Research Article

Indian Journal of Extension Education
Vol. 59, No. 3 (July–September), 2023, (126-131)

ISSN 0537-1996 (Print)
ISSN 2454-552X (Online)

Feasibility Analysis of Solar-Powered Tubewells in Arid and Sub-humid Regions of Rajasthan

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ARTICLE INFO

Keywords: Solar-powered pump, Capital investment, Economic feasibility, Bootstrap data development analysis, Rajasthan

http://doi.org/10.48165/IJEE.2023.59324

Conflict of Interest: None

ABSTRACT

The study analysed the investment and returns of installing solar-powered pumps, besides their economic feasibility and efficiency in arid and sub-humid regions of Rajasthan based on primary data collected for the year 2018-19. The feasibility analysis while accounting for different climatic regions of Rajasthan is imperative to examine since it influences the depth of water table and required power to extract groundwater which would, affect economic feasibility of pumps. Only subsidised investment in solar-powered tubewells was found to be economically feasible in both regions. The efficiencies of solar-irrigated farms and savings in cost after installing solar-powered pumps were found to be higher for sub-humid region, which may be attributed to better utilisation of solar pumps, cultivation of high-value vegetables and adoption of improved technologies. The major constraint faced by farmers in adoption of solar-powered pumps in arid region was found to be their non-functioning in higher water table situations, while in sub-humid region, it was a high initial investment. Hence, there is need to have custom-made policies according to climatic regions of the country and to increase awareness regarding benefits of adoption of advanced technologies and high-value crops which can complement the benefits of adoption of solar-powered pumps.

INTRODUCTION

Since the 1970s, India's policy focus on achieving food self-sufficiency led to liberalised energy policies for the agriculture sector *viz.*, elimination of metering, introduction of flat electricity tariffs and then subsequently free electricity and subsidised diesel supply to agriculture. This has led to indiscriminate extraction of groundwater in the country led by electricity (76%) and diesel-powered tubewells (22%). Central Ground Water Board has estimated 14 per cent of its assessment units as 'over-exploited' in India (GoI, 2022). India has been categorised as the world's largest user of groundwater and out of the total extraction, 87 per cent is utilised for irrigation purposes in the country. However, these liberalised policies have created a water-food-energy nexus in India where food security has been achieved at the cost of groundwater, energy and environmental sustainability (Mukherji, 2017; Yashodha et al., 2021; Mukherjee et al., 2022; Kaur & Sharma, 2022).

Recognising this, *Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan Yojana* (PM-KUSUM) was launched in 2019 with a target to install 30.8 GW solar capacity by March 31, 2026. As on December 2022, around 5 lakh solar pumps have been

Received 20-06-2023; Accepted 30-06-2023

installed in the country (GoI, 2023). Solar pumps provide an emission-free power supply and can be available to farmers during the daytime too which helps in ensuring timely irrigation for the crops (Kishore et al., 2017; Kumar & Kandpal, 2007). Grid-connected solar pumps also provide an additional source of income to farmers. Thus, solar irrigation has the potential to make a substantial contribution towards enhancing access to irrigation and increasing farmers' income (Singh et al., 2017).

Rajasthan is one of the most attractive destinations to harness solar energy as it has the highest solar energy potential (142.31 GWp) among Indian states based on land availability and solar radiation (GoI, 2023). Rajasthan has a share of 21.7 per cent of the total cumulative solar pumps installed in the country as on Dec 2022. Several studies have estimated that solar-powered pumps have near-zero operational cost, have a long life and their use could raise the productivity of crops, increase farmers' income and they can also provide higher resilience to drought (Kishore et al., 2015; Kishore, 2004; Mukherji, 2007; Pramod et al., 2022). Some studies have estimated the economic feasibility of solar-powered pumps and found that only subsidised investment in solar-powered pumps generated impressive net present worth, benefit-cost ratio and internal rate of return, while it is not found feasible to invest in solar pumps without subsidy (KPMG, 2014; Singh et al., 2017; Gautam & Singh, 2020).

However, the feasibility analysis of solar pumps while accounting for the different climatic regions of Rajasthan has not been done which is very imperative to examine since it influences the depth of water table in any region and the power required by pump to extract the groundwater, which would, in turn, affect the economic feasibility of pumps. Therefore, the present study aims to analyse economic feasibility as well as efficiency of solar-irrigated farms for arid and sub-humid regions of Rajasthan, separately.

