

Solar photovoltaic (SPV) pumps are a robust and well-accepted technology today, some important reasons for this are a drop in photovoltaic prices and development in power electronics components used in the system. Several case studies in literature indicate substantial economic benefits and competitiveness in terms of conventional options.

Applications of SPV pumps for irrigation have come up in the last couple of decades with many countries adopting it. Bangladesh, Benin, Zimbabwe along with India are a few countries that are promoting SPV pumps through various schemes.

SPV pumps are being promoted to reduce fossil fuel usage through reduction in diesel consumption and the attendant reduction in greenhouse gas emissions, to address the shortfall in grid connectivity, and, to provide improved livelihood opportunities for poor farmers. In the Indian context, rain-fed farming still remains a major mainstay and only 70 million out of 140 million land holdings receive irrigation. Most poor farmers do not have a reliable source of irrigation and unreliable monsoons over the past few years have forced farmers without access to grid electricity to look at alternate sources such as diesel pumps where a water source exists, or practice deficit irrigation.

In India, solar irrigation pumps were first introduced by the Ministry of Non-Conventional Energy Sources (MNES) now Ministry of New and Renewable Energy (MNRE) for drinking water supply and irrigation. About 13964 solar pumps were disseminated from 1992 to 2014. A majority of India's population is dependent on agriculture for livelihood. However, canal irrigation is limited to some areas only and hence in most parts farmers rely on pump sets for irrigation. A 2014 report on the study conducted by KPMG for Shakti Sustainable Energy Foundation estimated 18 million pumps which are connected to the grid and 7 million pumps running on diesel. The objective of the scheme was to improve energy access, replace diesel pumps and deploy solar technology in rural areas.

In India, several state governments have, or are in the process of, instituting schemes to promote solar pumps for different reasons. In Rajasthan close to 20,000 solar pumps have been distributed till 2015 to address the long wait time for a grid connection. In Bihar 1,560 solar pumps have been installed since 2013 to address the poor grid penetration and cut down diesel usage. Karnataka and Gujarat have introduced schemes for net-metering in grid connected SPV pumps.

1.2. Background of the scheme in Maharashtra:

Maharashtra has good grid penetration with 3.8 million cultivators using electricity for irrigation, out of a total of 11 million cultivators. Others either employ diesel pumps or practice rain-fed irrigation.

The Ministry of Power announced an Off-grid Solar Pumping Programme for FY 2014-15 with MNRE setting a target of one lac solar pumps in the country. In Maharashtra, the honorable Chief Minister Shri. Devendra Fadnavis declared that 5 lakh solar agricultural pumps would be implemented as part of the scheme. MEDA requested MNRE to revise it to 10,000 pumps, which was later revised to 7,540 pumps.

These systems were meant to be offgrid. 80% of the total numbers of pumps were to be distributed in the suicide prone districts of Vidarbha region of Maharashtra i.e. Akola, Amravati, Buldhana, Wardha, Washim and Yavatmal. The project was initially applicable only to farmers having land holdings less than 5 acres but that was later revised to 10 acres. With land holdings up to 5 acres a farmer could avail a subsidy of 95% subsidy, and between 5-10 acres a subsidy of 85%. The connections were subject to the condition that she/he did not have a grid-based agricultural connection, and in addition had a water source on their farm.

1.3. Objective of this study

All these schemes require a heavy subsidy to the farmer. 3-5 HP SPV pumps cost ~Rs. 3,25,000-6,75,000. Governments have declared subsidies of 80 – 95 %. Even considering the subsidy in grid supplied agriculture, SPV pumps are still largely a more expensive solution for the government to promote, except for remote and hilly locations. In such a scenario it is important that solar PV schemes are targeted to the appropriate beneficiaries who derive the desired benefits, and the schemes are not instead captured by richer farmers.

In this work we develop a framework to determine pump sizes appropriate for small and marginal farmers in a particular district, using secondary datasets. This has not been done, though several papers exist on pump sizing with and without storage tanks, using different types of pumps, and, for specific crops in specific regions. We do not consider storage tanks since they are too expensive for small farmers. A storage tank designed to address the peak irrigation months of October and November in Maharashtra could cost ~Rs. 4,00,000.

We also conduct surveys of beneficiary and non-beneficiary farmers in Vidarbha and do an analysis of the outcomes of the Maharashtra scheme.

The study was conducted for two adjacent districts, Akola and Buldhana, because the solar PV scheme of the government of Maharashtra was focused in the Vidarbha region. We present secondary level datasets that are used to identify factors determining typical pump sizes, i.e., cropping pattern, daily peak irrigation requirement of the crops, cultivated area, rainfall, water head, and solar insolation. The calculations for the required pump models for typical heads and land holdings has only been presented for Buldhana, since the two districts are agro climatically similar.

Surveys were conducted with 19 SPV pump beneficiaries in 10 villages of Buldhana and Akola – locations shown in Fig.1.1. The surveys are used to ratify the framework and also to understand the outcomes of the scheme. A few surveys were also conducted with beneficiaries in Nasik and Amravati.

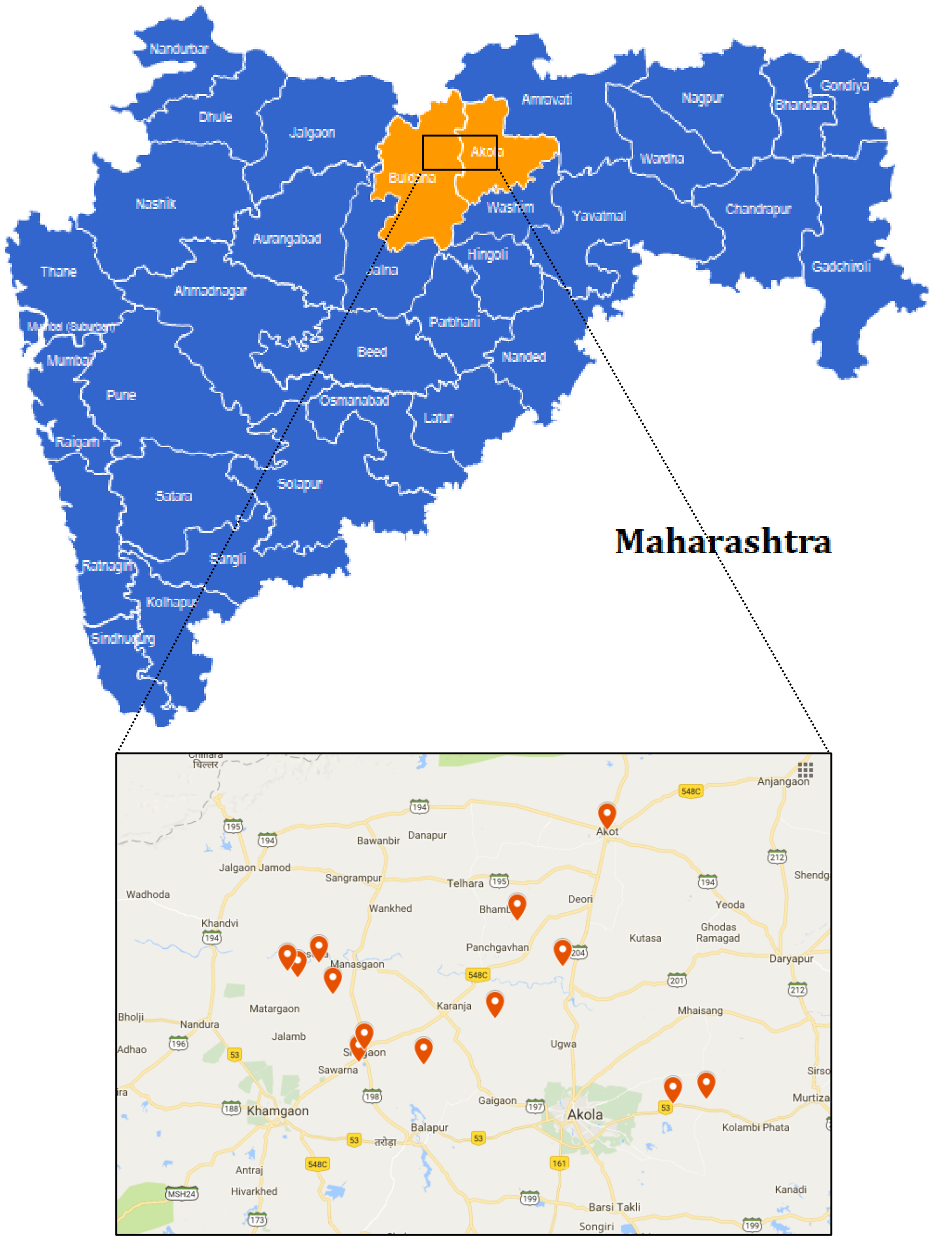

Figure 1.1: Locations of farmers surveyed in Buldhana and Akola

We also look at the net-metering potential. Since irrigation is a very seasonal requirement, maximum use of the PV panels can be made if they are grid connected. In addition, net-metering can be an incentive for efficient water use. The danger here is that farmers could game the system depending on the net-metering tariff. To avoid this, the tariff should be low in the season of low water requirement and high in the watering season. We use the developed framework to find the expected usage pattern of the system, and hence the pattern of power fed back on the grid over the year.

