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What Determines the Adoption of Solar-Powered Irrigation Pumps in India? An Analysis of Macro and Micro-Level Data

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ABSTRACT

The climate-friendly solar-powered irrigation pump is expected to reduce the exploitation of groundwater, save electricity costs, and increase income for farmers. It is also expected to reduce global warming by reducing CO_2 emissions, etc. Therefore, solar-powered irrigation pumps have been promoted with an attractive subsidy scheme by the government of India. Though the adoption of solar pumps has been increasing at a faster pace in recent years, the intensity of adoption of such pumps is not appreciable in many states in India. Since the adoption of solar pumps is still in a nascent stage, an attempt has been made in this study to find out the determinants of the adoption of solar pumps using both macro and micro-level data. While the macro-level analysis was carried out using the data of 17 major states, the micro-level analysis was carried out using survey data collected from 304 sample farmers belonging to four districts of Tamil Nadu. The multiple regression analysis carried out covering data from major states shows that the electricity tariff rate influences the adoption of solar pumps positively and significantly, while the share of the non-foodgrains area to the cropped area determines its adoption negatively and significantly. The logit regression results estimated by using field survey data suggest that the education of the farmer, cropping intensity, and farm size are more likely to influence the adoption of solar irrigation pumps.

Keywords: Cropping intensity; farm size; groundwater; irrigation; solar irrigation pump

JEL codes: Q12, Q16, Q25, Q41

I

INTRODUCTION

Groundwater became a dominant source of irrigation water since the mid-1980s in India. From less than 6 million hectares (mha) in 1950-51, the area under groundwater irrigation increased to 48 mha in 2019-20, which is over two-thirds of India's net irrigated area. Groundwater irrigation provides many added benefits to farmers as compared to other sources of irrigation. Therefore, over the last 50 years, Indian farmers have pumped massive investment into groundwater structures, which is estimated to be in the order of US$ 12 billion (Shah *et al.*, 2006). Besides increasing cropping intensity, productivity, and production of crops, groundwater irrigation also helps to enhance the wage rate and employment opportunities for agricultural labourers as well as to reduce rural poverty (Narayanamoorthy, 2001; Narayanamoorthy & Deshpande, 2003). While the positive benefits of groundwater irrigation are well known, the over-exploitation of groundwater of late has resulted in depletion of the water table, salinization, and quality deterioration in different parts of the country (Narayanamoorthy, 2010; 2015; 2022).

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With the expansion of groundwater-irrigated area, many changes have taken place in the power sector of India as there is a close nexus between groundwater irrigation and electrical energy consumption. This is evident from the energisation of pumpsets which has increased from 5.13 lakhs in 1965-66 to 217.99 lakhs in 2019-20. To woo the farmers, many states have introduced a flat-rate tariff system or free electricity for the agricultural sector, which has increased the consumption of electricity substantially. For instance, at the all-India level, the electricity required to create one hectare of groundwater irrigated area has increased from about 376 kWh in 1970-71 to about 4,618 kWh in 2018-19. The introduction of a flat-rate tariff system or free electricity has prompted heavy exploitation of groundwater (Kumar, 2005). As a result, not only the water level has gone down drastically in most of the regions but also resulted in an increased requirement of electricity to pump-out per unit of water from wells (Shah, 1993; CGWB, 2021). The recent data published by the Central Groundwater Board shows that out of the total 6965 blocks assessed in India, the groundwater level in 2529 blocks is in precarious condition (CGWB, 2021).

The solar-powered irrigation pump (SIP) is expected to help reduce the exploitation of groundwater, save electricity consumption and its costs, increase income for farmers, reduce global warming by reducing CO_2 emission, etc. Therefore, to control the over-exploitation of groundwater and reduce the consumption of electricity, solar-powered irrigation pumps have been promoted with an attractive subsidy scheme. For instance, a very ambitious scheme namely PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) was introduced in 2019 with a budget of Rs. 34,422 crores for installation of SIP aggregating 25.75 GW capacity of solar power. PM-KUSUM aims at "ensuring energy security for farmers in India, along with honouring India's commitment to increase the share of installed capacity of electric power from non-fossil-fuel sources to 40% by 2030 as part of Intended Nationally Determined Contributions (INDCs)" (https://pmkusum.mnre.gov.in). As a result of efforts taken by the centre and state governments, the number of SIP installed has increased from a mere 7,148 in 2008-09 to 3,49,781 in 2021-22 (Shah, *et al.*, 2017; CSE, 2019).