METHODOLOGY

To analyse the feasibility and efficiency of solar-irrigated farms, a multistage sampling framework was used to collect the primary data from arid and sub-humid climatic regions of Rajasthan. Three blocks were chosen purposively each from arid and sub-humid regions based on the criteria of adoption of improved technologies like solar pumps and micro-irrigation technologies. These blocks fall in the district of Jodhpur, Jaipur, and Alwar. Thus, primary data from 180 randomly selected farmers were collected from randomly selected village clusters from these blocks for the year 2018-19.

Tabular analysis was done to analyse the investment and returns of installation of solar-powered pumps. The returns of installation of a solar-powered pump over an electricity-powered pump are estimated by calculating the average savings in cost after the installation of a solar pump, which is the difference between the average total variable cost per ha for an electricity-powered pump and the average total variable cost per ha for a solar-powered pump. Thus, these savings in cost mainly comprise savings in maintenance and fuel (electricity/diesel) cost.

The economic feasibility of investing in solar-powered pumps was estimated with the help of net present worth (NPW), benefit-cost ratio (B:C) and internal rate of return (IRR). The net economic groundwater productivity of solar-irrigated farms was calculated by dividing the total value of crop output by the total cost of irrigation. It tells how much of the value of crop output is produced per unit of cost of irrigation. The efficiencies *viz.*, technical efficiency (TE), allocative efficiency (AE) and economic efficiency (EE) of solar-irrigated farms under variable returns to scale (VRS) assumption have been estimated by using the bootstrap data envelopment analysis (BDEA) approach, which provides accurate and reliable efficiency estimates after correcting biases present in traditional data envelopment analysis approach.

Gross return on irrigated land (Rs./ha) was used as the dependent variable to calculate the efficiency of irrigated land. The independent variables used in the TE model are- irrigation applied (m^3/ha), seed (kg/ha), fertilizers used (kg/ha), manure (kg/ha), labour (days/ha) and machine hours (hrs./ha). The prices of these independent variables were used for the EE model- irrigation charges (Rs./ha), seed prices (Rs./ha), fertilizer prices (Rs./ha), manure prices (Rs./ha), labour charges (Rs./ha) and machine charges (Rs./ha).

Garrett's ranking method was also used to rank the various constraints faced by farmers in the adoption of solar-powered pumps in the arid and sub-humid regions, separately.

RESULTS AND DISCUSSION

In the arid region, most of the sampled farmers belong to medium and large categories and the average size of landholdings was larger (9.4 ha). On the other hand, in the sub-humid region, most of the surveyed farmers belong to the small and semi-medium categories and the average size of landholding was comparatively smaller (2.8 ha). The major crops cultivated in the arid region were bajra, wheat, cumin, groundnut, mustard and cotton and 32.4 per cent of the cropped area was under high-value crops (Table 1). The farmers with both electricity and solar energy sources were found to have highest cropping intensity as expected and were practicing a diversified farming system. The farmers mentioned that while the solar pumps have provided them a flexibility to irrigate the crops during day time, but they (especially 3 HP pumps) are not useful to pump out the water from a deeper groundwater table. That might be the reason behind the farmers having only solar energy source going for lesser diversified cropping system with less water-requiring crops.

Farmers in the sub-humid region had mainly grown wheat, bajra, mustard, cotton, and cucumber and cabbage among vegetables with 44 per cent share of the cropped area under high-value crops. Farmers with electricity energy source were found to be having highest cropping intensity followed by farmers with both electricity and solar energy source. Farmers with both electricity as well as solar energy source were found to have cultivated more of high value vegetables like cucumber, tomato and cabbage, while farmers with only electricity energy source had grown mainly field crops like wheat, bajra, mustard and cotton.