1.4. Structure of the report

The report has been organized as below

Chapter 1: Introduction
Gives the brief introduction and objectives for the study

Chapter 2: Overview of Solar PV pumps
Discussed about the technology, advantages and disadvantages compared to diesel. It briefly lists the schemes being implemented in different part of the world and states in India

Chapter 3: Determination of Solar PV pumps for typical small farmers in Akola and Buldhana
This chapter talks about the datasets that are used in the framework. We also discuss the methodology used to arrive at typical farmer profiles in a region and identifying her/his irrigation requirement.

Chapter 4: Analysis of the scheme implementation
In this chapter we look at the current energy and water scenario in agriculture in Maharashtra. We take a case study for Buldhana district in Maharashtra and arrive at solar pump capacity for a typical farmer in the region. We ratify our findings with the primary survey data that was carried out in Buldhana and Akola. At the end of this chapter, we explore the option of net metering.

Chapter 5: Conclusion
This chapter discusses our findings and analysis from the Maharashtra scheme.

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CHAPTER 2: OVERVIEW OF SOLAR PV PUMPS

2.1. Solar PV pumps

A Solar PV pump is a device used to pump water using the energy of the sun. The electric power for the pump is generated by a set of SPV arrays calibrated and matched to deliver the power to the pump. A normal mechanical pump like a submersible, surface or deep well can be attached with the power conditioning systems to work as an SPV pump. Solar water pumping system consists of a set of solar PV panels or array, a motor pump set, and a controller or some set of electronics.

The building block of an array is a Photovoltaic (PV) cell. PV cells are semiconductor devices that convert sunlight into direct current electricity. The PV cell circuits are sealed in an environmentally protective laminate which makes up the module. These modules assembled together for the ease of field installation are called as panels. Solar array is a set of panels connected together.

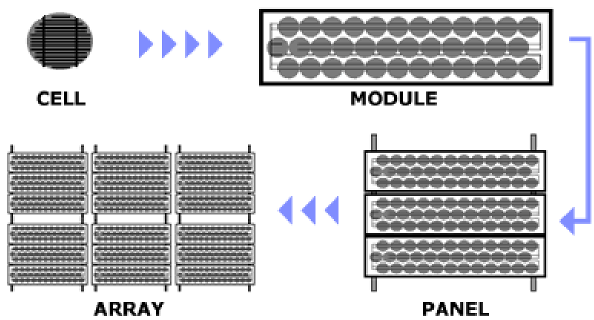

Figure 2.1: PV array

The array is mounted on a suitable structure which has provision for tracking the sun. The motor can be a D.C (brushed or brushless) or an A.C. induction motor. The electronics include a Maximum Power Point Tracker (MPPT), drive, controls and protection.

An MPPT is an algorithm that is included in charge controllers used for extracting maximum available power from the solar array regardless of the connected load. MPPT checks the output of the array and compares it to the load, then fixes the best power that a PV array can produce to convert the voltage to get maximum current.

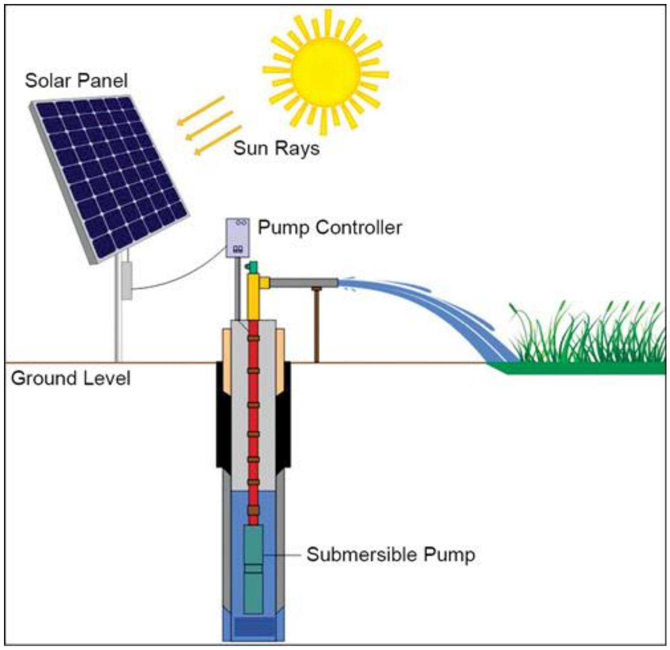

Figure 2.2: Solar water pumping system

In case of an A.C motor, the controller includes an inverter of some kind. A Variable frequency drive (VFD) is commonly present in motors today. A VFD is a motor controller that works by varying the frequency and voltage supplied to a motor. A motor's speed is directly proportional to frequency and when the application requires the motor to run at lower speeds it ramps down the frequency, and in turn, reduces the voltage level required to meet the motor's load. A VFD helps the motor to work even at low levels of solar insolation.

2.2. Advantages, Disadvantages, comparison with grid, diesel;

Solar water pumping technology is new compared to diesel and grid energization. Grid based and diesel pumps are tried and tested by farmers all over the globe. When comparing these 3 technologies it is important to look at social, ecological and techno-economic factors. Table 2.1 gives a comparison of the 3 technologies.

Table 2.1: Comparison of diesel, grid connected and solar pump

Type	Advantages	Disadvantages
Diesel pump	Fast and easy installation	High operational costs along with fluctuating fuel supply and price
	Easily movable	High maintenance cost
	Low capital cost	Shorter life
	Suitable for intermittent irrigation needs	Air pollution, GHG, loss of foreign exchange
	Economics favorable if the grid is already extended	Grid extension is expensive for remote locations

Grid connected pumps	Subsidized supply (from the farmer's point of view)	Hours of pumping dependent on utilities
	Electricity supply taken care by the utility.	Power surges results in pump breakdowns
		Night time supply
Solar pumps	Low maintenance cost	High investment cost
	Long lifetime	Fluctuating output based on cloudy periods and seasons
	Low to nil operational cost	Repair requires skilled technicians
	Unattended operation	Expensive parts
	Daytime supply of water	Requires space for installation of panels
	Ideal for remote locations	

Cost of operating a diesel pump is high due to diesel cost. Often farmers have to travel far to get the diesel for their pump as well which adds to the transportation cost. However, farmers are known to use diesel pumps for intermittent needs of irrigation.

We do a cost comparison for diesel pump, grid based pump and solar pump to look at their lifecycle cost using Net Present Value (NPV). For the calculations we are assuming an inflation rate of 5% and discount rate of 12%. We assume an electric pump has a life of 10 years, a diesel pump 5 years, and a solar pump 20 years. The calculations are done for 5HP pumps over a period of 20 years considering 200 days of irrigation with the solar PV pump being used to its maximum in that period and the electric and diesel pumps for 6 hours a day for an equivalent water output.

Table 1.3: Lifecycle cost of grid based pump for 200 days of irrigation

Cost component	Reference for cost	Cost in Rs.	NPV in Rs.
Average cost for releasing an Ag. connection	MSEDCL Schedule of charges, Annexure I	48000	48000
Cost of electric pump at 0th year		21700	21700
Pump replacement at 10th year		19000	11381
Electricity (200 days, 6 hours/day)	Cost of Supply as per MERC tariff order 2016-17	28467 (annual cost)	330195 (20 years)
Lifecycle cost			**4,11,275**

Table 2.4: Lifecycle cost of diesel pump for 200 days of irrigation

Cost component	Reference	Cost in Rs.	NPV in Rs.
Cost of pump		21640	21640
Cost of pump at 5th year			15672
Cost of pump at 10th year			11349
Cost of pump at 15th year			8219
Diesel (200 days, 6 hours/day)	Cost of diesel at Rs 60/ltr	48000 (Annual cost)	556755 (20 years)
Lifecycle cost			**6,13,635**

Table 2.5: Lifecycle cost of a solar pump

Cost component	Reference	Cost in Rs.	NPV in Rs.
Cost of the solar pump	Tender documents of Maharashtra solar pump scheme	540000	540000
Annual Maintenance cost		5000	57995
Lifecycle cost			**5,97,995**

Here we have considered 200 days of irrigation at full capacity of the solar PV system and equivalent usage of the diesel and electric pumps. We see that the grid based system turns out to be 2/3 cost of the solar PV system, while the diesel system is almost the same as a solar PV system. But this will change drastically with the seasonality of irrigation.

For many regions of India, including Vidarbha where this scheme was implemented, the irrigation is very seasonal due to availability of water. The cost effectiveness of solar PV system drops as the number of days of pumping decrease.

For example, as will be shown later in this report in Chapter 4, a 1 ha farmer in Akola, can use a 3 HP pump, and will only use it for 98 hours a year over a period of 5 months. Considering this, the solar PV pumps turns out to be more expensive compared to both diesel and electric since the capital expense is not defrayed by usage.

Tables 2.6 - 2.8 look at the lifecycle cost of the three systems for limited irrigation needs of 98 hours over 5 months. For small irrigation needs the lifecycle costs of grid based and diesel pump are comparable however as pumping requirements increase the cost of diesel pump increases.