After the introduction of solar-powered irrigation pumps in India, a few studies have been carried out covering different aspects. Some studies have focused on the aspect of promoting solar power as a remunerative crop (Shah *et al.*, 2017), while others have analysed Karnataka's solar pumps scheme of 'Surya Raitha' (Shah, *et al.*, 2014; Durga, *et al.*, 2021). Studies have also analysed the policy aspects including the problems associated with the solar pumpsets (Mishra, *et al.*, 2016; Nathan, 2014; Bassi, 2015; Sahasranaman, *et al.*, 2021). In the context of scaling up demand-side management, Sreedharan, *et al.*, (2020) have used multi-stakeholder cost-benefit regulatory frameworks for studying the solar pumping programmes. Though the solar irrigation pump was introduced in India sometime during 1993 with the support of the Ministry of New and Renewable Energy (MNRE), Government of India, the progress in the adoption of such pump was very low till 2014-15. The dedicated scheme to promote solar pumps for drinking water and irrigation was started as part of the Jawaharlal Nehru National Solar Mission (JNNSM) by the Government of India. The introduction of PM-KUSUM with a larger budget and an attractive subsidy in 2019 has helped to increase the adoption of solar irrigation pumps in different states. However, even after providing attractive subsidies up to 90 percent of the capital cost, the total installation of solar pumps as of 2021-22 was only 3,49,781, which comes to just 1.60 pumps per 1000 hectares of cropped area in India. While the adoption level of solar pumps is very high in a few states, the same is very low in many states in India. Since the solar pump is promoted to provide assured energy supply and water security to farmers, enhance farmers' income, de-dieselize the farm sector, and reduce environmental pollution by reducing carbon emissions, it would be useful to study what determines the adoption of solar irrigation pumps so that appropriate policies can be formulated to increase the adoption of such irrigation pump. Though studies have analysed a few aspects of solar irrigation pumps, studies somehow have not analysed the factors determining the adoption of such climate-friendly pumps. Therefore, in this study, an attempt was made to find out the determinants of solar irrigation pumps using both micro and macro-level data.

II

STUDY AREA, DATA AND METHOD

Both the micro (survey data from Tamil Nadu) and macro-level (state-level data) data have been used for the analysis in this study. For the macro-level analysis, data from 17 major states was used. The available data from secondary sources shows that the adoption of solar pumps has increased from 7,148 in 2008-09 to 3,49,781 in 2021-22 at the all-India level. However, the adoption of such pumps is not the same across states, which varies from 45 in Assam to 75,748 in Rajasthan in 2021-22 for which the latest data is available. Therefore, using data from 17 major states of the year 2021-22, an attempt was made to study the determinants of solar irrigation pumps. Earlier studies have shown that the adoption of any new technology or input in agriculture is determined by many demographic and agro-economic factors. The solar irrigation pump is a new agricultural technology and therefore, its adoption will also be governed by the factors that determine the adoption of any other agricultural technology. Though the factors determining the adoption are not the same across all technologies or inputs in agriculture, we have considered eight independent variables that are expected to determine the adoption of solar irrigation pumps. The description of the variables used in the regression analysis is presented in Table 1. The factors such as the farmer's education, size of holding, the availability of irrigation, density of diesel pumps, percentage of villages electrified, cropping intensity, tariff rate of electricity supplied for agricultural purposes, percent of the non-foodgrains area to cropped area (proxy variable to reflect the commercialisation of agriculture), one way or the other, are expected to play an important role in the adoption of solar irrigation pumps. Keeping this in view, the following multiple regression model is constructed to study the determinants of the adoption of solar irrigation pumps at the state level:

$$SPI = a + b_1ASH + b_2CI + b_3\ ETD + b_4IRA + b_5NDP + b_6NVE + b_7NFA + b_8RLR + \mu \qquad (1)$$

Where,

SPI = Solar pump intensity (numbers per 1000 ha of cropped area)

ASH = Average size holding (in hectares)

CI = Cropping intensity (in percent)

ETD = Electricity Tariff Rate Dummy (0 = free electricity; 1 = others)

IRA = Irrigated area to cropped area (in percent)

NDP = Number of diesel pumps (in thousand)

NVE = Number of villages electrified (in percent)

NFA = Non-foodgrains area to gross cropped area (in percent)