Investment and returns of solar-powered tubewells

In arid region, all of the large category farmers had tubewell, while only 33 per cent of small and semi-medium farmers had

Table 1. Cropping pattern prevailing in arid and sub-humid regions of Rajasthan

Energy source	GCA (ha)	NCA (ha)	CI (%)	Share in GCA (%)							
				Bajra	Cotton	Wheat	Cumin	Mustard	Groundnut	Vegetables	Others
Arid region											
Electric	15.3	10.3	156.9	17.8	9.2	19.0	11.7	7.9	17.3	14.3	2.9
Electric + Solar	28.0	14.8	180.6	32.5	9.1	11.1	20.1	8.1	3.1	15.9	-
Solar	9.8	5.5	177.3	30.8	-	5.1	38.5	-	-	25.6	-
Total	15.2	9.4	169.4	21.9	9.1	17.2	14.5	9.7	14.2	11.6	1.8
Sub-humid region											
Electric	4.5	2.3	198.5	21.2	12.8	22.7	1.7	15.1	3.9	20.6	2.0
Electric + Solar	12.8	6.4	177.9	1.6	-	14.7	-	-	-	77.8	6.0
Solar	3.5	2.0	175.0	20.0	10.0	17.5	-	12.5	-	40.0	-
Total	5.4	2.8	191.9	20.4	12.6	21.9	1.1	12.9	2.5	25.3	3.4

Source: Authors' survey-based findings.

Note: GCA: Gross cropped area, NCA: Net cropped area, CI: Cropping intensity.

ownership of tubewell. 73.2 per cent of the farmers had electricity only while only 2.8 per cent had solar only as the energy source and 23.9 per cent had both electricity as well as a solar energised tubewells. While in sub-humid region, almost 77.8 per cent of the sampled farmers had tubewell. 68.6 per cent of the farmers had electricity only as the energy source while 5.7 per cent had solar only and 25.7 per cent had both electricity as well as a solar energy source. Farmers opined that electricity for agriculture-related work is not available round the clock in Rajasthan and having solar energy along with electricity benefits them by ensuring the availability of adequate and timely irrigation for their crops.

The average investment in the installation of solar-powered pumps and resulting returns (savings in cost over electricity-operated pumps) in both arid and sub-humid regions is given in Table 2. In the arid region, the average own investment per farm in solar tubewell installation was found to be Rs. 1.78 lakh and Rs. 2.12 lakh for 3 HP and 5 HP tubewells, respectively. While in the sub-humid region, it was Rs. 71,500 and Rs.1.34 lakh for 3 HP and 5 HP tubewells, respectively. Gautam & Singh (2020) also found the farmers' share in average cost of installation of tubewell in Jaipur district in the similar range. The higher total and own investment in solar pump installation in arid region may be attributed to larger landholdings and higher depth to the water table. The average subsidy on solar tubewells was found to be 86 and 64 per cent in arid region and 86 and 69 per cent in the sub-humid region for 3 HP and 5 HP tubewells, respectively. The farmers revealed that the average expected life of the solar system is 19-20 years in the arid region and 16-17 years in the sub-humid region.

The savings in cost (difference between the average variable cost for an electricity-powered pump and a solar-powered pump) due to the adoption of the solar-powered pump was found to be Rs. 15,955 per farm or Rs. 1,245 per ha for 3 HP pump and Rs. 25,295 per farm or Rs. 1,605 per ha for 5 HP pump in arid region. For sub-humid region, it was found to be Rs. 32,723 per farm or Rs. 8,555 per ha for 3 HP pump and Rs. 74,836 per farm or Rs. 9,614 per ha for 5 HP pump, which is comparatively higher than that in the arid region. It may be because most of the farmers had both electricity and solar energy source as solar alone can't be operated effectively due to the higher depth of water table in arid region. On the other hand, in the sub-humid region, comparatively, a larger number of farmers had only solar-powered pumps as solar can be operated effectively there. Though the average variable cost per ha was higher in the sub-humid region, but the average savings in cost after the adoption of solar pumps was found to be higher because of better utilisation of solar pumps coupled with the adoption of advanced technologies and cultivation of high-value agricultural crops. Singh et al., (2017) in their study also found the similar range of cost savings due to adoption of solar-powered pump, moreover, they also found that these savings in cost have been in fact higher over the diesel operated tubewells in comparison to savings over electricity operated tubewells.