Table 2.6: Lifecycle cost of a grid based pump

Cost component	Reference for cost	Cost in Rs.	NPV* in Rs.
Average cost for an Ag. connection	MSEDCL Schedule of charges, Annexure I	48000	48000
Cost of electric pump	5 HP ISI standard pump	21700	21700
Pump replacement at 10th year		21700	11381
Cost of electricity (5 months irrigation period days, 98 hours total in a year)	Cost of Supply as per MERC tariff order 2016-17	2325 (annual cost)	26966 (20 years)
Lifecycle cost			**1,10,372**

*NPV: Net Present Value

Table 2.7: Lifecycle cost of a diesel pump

Cost component	Reference for cost	Cost in Rs.	NPV in Rs.
Cost of pump	Standard diesel pump cost	21640	21640
Cost of pump at 5th year		21640	15672
Cost of pump at 10th year		21640	11349
Cost of pump at 15th year		21640	8219
Diesel (200 days, 6 hours/day)	Cost of diesel at Rs 60/ltr	4412 (annual cost)	51172 (20 years)
Lifecycle cost			**1,08,052**

Table 2.7: Lifecycle cost of a 1HP solar pump

Cost component	Reference	Cost in Rs.	NPV in Rs.
Cost of the solar pump		150000	150000
Annual Maintenance cost		3000	34797
Lifecycle cost			**1,84,797**

Solar PV pumps do have high upfront costs which is a deterrent, but in addition the seasonality of irrigation also makes diesel and electric more cost effective. For remote locations, diesel and solar PV may be more cost-effective. Diesel will work only for low head applications.

2.3. Usage in various parts of the world

With the reduction in PV costs and increasing awareness of the technology, many countries have come forward to launch programmes for implementation of solar pumping for irrigation. Bangladesh has set a target to deploy 50,000 solar pumps by 2025 with India targeting 1,00,000 by 2020 and Morocco of 1,00,000 nos by 2022.

In Zimbabwe, Oxfam's Ruti Dam Irrigation Scheme solar pumps were used to increase coverage from 40 to 60 hectares. Over 270 small holder farms have benefitted from this by increasing their income from agricultural produce. In Benin, Solar Electric Fund has set up a solar pump with drip packaged under a cooperative where women farmers practice farming on full plant beds. The produce is either consumed by her family or sold.

Bangladesh is a highly agrarian country and farmers have been using diesel pump for irrigation. Currently there are 1.34 million diesel pumps. Infrastructure Development Company Limited (IDCOL) has set a target to replace the existing diesel pumps with solar pumps. They are also promoting an ownership model wherein farmers can sell water to the nearby farmer.

Not so far away, Nepal has also set a target of 2.1GW solar capacity by 2030 which will be implemented by solar home lighting systems, pumps and cooker. However the details of their scheme are not very clear.

2.4. Schemes in other states of India

Solar pumps scheme in India started in 1992 when Ministry of Non-Conventional Energy Sources (MNES) which is Ministry of New and Renewable Energy (MNRE) introduced the Solar pumping programme for drinking water. The Ministry of Power announced off-grid solar pump scheme with a target of 1 lac pumps in the year 2014-15.

In India several states have provided subsidies for solar pumps to farmers. Rajasthan and Bihar were one of the first few states to implement the programme. The states have implemented schemes differently based on the farmer conditions in their regions. The different schemes in India and the subsidy and capacities offered are summarized in Table 2.6. Rajasthan was the flag bearer in 2010, offering 86% capital subsidy on small irrigation pumps. Bihar followed suit in 2013-14 by launching the Bihar Saur Kranti Sinchai Yojna offering about 90% subsidy on the capital cost.

Table 2.6: Solar pump scheme in different states in India

	Name of Scheme	Subsidy offered	Pump capacities	Beneficiary preference	FIT
Karnataka	Surya Raitha	90%	Up to 5 HP	No grid connection	Yes
Bihar	Bihar Saur Kranti Sinchai Yojna	90%	2kWp	Small farmers (1-5 acres)	-
Rajasthan	Rajasthan solar water pump programme	86%	200Wp-10kWp	Min 0.5 ha land with 0.5 ha under horticulture, drip irrigation and farm pond	-

Gujarat	Solar water pump scheme by GGRC	AC: Rs 32,400 per HP. DC: Rs 40,500 per HP	3 & 5 HP	Women farmers and existing drip system	Yes
Chhattisgarh	Saur Sujala Yojna		3 & 5 HP	No agricultural connection	-
Maharashtra	Solar agricultural pump	95% & 85%	3,5,7.5 kWp	No agricultural connection	-

2.4.1. Rajasthan:

In Rajasthan the scheme was carried out by the Horticulture Society under the Agriculture Department of Government of Rajasthan. The major objectives of the scheme were to increase irrigated area, productivity, reduce the queue for grid connection, reduce usage of diesel pumps and promote environmental sustainability. Amongst the many Government of India (GoI) schemes, the Water Harvesting Structures (WHS) Scheme, *Rashtriya Krishi Vikas Yojana* (RKVY) was tied to the Jawaharlal Nehru National Solar Mission (JNNSM) to implement the scheme in the state. Thirty percent of the funding comes from MNRE and 56% from RKVY. A clause of free maintenance for 5 years is embedded in the scheme which was borrowed from the experience of Public Works Department on roads. It was observed that contractors who had a 5 year free maintenance clause built superior roads than the ones with 1 year maintenance. This clause has been built in the Maharashtra scheme as well. In addition, suppliers have to provide a light outlet for 100W and a home lighting system as an integral part. The applications were received by the district authorities and in case the numbers of applicants were more than the target then the beneficiaries were selected by a system of lottery.

A total of 86% subsidy is provided to farmers under the condition that the farmers had farm ponds (*diggis*), did horticulture on at least 0.5 ha of land and used drip irrigation. Farmers have to apply to Horticulture Department with a Demand Draft for Rs 10000, land ownership record, a tri-partite agreement among the farmer, supplier and horticulture department, quotation from an empanelled firm and a technical drawing of the structure. Once the adherence to the conditions is checked, a lottery is conducted in the presence of District Collector. If a farmer is chosen, she/he has to deposit 14% of the amount minus Rs 10000. In effect, it applied to the large and rich farmers and not small and marginal farmers. The IWMI report on solar pumps said that most farmers stayed in towns and employed agriculture laborers to look after their farms as most of them either had government jobs, political positions or were agricultural input dealers.

Rajasthan has been facing fast rate of ground water depletion which was a primary reason for it to include drip irrigation as a necessary criteria. However, there is no guarantee of groundwater conservation when the farmer can increase the irrigated land. The report also said that farmers use solar pumps to fill water from tube wells in to their farm ponds (*diggis*) and often did not irrigate their fields via drip irrigation. Thus in spite of garnering interest from farmers it failed in trying to meet the long term stakes of farmers in usage. With such high subsidy being offered to well of farmers, it is clearly leading to a case of elite capture in the state.

The Rajasthan scheme was also in talks with reports of corruption at different levels in terms of accepting applications, verification and approving. This led to a lot of gold plating of the SPV systems by suppliers. In 2012-13, MNRE had maintained the benchmark cost of 2011-12 which the suppliers referred to. This amounted to Rs 5.70 lakh for a 3 HP system. The subsidy regime discouraged innovations and cost reductions to farmers. A court case was filed in this regard in the Rajasthan High court. A second issue that was raised was in terms of targeting of the scheme towards richer farmers. Although the scheme set out to meet the energy demand in agriculture and enhance irrigated area it eventually benefitted the high remunerative crop growing farmers.

Farmers who benefitted from the scheme were uniformly happy with the performance. It is easy to switch on and off and there is practically no maintenance required apart from dusting of the panels once a month. Some farmers did report issues with auto tracker, strength of installation and the motor and were not happy with the after sales service. However, these farmers were few in number. The state has also seen a non-subsidy market for solar pumps. A farmer who purchased a non-subsidy solar pump of 3 HP at Rs 1.4 lakh told the IWMI researchers that he saved Rs 60,000 in electricity charges which would be spent in the 10-12 months of getting the subsidized solar pump.

The Rajasthan Experience has been bright so far and the Govt. has been aggressively pushing for solar pumps. In March 2017, announcements to include 7.5-10 HP pumps were also made which forecasts the growth of solar pumps in the state.

2.4.2. Bihar:

Bihar has one of the world's best groundwater aquifers. In spite of this their cropping intensity is very low. This has been attributed to economic water scarcity due to lack of rural electrification and high price of diesel. The solar pump scheme was promoted in the state to increase cropping intensity by increasing irrigated area. In 208, to mitigate the effects of drought, the Govt. started a cash transfer scheme for diesel pumps which was marred by high transaction costs. Following this, the Bihar Saur Kranti Sinchai Yojna was introduced with 90% subsidy on a 2kW$_p$ solar pump. Smaller pump was targeted to reach the irrigation needs of small and marginal farmers. The cost of the solar pumps in Bihar were priced between Rs 1,40,000 and Rs 1,50,000 per kWp.