RLR = Rural literacy rate (in percent)

a = Constant to be estimated

b = Regression coefficient to be estimated

μ = Error term

For the micro-level analysis, the primary data has been collected from four districts of Tamil Nadu state. Tamil Nadu is one of the important states in terms of using groundwater irrigation, accounting for about 62 percent of its total net irrigated area in 2019-20. The state also has a unique record of providing free electricity for irrigation pumps since 2006, which reportedly prompted the farmers to over-exploit the groundwater. Probably because of the depletion of the groundwater level, the requirement of electricity to create one hectare of groundwater irrigation is very high in Tamil Nadu (8,643 kWh) as compared to India’s average of about 4,618 kWh in 2018-19. The cumulative installation of solar pumps has also steadily increased in the state from 829 in 2008-09 to 6,646 in 2021-22, which is an increase of about 16 percent per annum. Because of these reasons, Tamil Nadu state becomes an obvious choice to carry out the micro-level analysis by using field survey data.

TABLE 1. DESCRIPTIVE STATISTICS OF THE VARIABLES USED IN THE STUDY

Variable	Description	Unit	Average	Standard deviation
ASH	Average size of holding	Hectare	1.34	0.87
CI	Cropping intensity	Percent	149.85	26.84
ETD	Electricity tariff dummy	1= paid electricity; 0= free electricity	0.76	0.44
IRA	Irrigated area to gross cropped area	Percent	52.23	26.86
NDP	Number of diesel pumps	in lakhs	6.42	8.28
NFA	Non-foodgrains area to gross cropped area	Percent	36.69	23.15
NVE	Number of villages electrified	Percent	62.25	28.43
RLR	Rural literacy rate	Percent	69.20	7.97
SPI	Solar pumps intensity per 1000 ha of gross cropped area	Hectare	2.29	2.90

Sources: Computed using Census of India, (2011); CEA (2021); MoAFW, (2021); GoI, (2023); MoSPI (2023).

A total of 1000 farmers have installed solar pumps using the government-supported schemes in Tamil Nadu state during 2019-20, but the distribution of solar pumps is highly varied across the districts. Therefore, the sample farmers have been selected from four districts namely Dindigul, Pudukkottai, Sivagangai, and Virudhunagar, where a total of 204 (19.40% of the state's total) farmers have installed the solar pumps to irrigate the crops during 2019-20. There are two main reasons for selecting these four districts for the study. First, these districts have an average level of adoption of solar pumps to the state's average. Second, these four districts also have relatively less coverage of irrigation.

From the selected districts, a total of 304 sample farmers have been selected for this study: 152 solar irrigation pumps using farmers and 152 electric irrigation pumps using farmers. These 152 solar pumps using sample farmers account for 15% of the total solar pump installed in Tamil Nadu. The farmers using solar pumps have been selected randomly using the list obtained from the Agricultural Engineering Department (the implementing agency in Tamil Nadu) of the respective districts. The electric irrigation pump-using farmers, who are located very close to the sample farmers of solar irrigation pump-using farmers, have been selected as the non-solar pump-using sample farmers to minimise the variations in the agro-ecological factors between the two categories of farmers. From each district, the sample farmers from the solar pump category have been selected by following the proportional sampling method. While the farmers who installed the solar pump during 2019-20 have been selected as the sample farmers, the field data from the sample farmers has been collected pertaining to the agriculture year 2021-22 (reference period of the data).

The relevant social and agro-economic data has been collected from the sample farmers using a pre-tested interview schedule.

To study the determinants of the adoption of solar irrigation pumps, a logit regression analysis has been carried out. It is a known fact that the adoption of new technology in agriculture is determined by many demographic and agro-economic factors, which also vary from crop to crop. Generally, logit regression is used to find out the effect of change in the independent variables on the probability of adoption of a technology when the participation fits into a dichotomous choice, essentially taking on the value of 1 for the adoption of a technology and zero for the non-adoption of a technology (Suresh, *et al.*, 2007; Devi, *et al.*, 2014 and Suvedi, *et al.*, 2017). Taking the data of the adopters and non-adopters of solar pumps, a logit regression has been estimated using the variables that are expected to influence the adoption or non-adoption of solar pumps. The reduced form of the binary logit regression model used for the estimate is given below:

$$Z = a + b_1AGE + b_2CI + b_3CMY + b_4EDU + b_5FAM + b_6FAS + b_7IRA + \mu \quad ....(2)$$

Where,

Z = dependent variable (1 for solar pump adopters & 0 for non-adopters)

AGE = Age of the farming head (in years)

CI = Cropping intensity (in percent)

CMY = Community of the farmer (0 for SC/ST and 1 for other farmers)

EDU = Education of the farming head (in years)

FAM = Family size (in numbers)

FAS = Farm size (in acres)

IRA = Irrigated area to cropped area (in percent)

a = Constant to be estimated

b = Regression coefficient to be estimated

μ = Error term

Of the seven independent variables included in the regression model, four are demographic variables (age, community, education and family size) and the remaining three (cropping intensity, farm size and irrigated area) are agro-economic variables. Many earlier studies have also used these variables while the studying adoption behaviour of the farmers in different farm technologies. Therefore, it is expected that these variables one way or the other would determine the adoption of solar irrigation pumps.