Table 2. Average investment and returns of solar-powered tubewells

Particulars	Arid		Sub-humid	
	3 HP	5 HP	3 HP	5 HP
Average net cropped area (ha)	9.1	12.8	3.8	8.5
Average own investment per farm (Rs.)	1,77,500	2,12,000	71,500	1,33,500
Average own investment per ha (Rs./ha)	7,700	28,782	25,139	35,378
Average subsidy (%)	0.86	0.64	0.86	0.69
Average expected life (years)	19	20	16	17
Average savings in cost per farm (Rs.)	15,955	25,295	32,723	74,836
Average savings in cost per ha (Rs./ha)	1,245	1,605	8,555	9,614

Source: Authors' survey-based findings.

Table 3. Economic Feasibility of Solar-Powered Tubewells

Region	3 HP Pump				5 HP Pump			
	Subsidy	NPW	B:C	IRR (%)	Subsidy	NPW	B:C	IRR (%)
Arid	Without	-417507	0.3	-	Without	-520125	0.1	-
	60 %	-58578	0.8	-	60 %	-159314	0.4	-
	86 %	96957	2.1	15	75 %	69111	1.6	12
Sub-humid	Without	-274359	0.5	-	Without	-122831	0.7	-
	60 %	32070	1.2	2	60 %	381218	3.1	28
	86 %	164856	3.1	29	75 %	445815	4.9	51

Source: Authors' calculations.

Feasibility of solar-powered tubewells

The economic feasibility analysis of solar-operated tubewells showed that with 86 per cent of subsidies on investment, solar tubewells generated an NPW of Rs. 96957 for 3 HP pumps in arid region with a B:C ratio of 2.1 and an IRR of 15 per cent (Table 3). With 75 per cent of subsidy for 5 HP pumps, solar tubewells generated an NPW of Rs. 69111 with a B:C ratio of 1.6 and an IRR of 12 per cent. However, with a 60 per cent subsidy and without subsidies, investment in solar pumps was not found economically feasible for both 3 and 5 HP pumps in arid region.

In sub-humid region, 86 per cent subsidy on investment in 3 HP solar pump and 75 per cent subsidy on investment in 5 HP solar pump was found to be impressively economically feasible. With a 60 per cent subsidy also, 5 HP solar tubewells generated an impressive NPW of Rs. 381218, a B:C ratio of 3.1 and an IRR of 28 per cent. However, 3 HP solar tubewell with a 60 per cent subsidy generated a moderate NPW of Rs. 32070, B:C ratio of 1.2 and a poor IRR of 2 per cent. Further, as expected, without subsidies, investment in solar tubewells was not found economically feasible for both 3 and 5 HP pumps in sub-humid region too. Similar results were also reported by Singh et al., (2017) and Gautam & Singh (2020). In another study by KPMG (2014), IRR was found to be higher for the replacement of diesel pumps with solar pumps compared to the replacement of electricity pumps.

Economic productivity and efficiency of solar-irrigated farms

The net economic groundwater productivity was found to be 39.3 and 65.2 for 3 and 5 HP, respectively for sub-humid region (Table 4). However, net economic groundwater productivity was found to be poor as 10.1 for 3 HP and 4.9 for 5 HP solar pumps in arid region. It indicates that farmers in the sub-humid region were able to generate higher value of crop produce per unit of money spent on irrigation.

The above measure of groundwater irrigation productivity tells the productivity of farms with respect to only irrigation. Since irrigation as an input affects the marginal productivity of other inputs too *viz.*, fertilizer, manure, labour, *etc.*, it becomes imperative to analyse the overall efficiency of solar-irrigated farms in the regions. The average technical efficiency (TE) of the solar-irrigated farms in arid region was estimated to be 0.61 for 3 HP pump and 0.55 for 5 HP pump and the average economic efficiency (EE) was 0.43 and 0.42 for 3 and 5 HP pump, respectively (Table 4). These efficiency scores denote that the farms are overusing inputs and there is a scope of reduction of input use without affecting the level of output. There exists significant cost inefficiency too in the farms in arid region. On the other hand, allocative efficiency (AE) was found to be comparatively higher *i.e.*, 0.71 and 0.72 for 3 and 5 HP pump, respectively.