Solar pumps were first experimented in 2012 in Bihar by the Department of Water Resources in Nalanda district where 7.5 HP solar pumps were put up on 34 public tube-wells in 20 villages. An operator was appointed by the Govt. to provide water at Rs 5 per katha (1 acres =32 katha) and he was paid Rs 2500 as fixed monthly salary. No one from the govt. or Claro energy went back to collect the revenue or pay the salaries. In some areas the operators started treating the revenue as their income and expanded the irrigation network by investing their private capital. While in others the operators increased the price for irrigation to up to Rs 15 per katha whereas the price with diesel powered irrigation was at Rs 20 per katha. It thus failed to achieve affordable irrigation for small and marginal farmers.

In the survey conducted by IWMI in Bihar, it was found that out of the 31 beneficiaries under BSKSY only 4 relied exclusively on solar irrigation whereas the rest had a diesel or electric pump as a back-up. Here too the medium and large farmers are the ones who availed the benefits of the scheme. Smaller capacities were promoted as it was expected that farmers have small irrigation requirement however, farmers complained that it took them twice as long to irrigate a bigha (1acre=1 bigha) as compared to diesel and electric.

In Bihar, only MNRE empanelled companies with experience of more than 3 years and an annual turnover of Rs. 10 crores could participate which created an entry barrier for new companies. Thus only 5 companies participated till 2016. The lowest quoted price became the base price for BREDA to supply pumps. Farmers have no say in terms of whom to buy from but just the type: AC or DC. Districts were allotted to companies based on type and demand. This created a non-competitive environment where companies did not strive to maintain after-sales services. Twenty-nine out of thirty one farmers faced performance issues once or twice in a year which sometimes took 3 weeks to resolve and in some cases 3-5 months.

Bihar being a state where most farmers are water buyers, providing capital subsidy to well owners is inadequate to achieve the objective of enhancing irrigation access to small farmers.

2.4.3. Karnataka:

In Karnataka free power is provided for agriculture, the subsidies have been rising over the years. The Surya Raitha Scheme is promoting grid connected solar pumps as a ‘remunerative crop’ that earns a feed-in tariff. This in turn promotes water use efficiency. Farmers who have not availed the subsidy can sell the power at Rs.9.56 per unit, and farmers who have availed it can sell it at Rs.7.20 per unit.

2.4.4. Maharashtra:

In consonance with the announcement at the Centre for installation of solar pumps in the country, the Maharashtra, government announced a target of 5 lac solar pumps which was later revised to 7,540 pumps by Maharashtra Electricity Development Authority (MEDA). The scheme was announced by the Honorable Chief Minister Shri. Devendra Fadnavis in 2014-15. It was designed to provide 95% subsidy on solar pumps to small and marginal farmers who did not have an agricultural connection with a special focus to drought prone areas.

The scheme is implemented by Maharashtra State Electricity Distribution Company Limited (MSEDCL) and MEDA. The Central Govt. gives 30% of the system cost with State Govt. contributing 5% and 60% is taken as a loan from financial institutions while the farmer puts in the balance 5% on the system cost. The loans are taken in the name of farmers however, MSEDCL pays the loan amount.

Farmers who want to avail the scheme have to follow the below criteria:

- No agricultural grid connection,
- Land holdings less than 2 ha, which was later revised to 4 ha,
- Water source on their field.

Eighty percent of the 7,540 pumps were allotted to suicide prone districts of Vidarbha: Akola, Amravati, Buldhana, Washim, Wardha & Yavatmal and the rest other districts.

For the application process, the farmer has to fill out a form which is available at the Sub-division level. The forms are scrutinized by the officials at the Taluka by the Krishi Adhikari and MSEDCL after which it is sent to the District Authority. The forms are finally sent to District Committee which comprises the Collector, District Krishi Adhikari, Ground Water Board and MSEDCL officials. Once, these are approved vendors visit the farmer's field to assess the land area, head and cropping to recommend a connection to her/him. MSEB then releases an order to the farmers to make the upfront payment. After the payment is done, vendors are asked to install the systems on site.

The vendor has to maintain the pump for 5 years, and is obligated to respond to customer complaints within 48 hours, failing which they face monetary penalties. Only 2 vendors were selected for the implementation of the scheme in Maharashtra, Jain Irrigation and GGDCL.

Solar pumps have been priced differently in different states with the lowest in Gujarat at Rs 70,000 per kWp. In Maharashtra, it was priced at Rs 1,08,000 per kWp whereas in Bihar it was priced at Rs 1,40,000 and Rs 1,50,000 per kWp. The Govt. held the procurement of these pumps after an RTI was filed. In our discussions with MSEDCL we found that a 5 year insurance period was included which escalated the price for the state of Maharashtra.

So far only Karnataka and Gujarat offer the option to farmers in terms of feeding the excess energy generated back to the grid. Chhattisgarh has launched the solar pump scheme recently and announced it in mid-2016. The scheme offers 3 and 5 HP pumps for farmers with no agricultural connection. As it is a fairly new scheme, the acceptance of the scheme is yet to be known.

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CHAPTER 3: FRAMEWORK DESIGN FOR DETERMINATION OF APPROPRIATE SOLAR PUMP SIZE FOR A REGION

Many studies have been done to calculate solar pump capacities for a farm plot of a certain size for a particular crop and region. However, at the policy level it is important to be able to identify the right application of a technology at a broader level. Especially in a capital intensive, heavily subsidized scheme as the solar pumps, it is very important to identify the right beneficiaries and give them the appropriate capacities. This will also help in avoiding a situation similar to the one observed in the Rajasthan scheme. In the framework which is discussed below we have used secondary datasets to arrive at typical profiles of small and marginal farmers and hence determine pump capacities.

3.1. Secondary datasets

Secondary data analysis is pivotal to the role of this study as this offers insight into the characteristics of a region. The data used in this study is available in public domain and has been collected by periodic surveys of the government. Data from different sources has been used to draw a typical farmer profile for a region. The following secondary datasets were used in our calculations:

3.2.1. Agricultural census:

The Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Govt. of India has been conducting Agriculture census every 5 years since 1970-71. It is a broader system of data collection in India where the structural characteristic of agriculture is captured. The basic data is collected in terms of operational holding by the characteristics of the land holder in terms of cropping pattern, land use, irrigation and tenancy details. This data was used to find the typical land holdings in a region.

3.2.2. Minor Irrigation Census

Irrigation schemes using either surface water or ground water and having a command area of less than 2000 hectares individually are categorized as Minor Irrigation Schemes. The census is carried out by the Minor Irrigation Division of the Ministry of Water Resources, Govt. of India. The Census is supposed to be carried out every 7 years. However, the last available data is for the year 2006-07. The data for the year 2013-14 is yet to be released. For our study we have used the data from2006-07 to find typical water depths. We only considered tube wells, dug wells and farm ponds, sources that are present on the field, because these are the only sources eligible in the Maharashtra government scheme

3.2.3. District level cropping pattern data

Department of Agriculture, Government of Maharashtra collects and publishes the cropping pattern for all districts in Maharashtra every year. The data includes area, production, and productivity, of different crops separately for the kharif, rabi, and year-round seasons. We have used it to find the typical cropping pattern of a farmer in a district. The crops with maximum area under cultivation are considered as typical crops grown by a farmer. Monthly rainfall data

The Department of Agriculture collects daily rainfall data circle-wise. The Rainfall Recording and Analysis division has been capturing this data since 1998. The average normal rainfall data for a district is considered for the purpose of our study.

3.2.4. Evapotranspiration rates (Et_0)

Evapotranspiration is the term used to describe the water needs of a plant, specifically a reference grass. It is the sum of water lost by the process of evaporation and transpiration. Under the Rashtriya Krishi Vikas Yojna, Mahatma Phule Krishi Vidyapeeth, Rahuri, has published evapotranspiration values for 10 districts in Maharashtra. These values are available fortnightly and monthly. However, as Buldhana was not in their purview for our case study we have used the Et_0 values published in a paper by the Indian Meteorological Department for the weather station nearest Buldhana.

3.2.5. Crop coefficients (Kc)

Crop coefficients are properties of plants that are used to predict the evapotranspiration as compared to the reference grass. Hence Et_0 and K_c together can predict the water requirement of a plant. These are different for different plants and at different stages of its growth. Crop coefficients are published by Food and Agriculture Organization (FAO) for some typical crops growing in different regions.

3.2.6. Solar Insolation

The monthly daily average insolation values are important to know the estimate the input solar resource based on which the output can be calculated. NASA's Earth Science Enterprise Program gives the daily solar radiation- horizontal month-wise based on the co-ordinates of a location. The data from this site has been used for calculating the daily average solar insolation.

3.3. Identification of farmer profiles

It has been observed that farmers in a region commonly grow similar crops based on the agro-climatic resources that are favorable for the region. Identification of farmer profiles is to characterize farmers based on their resources in terms of land holdings, cropping and water source. As discussed earlier, Agriculture Census captures details of farmers in terms of their land holdings and they are classified as marginal (0-1 ha), small (1-2 ha), semi-medium (2-4 ha), medium (4-10 ha) and large (> 10 ha). To identify the majority farmer class in a region, data from the census can be used to highlight the numbers and percentages.