III

RESULTS AND DISCUSSION

Although the main focus of the study is to find out the determinants of the adoption of solar irrigation pumps both at the macro and micro-levels, it is useful to understand the trends in the adoption of such irrigation pumps across the states before analysing the determinants. As mentioned earlier, the adoption of solar pumps has increased from 7,148 in 2008-09 to 11,626 in 2013-14 and further to 3,49,781 in 2021-22 at the all-India level (see, Table 2). That is, the adoption of solar pumps registered a growth rate of just 8.44 percent per annum between 2008-09 and 2013-14, but the same registered a very high growth rate of 45.97 percent per annum between 2013-14 and 2021-22. The introduction of the PU-KUSUM scheme with attractive subsidies in 2019 has not only altered the adoption map of solar irrigation pumps but also increased the pace of adoption significantly.

The scenario of solar pumps' adoption at the state level is somewhat different from the national level picture. Till the year 2013-14, the level of adoption of solar pumps was less than 1000 in most of the states except for Punjab and Rajasthan, where the adoption was less than 5000. This has completely changed during 2021-22, where, the adoption of solar pumps was more than 5000 in most of the states except for Assam, Bihar, Kerala, and West Bengal. In fact, the adoption of solar pumps was more than 10,000 in 11 out of 17 major states considered for the study. While the highest adoption was found in Rajasthan (75,748) followed by Chhattisgarh (61,970), it was also varied in the range of 25,047 to 35,492 in states like Madhya Pradesh, Andhra Pradesh, Haryana and Uttar Pradesh. Not only has the adoption level increased substantially since 2013-14 in all the 17 states considered for the study, all these states have also registered a very impressive growth rate in the adoption of solar pumps between 2013-14 and 2021-22. Though the adoption of solar pumps has increased substantially, the level of adoption varies considerably across the states. It is difficult to gauge anything from the data discussed above as to why the adoption varies across the states. What are the factors controlling the adoption of solar pumps? We attempt to provide the answers to these two questions using the results estimated from a multiple regression in the following section.

TABLE 2. TRENDS IN ADOPTION OF SOLAR PUMPS BY MAJOR STATES IN INDIA, 2008-09 to 2021-22

States	2008-09	2013-14	2021-22	Annual Compound Growth Rate (percent)		
				2008-09 to 2013-14	2013-14 to 2021-22	2008-09 to 2021-22
1. Andhra Pradesh	613	613	34045	0	56.26	33.23
2. Assam	45	45	45	0	0	0
3. Bihar	139	139	2813	0.00	39.68	23.96
4. Chhattisgarh	93	240	61970	17.12	85.35	59.11
5. Gujarat	85	85	11981	0	73.29	42.40
6. Haryana	469	469	33901	0	60.90	35.77
7. Jharkhand	0	0	11387	---	---	---
8. Karnataka	532	551	7734	0.59	34.11	21.07
9. Kerala	810	810	818	0	0.11	0.07
10. Madhya Pradesh	87	87	25047	0.00	87.61	49.85
11. Maharashtra	228	239	13741	0.79	56.86	34.01
12. Orissa	8	56	10308	38.31	78.51	66.78
13. Punjab	1821	1857	11079	0.33	21.95	13.77
14. Rajasthan	283	4501	75748	58.58	36.85	49.07
15. Tamil Nadu	829	829	6646	0	26.02	16.03
16. Uttar Pradesh	751	575	35492	-4.35	58.10	31.71
17. West Bengal	48	48	653	0	33.65	20.50
All India	7148	11626	349781	8.44	45.97	32.03

Source: MoSPI (2023).