The average TE of the solar-irrigated farms in sub-humid region was estimated to be 0.66 for 3 HP pump and 0.57 for 5 HP pump and the average EE was 0.46 and 0.44 for 3 and 5 HP pump, respectively. Here also, there is a scope of reducing input use without affecting the level of output. Here too, AE was found to be comparatively higher *i.e.*, 0.67 and 0.72 for 3 and 5 HP pump, respectively. Similar efficiency scores of solar-irrigated farms were reported by Kumar (2021) which were though lower than the efficiencies of farms having electric pumps but were higher than the efficiencies of farms having diesel-operated pumps. The low estimates of efficiencies reveal that the output is not being produced with the optimal combinations of inputs, given their respective prices. The efficiencies of solar-powered farms in sub-humid region were found to be higher than that in the arid region. As explained above, the higher efficiencies in sub-humid region may be attributed to the cultivation of high-value vegetables and the adoption of improved agricultural technologies.

Table 4. Net economic groundwater productivity and efficiency of solar-irrigated farms

Region	3 HP pump				5 HP pump			
	Net economic groundwater productivity	Technical efficiency	Allocative efficiency	Economic efficiency	Net economic groundwater productivity	Technical efficiency	Allocative efficiency	Economic efficiency
Arid	10.1	0.61	0.71	0.43	4.9	0.55	0.72	0.42
Sub-humid	39.3	0.66	0.67	0.46	65.2	0.57	0.72	0.44

Source: Authors' calculations.

Table 5. Constraints to the adoption of solar-powered pump

Rank	Arid	Garrett score	Sub-humid	Garrett score
1	Doesn't work as higher water table	71.7	High initial investment	72.6
2	Non-availability of subsidy for more than > 5 HP	68.2	Small land holding	68.3
3	High initial investment	62.7	Doesn't work the whole year	62.4
4	Lottery-based subsidy provision	60.0	Inadequate subsidy and difficulty in getting it	60.1
5	High fragmentation of holding	56.0	Lack of capital to cover whole land holding	52.4
6	Diggi is required for subsidy but land is less	52.6	High fragmentation of holding	50.4
7	Doesn't work the whole year	52.0	Delay in supply of system	48.2
8	Inadequate subsidy and difficulty in getting it	47.4	Poor off-farm income	47.8
9	Delay in sanction of loan	44.5	Delay in sanction of loan	46.6
10	Inadequate loan	36.3	Lack of demonstration in KVK/Agri. Dept.	40.5

Source: Authors' survey-based findings.

Constraints to the adoption of solar-powered pump

Garrett's ranking method was used to rank the various constraints faced by farmers in the adoption of solar-powered pumps in both arid and sub-humid regions (Table 5). For arid region, the highest ranked constraint was found to be its non-functioning in higher water table situations. Because of this reason, farmers were found to be using electricity-powered pumps to extract the groundwater and collect it in diggi (water storage structure) while solar energy is used for pumping the water from diggi to the fields.The next highest ranked constraints were found to be the non-availability of subsidy for more than 5 HP pump and high initial investment. These constraints are followed by lottery-based subsidy provision, high fragmentation of landholding, requirement of diggi for subsidy but the constraint of land, its non-functioning round the year, inadequate subsidy and difficulty in getting it, delay in sanction of loan and inadequate loan amount.

Whereas for sub-humid region, the highest ranked constraint in the adoption of solar-powered pumps was found to be high initial investment followed by small landholding, and its non-functioning round the year. These constraints are followed by inadequate subsidy and difficulty in getting it, lack of capital to cover whole landholding, high fragmentation of holding, delay in supply of system, poor off-farm income, delay in sanction of loan and lack of demonstration in Krishi Vigyan Kendra (KVK)/ Agriculture Department. The small size of landholding and lack of ability of solar pumps to work for the whole year were also identified as constraints to the adoption of solar pumps in past studies *viz.* Kumar (2021) and Singh et al., (2017). High initial investment as a major constraint to the adoption of solar pump was also reported by Choudhary et al., (2022).

CONCLUSION

The study has reported significant benefits of the installation of a solar-powered pump while its economic feasibility is considerably dependent on the provision of subsidy. Thus, there is a need to expand the installation of subsidised solar pumps among the small and marginal farmers too where the adoption is still poor. Since the major constraint in the adoption of solar-powered pump in arid region is deeper water table, there is a need to increase the capacity of solar pumps. The custom-made policies according to the climatic regions of the country might be more beneficial to have a sustainable use of groundwater resources. There is a need to increase awareness, especially among the farmers in the arid region regarding the benefits of the adoption of advanced technologies and high-value crops which can complement the benefits of adoption of solar-powered pumps.

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