By knowing the major farmer class in a region, land holding pattern in a region can be known. For estimating the irrigation needs of a farmer, land holding plays a crucial role as the capacity of the pump would determine the area that can irrigate in a given time frame. By using, Agriculture census data we have estimated a typical farmer profile for Buldhana in the next chapter.

Further, we look at the cropping pattern in that region by the area under each crop. Identifying the top 4-5 crops in terms of areas under cultivation gives a picture of what most farmers grow in that area.

The Agriculture Census is also used to highlight which are the most prevalent types of water sources in a region. The Minor Irrigation Census gives the depth of water sources in different villages. This can be averaged for a region and assumed as the typical head found.

3.4. Monthly crop water requirement

Crop water requirement is defined as the amount of water needed by the crop to meet the water lost through evapotranspiration. Crop water needs mainly depend on:

- Climate:

  Factors such as sunshine, temperature, humidity and wind speed determine the reference evapotranspiration for a place. Crop water requirement is high in dry, hot, windy and sunny place whereas it is low in cool, humid and cold place.

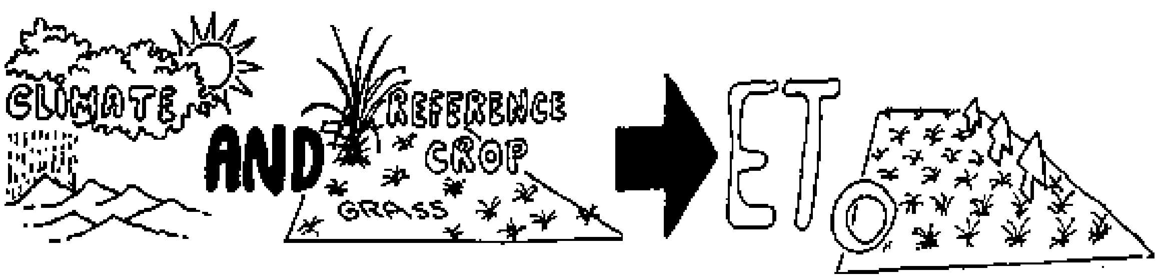


Fig 3.1: Reference Crop Evapotranspiration

The Reference Crop Evapotranspiration (Et_0) for a certain place and certain month/day of the year is measured for the reference crop, grass, in that place on a certain month/day, hence taking into account the climatic factors in that place and time of the year.

- Type of crop
- Growth stage of a crop

The relationship between grass crop and the crop grown is crop factor (K_c). A crop will have different water needs through its development. This factor takes into account the different growing period and their water needs with respect to grass in a particular month/day of year.

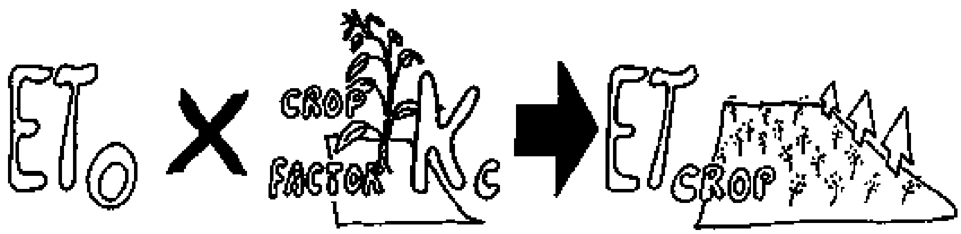


Fig 3.2: Crop Evapotranspiration

Water required by the crop can be supplemented by rainfall, irrigation or both. In the event of a rainfall, water infiltrates, stagnates on the surface or flows as runoff. Once the rain stops, water evaporates from the soil while the rest infiltrates into the soil. Of the water that infiltrates some percolates below the root zone while the rest in captured in the root zone. The term effective rainfall in essence is this water that is captured by the root zone of the plant. The effective rainfall P_e is calculated using the following formula [FAO]:

$Pe = 0.8 * P \; if \; P > 75$
$Pe = 0.6 * P \; if \; P < 75$
where, P is the rainfall in mm per month

The irrigation to be given to the crop can be calculated once the effective rainfall is known. If the effective rainfall is higher than the crop water need for a month, then external irrigation is not required. If the effective irrigation does not satisfy the crop water need, then the balance needs to be applied externally.

For the purpose of our study the net irrigation requirement is calculated on a monthly basis according to Eq. (1).

$$NIR = (Et_0 \times K_c) - P_e \qquad (1)$$

where,
NIR is Net irrigation requirement;
Et_0 is evapotranspiration rate;
K_c is crop coefficient;
P_e is effective rainfall.

3.5. Identifying solar pump characteristics

To find out the appropriate pump size requirement we need to know the irrigation requirement, head, and in case of a solar pump, we also need to know the solar insolation. We will be assuming a typical land holding with the dominant cropping pattern and typical head for the region.

After estimating a typical land size and cropping from section 3.3, we calculate the monthly irrigation requirement for a farmer. The maximum possible water demand in any month for a farmer growing any of the dominant set of crops in the district is used to determine the pump size.

It is important to know that the solar insolation varies across different months and the output from the pump would vary during these months. The monthly daily average solar insolation data is obtained from the NASA metrology site by entering the co-ordinates for the region. The MNRE specifications for pumps are given for a daily solar insolation of 7.15 kWh/m^2 incident on the surface of the PV array. For the purpose of identifying the solar pump characteristics, we need to consider the solar insolation in the month with peak demand. The solar pump capacity is identified based on the solar insolation for the peak demand month.

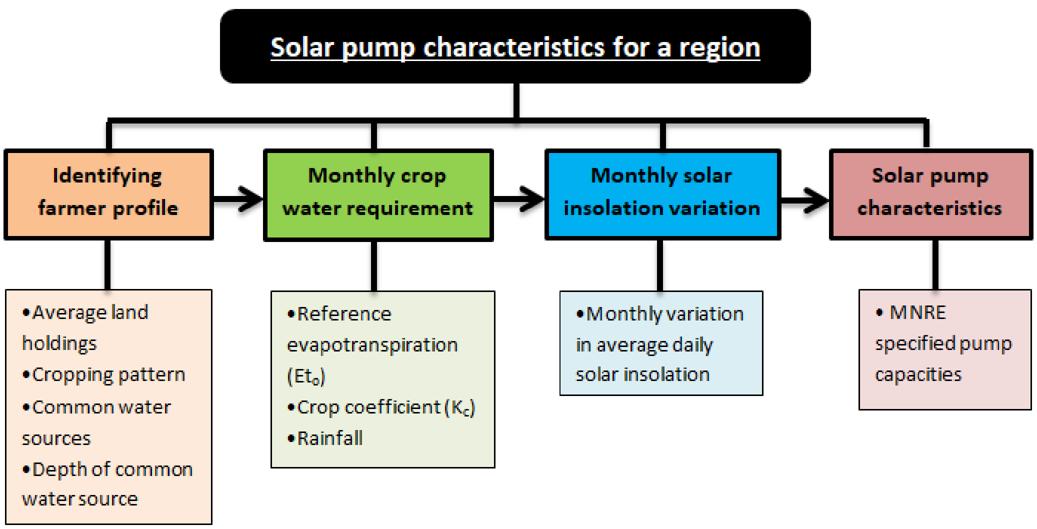


Figure 3.3: Identifying solar pump characteristics for a region

The scheme promoted both AC and DC pumps with specifications that meet MNRE guidelines. DC pumps require less maintenance; however maintenance is more convenient for AC pumps since they are the commonly used induction pumps with an established ecosystem in rural India. In general, DC pumps give 10% more water output but cost 20% more. For our calculations, we have considered AC pumps. We have assumed that the performance of the pumps meet the MNRE specification. Under this specification, the panels are expected to be manually tracked in an East-West direction three times a day and set to three optimum positions marked by the manufacturer. Generally, this would lead to a solar insolation of more than 7.15 kWh/m^2 in most places of India.

CHAPTER 4: APPLYING FRAMEWORK IN AKOLA AND BULDHANA

4.1. Overview of Agri. distribution system in Maharashtra and agricultural and water scenario in Maharashtra

Agriculture is one of the important sectors in Maharashtra. About 25% are cultivators and another 27% are agricultural labourers. According to the Agriculture Census 2010-11, there are about 1.38 crore total operation landholdings in the state with about 78% belonging to marginal and small farmers. Of the total 307.58 lakh ha geographical area of the State, the gross cropped area was 232.73 lakh ha while the net area sown was 173.45 lakh ha (56.4 per cent) for the year 2014-15. Maharashtra has 36 districts which are divided into 9 agro-climatic zones on the basis of rainfall, soil types, vegetation and cropping. The details of the zones are as seen in Table 4.1.

Table 4.1: Details of agro-climatic zones in Maharashtra

Sr. no	Agro-climatic zone	Characteristics	Districts	Major Crops
1	***South konkan coastal zone***	Very high rainfall zone	Ratnagiri, Sindhudurg	Rice, Ragi, Vari, Horsegra, Mango coconut, Arecanut, Cashewnut, Jackfruit
2	***North konkan coastal zone***	Very high rainfall zone	Thane & Raigad	Rice Vari, Udid, Tur Brinjal, Tomato, Banana, Chickoo, Sesamum
3	***Western Ghat zone***	Narrow strip extending from north to south along the crest of Sahyadri ranges	Kolhapur, Satara, Pune, Ahmednagar & Nasik, small area of Sindhudurg district.	Rice, Ragi, Kodra, Jowar, Gram, Groundnut, Niger. Sugarcane, Mango, Cashew, Jackfruit, Jamun and Karwand
4	***Transition zone I***	Located on eastern slopes of Sahyadri ranges	Spreads over 19 tahsils of five districts viz, Nasik, Pune, Satara, Sangli & Kolhapur	Groundnut & sugarcane, Potato, Onion, Chillies, Tomato, Brinjal, Mango, Guava, Cashew and Grapes
5	***Transition zone II***	Wide strip running parallel to eastern side of transition zone I	Tahsils of Dhule, Ahmednagar, Sangli & central tahsils of Nasik, Pune, Satara & Kolhapur districts	Jowar, Bajra, Groundnut, Wheat, Sugarcane, Udid, Tur Gram & Ragi.
6	***Scarcity zone***		Parts of Nadurbar, Dhule, Nashik, Ahmednagar,	Bajra, Jowar, groundnut, Safflower, pulses

			Pune, Satara, Sangli, Solapur and Beed	
7	***Assured Rainfall Zone***	Central Maharashtra Plateau Zone	Complete Latur, Buldhana. Parts of Aurangabad, Jalna Beed, Osmanabad, Akola, Amravati, Yavatmal, Jalgaon, Dhule & Solapur. Major parts of Parbhani & Nanded	Jowar, Cotton, Jowar, Bajra, Gram, safflower, Tur, Mung, Udid, Groundnut, Sesamum Safflower & Niger.
8	***Moderate Rainfall Zone***	Central Vidarbha Zone	Wardha, major parts of Nagpur Yavatmal 2 tahsils of Chandrapur & parts of Aurangabad, Jalna Parbhani & Nanded districts.	Cotton, Kh.Jowar, Tur, Wheat other Pluses & Oilseeds
9	***Eastern Rainfall Zone***	High Rainfall Zone	Entire Bhandara & Gadchiroli and parts of Chandrapur and Nagpur districts	Paddy, Gram, Lathyrus. Rb.Jowar Pulses and Oilseeds.

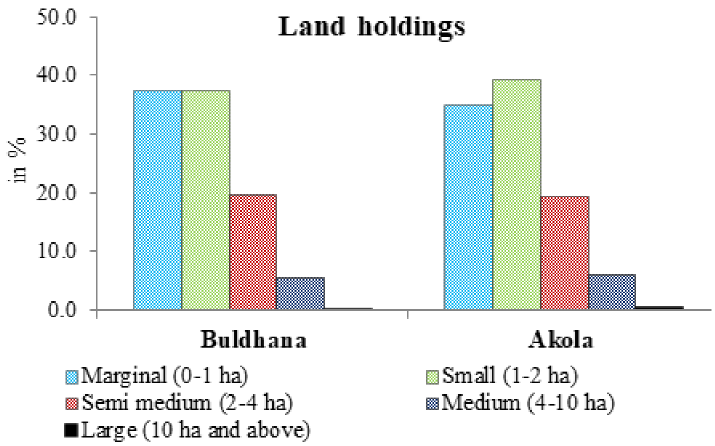
Maharashtra is one of the states where rainfall is satisfactory for agriculture. However, over the years dependence of groundwater has increased. The groundwater development i.e over-exploited, critical and semi-critical watersheds are highest in Nashik and Ahmednagar followed by Jalgaon, Solapur, Amravati, Sangli, Buldhana and Latur.

Increase in groundwater development has been attributed to growing of water intensive crops like sugarcane, banana, grapes, etc. Farmers are using energized pumps to withdraw groundwater for their irrigation. About 39.67 lakh agricultural pump sets are energized in Maharashtra.

4.2. Farmer profiles

From the methodology explained in the earlier chapter, we draw some results for identifying solar pump characteristics for a farmer in Buldhana.

The majority of farmers in Akola and Buldhana are marginal and small with up to 74% farmers having less than 2 ha of land according to the agricultural census 2010-11 as seen in Fig. 4.1. The proportion of marginal and small farmers is very high in the 2 districts. A majority of these farmers have land holdings less than 2 ha.



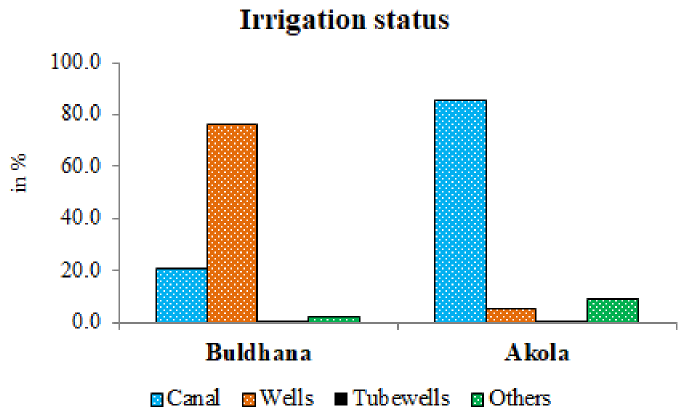


Figure 4.1: Landholdings and irrigation status in Buldhana and Akola

As can be seen in Fig. 4.1, farmers is Buldhana have open-wells to satisfy their irrigation needs. The agricultural census data lists canals as the irrigation source for 85% farmers in Akola and 20% in Buldhana. One of the criteria for the scheme is that the farmer needs to have a water source on their farms, hence open wells which are the next largest source, have been considered. Tube wells and open wells are the same for purposes of our framework.

To understand the water head, we used the Minor Irrigation Census 2006-07 data which suggests that in Buldhana, 90.6% of the open wells in 1366 villages have depth less than 20m.

In addition to land holdings, water source and water head, the cropping pattern needs to be known. From the crop statistics published for Maharashtra for the year 2015-16 we identify the maximum area under cultivation for the 2 districts. As seen in Fig. 4.2, soybean, cotton, pigeon pea, gram and maize are the major crops grown in these 2 districts. Soybean, cotton, pigeon pea and maize are kharif crops and in general farmers cycle through these crops over the years. Gram is a rabi crop.

In our interviews and surveys, we found that maize cultivation has reduced drastically this year due to infestation by wild animals. The animals feed on maize and farmers have stopped cultivating maize in the past few years for fear of destruction of the produce. Maize has thus not been included in the calculations

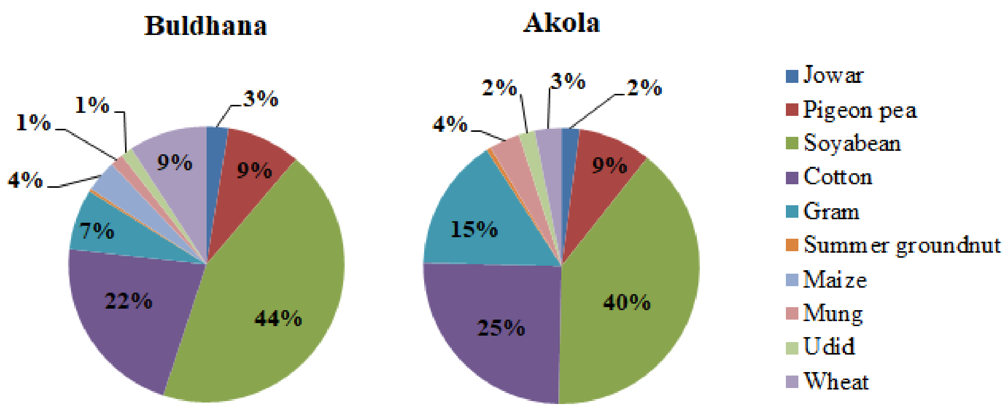


Figure 3.2: Crop statistics for Buldhana and Akola for 2015-16

From the above analysis, we arrive at a typical farmer's profile in Buldhana, as having 1 ha landholding, growing soybean, cotton, pigeon pea and gram, and irrigating from an open well with a depth of 20 m. For our purposes it doesn't matter too much if it is an open well or a bore-well.

4.3. SPV pump requirements for Buldhana

From the cropping pattern we calculated the month-wise daily water requirement for the crops using Et0, Re and Kc values shown in Tables 4.1 and 4.2, as discussed in chapter 3.

Table 4.1: Evapotranspiration rate and rainfall values

	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Et_0 (mm/day)	6.80	4.19	3.92	4.21	4.43	3.81	2.97	3.46	4.55	5.41	6.88	8.85
Monthly Rainfall (mm)	123.3	200.2	148.1	151	43.1	19.00	9.80	11.4	8.2	8.5	5.7	8.8

Table 4.2: Crop coefficient values

	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Cotton	0.70	0.80	1.10	1.25	0.90	0.80	0.70					
Soybean	0.5	1.15	1.15	0.5	0.90							
Gram						1.00	1.00	0.35	0.35			
Pigeon Pea		0.40	0.70	0.80	1.05	1.20	0.75					

The calculated monthly water requirement is shown in Fig. 4.3 for the typical crops. The maximum water requirement has been calculated by considering the crop with the maximum water requirement over a 1 ha land holding. This would be the maximum water required in any month, no matter what combination of the typical crops a farmer decides to grow. As can be seen the water requirement varies a lot through the year. In the peak summer months there is no water requirement for farmers growing these crops. The peak requirement occurs in the month of November at about 45,000 lts/day. The solar insolation is comparatively lower, hence the pump size has to be calculated based on this input. We calculate the pump size by considering the maximum water requirement, and solar insolation, in each month.

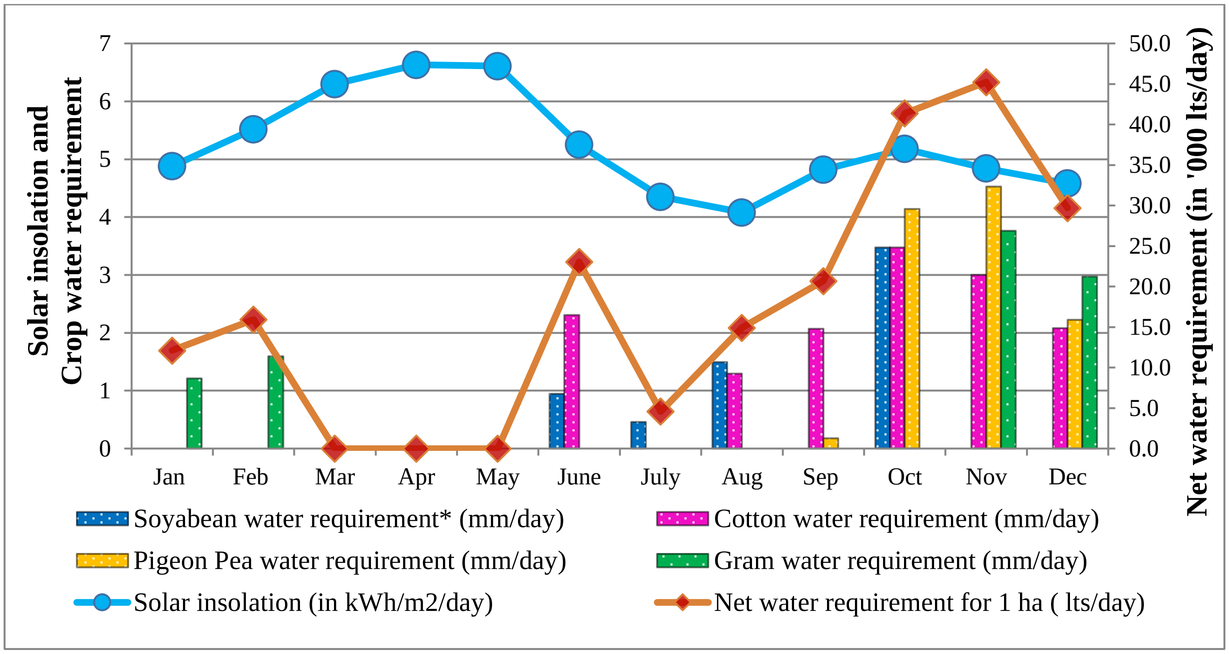


Figure 4.3: Crop water requirement for a 1 ha farmer in Buldhana

4.4. Solar pump characteristics

The water requirement calculated above is the water needed by the crop. However, some of it is lost in the fields and through evaporation. An efficiency factor called irrigation efficiency is introduced to account for these losses. The three most common irrigation methods, furrow, sprinkler and drip irrigation, are approximately 40%, 70% and 90% efficient, respectively. Solar pump capacities have been calculated for furrow irrigation since it is the most common method in Vidarbha, and common among small farmers everywhere. In addition, the upper limit of water requirement is calculated when we consider furrow. Drip and sprinkler method will have a reduced water requirement, but an increased head requirement since the water needs to be pumped through narrow pipes in drip or under pressure through the sprinklers.

Solar pump capacitates for a typical requirement have been calculated from the MNRE guidelines laid out for AC pumps under standard head and solar insolation condition. A typical 1 ha farmer using furrow irrigation with water depth of 20 m, would need a 3 HP pump designed for a 20 m head. With sprinkler she would require a 5 HP pump designed for a 50m head, and with drip she will require a 3 HP pump designed for a 35 m head. Table 4.3 shows the calculated ratings required for a few different heads, and 1 ha and 2 ha land holdings, using furrow irrigation.

Table 4.3: Solar pump requirement in HP for typical land holdings and water depths

Land Holdings \ Head (m)	10	20	50
1 ha	1	3	5
2 ha	3	5	>10

4.5. Ratification with field data

To test the framework developed, we conduct surveys of beneficiary farmers in Akola and Buldhana. We check for two things:

1. If the typical farmer profile developed is correct
2. If the pump types calculated using the framework make sense

We find that both these aspects are developed correctly by the framework. The crops grown and landholding sizes are definitely as per the district level cropping pattern and Agricultural census data. The water depths are somewhat in keeping with the Minor Irrigation census data. We do see a larger number of tube wells than predicted by the agricultural census data. One of the reasons could be that 6 of the tube wells belonged to a cluster of farmers in Chinchkhed village in Buldhana. It is also possible that the Ag census data is from 2010-11 and farmers do keep making new tube wells. The details are described in the following section.

19 beneficiary farmers were surveyed in the villages of Kalamba, Hatrun, Manabda, Borgaon Manju, Mirzapur and Nakhegaon, in Akola, and the villages of Bhongaon, Bhastan, Chinchkhed and Shegaon in Shegaon, Khamgaon blocks of Buldhana and Akola, Akot and Balapur blocks of Akola. They were selected to cover different pump sizes, types (AC, DC), and vendors.

Cotton, gram, pigeon pea and soybean are the predominant crops grown. Major source of irrigation is open wells ranging from 1.8 m to 18m depths, and the tube wells from 20 m to 66 m.

Table 4.4 shows the hours of pump usage by the farmers. Farmers who were using pumps to full capacity and had land holdings less than 5 acres are suspected to have large land holdings. In some cases, when farmers were asked regarding their total holdings they told us the land area that they had put on the forms for availing the solar pumps and not their actual holdings. Several pumps were under-used, in fact the only farmers, except for one, that were using the pumps to full capacity had more than 10 acres of land.

A 0.8 ha farmer growing cotton, soybean and pigeon pea, with an open well of 19 m depth, has a 5 HP pump. In the month of December, when water requirement is at a peak, he used the pump for only 10 minutes in a day. Similarly, a 2.6 ha farmer growing cotton, with an open well of 8.2 m depth has a 5 HP pump, and uses it for 3.5 hrs. A 6.5 ha farmer growing cotton, soybean and pigeon pea, with a tube well at 41m depth uses the pump for 4.5 hrs.

Table 4.4: Pump usage based on land holdings

Land holding	Less than 6 hours	Full capacity
0 – 5 acres	2	5*
5 – 10 acres	2	1
> 10 acres	2	7

*Suspected to have very large landholdings, much more than 10 acres

Table 4.5 captures some high level information for 24 beneficiary farmers. The data for six farmers from Nasik and Amravati, has also been presented here since they contribute to the scheme analysis, even though they have nothing to do with our framework.

Table 4.5: Farmer distribution over land holdings, distance from grid and irrigation source

Land holding		**Distance from grid(in m)**		**Irrigation source**	
Marginal (0-1ha)	1	*< 200*	8	*Well*	5
Small(1-2 ha)	6	*200-500*	1	*Tube well*	14
Semi-medium (2-4ha)	3	*500-1000*	6	*Farm pond*	2
Medium (4-10 ha)	8	*>1000*	9		
Large (10ha and above)	4				

Before this scheme, 8 farmers used diesel pumps and the others were largely rain fed. These farmers dug wells and tube wells so that they could apply for the scheme.

4.6. Net metering

In the course of the interviews it was observed that the farmers were not using the pumps to their full capacity, largely constrained by water availability. In our analysis which considers the water required, there were at least 3 months in which the farmer had no need for irrigation. This results in under-utilization of the solar pump. In such a scenario, a grid-connected pump could feed the energy generated into the grid.

Fig. 4.4 shows the average unused energy that can be fed to the grid through net-metering by the typical 1 ha farmer using a 3 HP AC pump by furrow irrigation. The farmer's cropping pattern is assumed to be soybean: cotton: pigeon pea: gram in the ratio 3: 1.67: 1: 1, in proportion to cropping in the district. The expected excess energy generation pattern overall in the district can be expected to follow this pattern. There is a lot of excess energy generated in Fig 4.4, this is because the 3 HP pump size was calculated allowing for a farmer to pump enough water for any combination of the 4 predominant crops on his 1 ha. So it could pump enough water for cotton on 1 ha in November, since it is the highest requirement of any crop in any month.

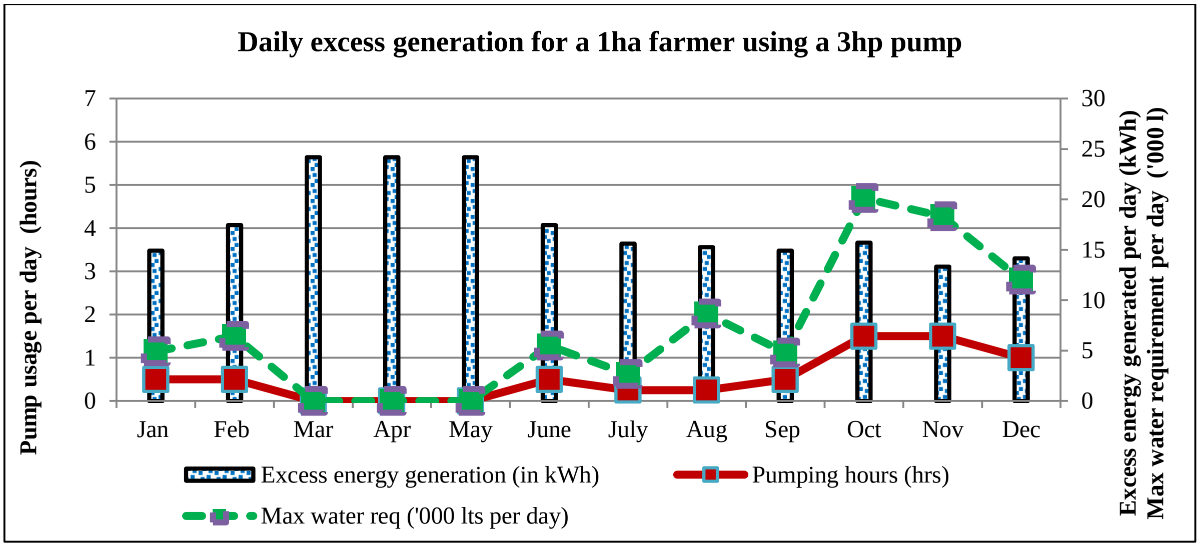


Figure 4.4: Excess energy generation, water requirement and pump usage by a 3HP solar pump for a typical 1 ha landholding in Akola

June shows a slight blip in pumping hours because crops planting may begin in June resulting in irrigation requirement if rainfall is not enough. This will be theoretical though, because it is unlikely that there is water in wells until there is rainfall. Hence June may have higher excess energy.

The option of feed-in-tariff can be explored for farmers such that they get lower tariffs during the non-usage months and higher tariffs for usage months, to promote water efficiency. This will hinder them from gaming the system. One of the concerns in net-metering is often that the farmers will choose to feed electricity back to the grid and not irrigate their lands for income. Keeping varying tariffs will keep the practice in check.

While this is a water deficit region, and most farmers would probably not overuse the water, this would be a very useful strategy in areas of high and year-round water usage such as sugarcane belts.

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CHAPTER 5: SOLAR PV SCHEME OUTCOMES

5.1. Farmers' response to the scheme

The surveys in Buldhana and Akola were conducted in December 2016. We interviewed MSEDCL officials in Akola, Buldhana and Yavatmal to understand the response to the scheme in different sub-divisions. In many places, the offices released newspaper articles on the scheme along with flex boards put up at different locations. We learnt that about 1481 applications had been received for the scheme in Akola alone out of which 935 qualified as per the criteria. Out of these only 206 farmers had paid the upfront cost required to process the order.

Discussions with MSEDCL officials and vendors suggested that many farmers were not convinced about the technology. In addition, forms were taken from many farmers who had no interest in buying the system, only because officials had been given targets to complete. We conducted informal discussions with a group of 8 farmers who had qualified as beneficiaries but did not pay after approval. We found that the farmers were:

- unsure of the post-maintenance period
- not agreeable to ceding their right to applying for an agricultural connection for 10 years, which was a condition of the scheme
- deterred by the cost in spite of the subsidy (minimum Rs.17,000 for a 3HP pump)
- afraid for the security of the system from wild animals and fellow villagers. Some of the wealthier farmers had put fencing around their systems to keep out animals. Two of the wealthiest farmers met had put an electric fence around it.

On the other hand the beneficiaries were happy due to daytime supply of water. In Maharashtra, as in many other states, farmers receive 8 hours of electricity per day. For 3 to 4 days in a week, the 8 hours are in the night. They had no complaints about the technology, but then the pumps were fairly new when the survey was conducted in December 2016.

5.2. Sizes of pumps distributed in the scheme

We find that small farmers, up to 4 ha of landholdings do not need pumps larger than 3 HP, and in fact could do with smaller pumps of even 1 HP. These small pumps are much more affordable for the small farmer. The cost could even be covered by the cost of diesel usage over 1 to 2 seasons for farmers using diesel.

5.2.1 Underutilization of distributed solar PV pumps

In general, we find that pumps are under-utilized when used for landholdings smaller than 4 ha. In addition, the paucity of water is a constraint, and many farmers cannot pump for more than 4-5 hours a day due to low water levels in the well. Vidarbha is a drought prone region and farmers are in general limited by the availability of water. According to the Agriculture census 2010-11, out of the 3,023,699 land holdings, 77.3% are rainfed. This shows up in our surveys of solar PV owners, as well as diesel pump and electric grid users in the region.

Out of the 19 farmers surveyed, in Buldhana and Akola, 8 explicitly stated they had plots greater than 4 ha but showed smaller plots in a family member's name, 5 additional farmers are suspected of having larger plots but did not say so. Most of these large farmers were using the pump all day. 4 out of the 5 farmers with landholding less than 4 ha were underutilizing their pumps.

Some farmers, who had tube wells, could use the pump for no longer than 10 to 20 minutes at a time with a wait for 0.5 – 1 hour for the bore to be recharged. A recharge test could be an additional requirement when setting up the pump on a tube well. A smaller pump would suffice in such cases.

The sizes of the distributed SPV pumps are larger than the requirement as calculated in Chapter 4 for farmers with less than 2 ha except for those using tube wells deeper than 50 m.

5.2.2 Diesel pump users in Buldhana

A survey of 5 diesel farmers in the villages of Talki Viro and Takli Hat in the same region indicated that they too are constrained by water and would have used the pumps longer if water had been available. See Table 5.1. Since the water available is less than the water required, the solar PV pumps that could replace the diesel pumps would be even smaller than the sizes indicated in Table 5.1.

Actual water usage in Table 5.1 has been estimated based on the number of waterings, and hours and days of pumping per watering as stated by the farmer, water depth of source, pressure head due to sprinkler or drip, and an assumed efficiency of 40%.

Table 5.1: Cropping and irrigation data of 5 diesel farmers surveyed

	Crops grown	Cropped Area (acre)	Water source	Water depth (m)	Water usage (mm)	Theoretical water requirement (mm)	Diesel spend (USD)	Irrigation method	Solar PV pump size for theoretical water requirement (HP)
1	Soybean	2.5	Well	10	69	196	39	Sprinkler	1.5
	Tur	0.5			256	338			
2	Cotton	3.5	Well, River	5	207	430	46	Furrow	2

3	Soybean	2.1	Well	10	93	196	31	Sprinkler	1.5
	Tur*	0.4			-	-			
4	Soybean	1.5	Well	10	75	196	77	Sprinkler	1.5
	Cotton	1.5			175	430			
5	Soybean	2.0	Well	13	75	196	77	Sprinkler	1.5

5.2.3 Grid connected pump users in Buldhana

Discussions with farmers using grid electricity for irrigation in Shegaon block of Buldhana, showed that the predominant crops, as expected, are cotton and soybean with some gram and pigeon pea. Intercropping of pigeon pea and gram with soybean is common. Soybean farmers commonly use sprinklers. Some cotton farmers use drip. Most farmers practice only kharif farming. Farmers can run their pumps for about 4 hours a day by which time the well runs out of water and needs to recharge. By October most water sources have dried up completely. Water usage is generally lower than the theoretical water requirement of the crop.

5.3. Main results from the study

As already mentioned above, smaller pumps, between 1 and 3 HP, could be more useful to the target group, and ensure a better response to the scheme. In fact, not having large pumps may discourage richer farmers from applying for the scheme.

The beneficiary farmers were happy with the scheme because of daytime supply. But the poor response to the scheme could be explained by the reasons given above and also, Maharashtra has good grid penetration with 3.8 million cultivators using electricity for irrigation, out of a total of 11 million cultivators. Hence the requirement for an alternative technology may not be high enough.

In Maharashtra, the plight of small and marginal farmers is worrisome with rising cases of suicides reported amongst them. Rising cost of production, uncertainty in weather leading to loss of produce and mounting debts puts them in a financial turmoil. Currently, the minimum upfront cost is Rs. 17,000 (for a 3 HP pump), which is too high for many marginal farmers.

One of the concerns of using SPV is with regard to groundwater extraction. In grid connected and diesel pumps, load-shedding and diesel prices could be used to prevent farmers from overusing water. But in case of SPV pumps, once installed, there is no cost to using a pump. It seems pertinent that regulatory structures with energy and water management are implemented. Grid connected solar pumps with net-metering could be a solution, especially in western and southern India, where there is good grid penetration. Net-metering calculations in section 4.6 show almost all of the energy being unused from March to July. While the districts analyzed here are water constrained, in other regions, an appropriate net-metering tariff in high-usage periods and lower otherwise, could encourage farmers to be water efficient.