Factors Determining the Adoption of Solar Pumps – A State-Level Analysis:

As mentioned in the methodology section, we have carried out multiple regression analysis treating the number of solar pumps per thousands of hectares of cropped area (abbreviated as SPI in the analysis) as a dependent variable with eight independent variables (ASH, CI, ETD, IRA, NDP, NVE, NFA, and RLR) to find out the determinants of the adoption of the solar pumps covering data of 17 states. The multiple regression results are presented in Table 3. The value of R^2 and adjusted R^2 estimated from the regression model suggests that the model used for studying the determinants of solar pumps is a good fit. Among the eight independent variables, the electricity dummy (ETD) used as a proxy for electricity tariff rate and the number of villages electrified (percent) in each state (NVE) have positively and significantly influenced the adoption of solar pumps. We expected that the ETD would positively influence the adoption of solar pumps, which turned out to be correct from the regression results. The ETD coefficient suggests that the adoption of solar pumps increases in those states where electricity is supplied with some amount of tariff rate (either kWh-based tariff rate or flat-rate system) as compared to those states where electricity is provided free of cost for agricultural purposes. This is not a surprising result because the farmers normally get discouraged from adopting solar pumps when the electricity is available free of cost.

TABLE 3. FACTORS DETERMINING THE ADOPTION OF SOLAR IRRIGATION PUMP: REGRESSION RESULTS OF 17 STATES

Variable	Units	Coefficients	t-value
ASH	Hectares	-0.958	-1.067[ns]
CI	Percent	-0.026	-0.827[ns]
ETD	(1= paid electricity; 0 = free electricity)	5.316	3.286[b]
IRA	Percent	0.007	0.260[ns]
NDP	Lakh numbers	0.038	0.481[ns]
NFA	Percent	-0.074	-3.183[b]
NVE	Percent	0.139	3.600[a]
RLR	Percent	-0.206	-2.186[c]
Constant		10.893	1.804[d]
R^2		0.776	
Adjusted R^2		0.552	
D-W Statistics		2.306	
F-value		3.461	
N		17	

Sources: Computed using sources referred in Table 1.
Notes: a, b, c, and d are significant at 1, 5, 10, and 20 percent level respectively; ns-not significant

It was expected that wherever the number of villages electrified (denoted in percentage) is more, the adoption of solar pumps would be less due to the availability of electricity connection. But, against our expectation, the coefficient of NVE turned out to be positive and significant. Since the adoption of solar pumps in numbers is relatively higher in most states where close to 100 percent of villages are electrified, the NVE turned out to be positive. The coefficient of another variable that turned out to be positive in determining the adoption of solar pumps is the number of diesel pumps (NDP). The positive coefficient of NDP signals that the states, which use more diesel pumps are increasingly adopting solar pumps. This was expected because the recurring cost for operating diesel pumps is very high, whereas the energy cost is zero for the solar pumps.

On the other hand, variables such as the average size of holding (ASH), cropping intensity (CI), the share of non-foodgrains area to cropped area (NFA), and the rural literacy rate (RLR) have negatively impacted the adoption of solar pumps. Among these, the coefficients of NFA and RLR have significantly influenced the adoption. The negative coefficient of NFA suggests that wherever the share of non-foodgrains area to cropped area is higher, the adoption of solar pumps is less per thousand hectares of cropped area. This is plausible because the farmers from the agriculturally advanced states with a high level of area under commercial crops may prefer to use electric pumps to operate them round clock instead of solar pumps which can only be operated for about 8 hours per day with bright sunlight. It was expected that the increased rural literacy rate (RLR) would have a positive influence on the adoption of solar pumps. However, the coefficient of RLR turned out to be negative. This is because the adoption of solar pumps is very low in all those states where the rural literacy rate is very high. There is also a possibility that the supply of electricity free of cost in those states where the RLR is high may have subsumed the influence of literacy rate in positively determining the adoption of solar pumps. Though the value of coefficients of ASH and CI are not significant, they suggest that wherever the average size of holding and cropping intensity is higher, the adoption of solar pumps is lower. This is true because the adoption of level solar pumps is relatively lower in all those states where the average size of holding and cropping intensity are higher. On the whole, the state-wise analysis suggests that among the variables considered for the analysis, the electricity tariff dummy appears to influence the adoption of solar pumps positively and significantly.

Factors Determining the Adoption of Solar Pumps: A Field Data Analysis:

Though the state-wise macro analysis provides some insights into the factors that determine the adoption of solar pumps, the field survey-based data analysis can give a better understanding of the adoption behaviour of farmers. Therefore, as highlighted in the methodology section, a logit regression analysis has been carried out using the field survey data to find out the important factors influencing the adoption of solar pumps. Many studies have established that the early adopters of any new technology in agriculture are mostly young and educated farmers**.** Since SIP is relatively a new technology introduced to help the farmers, let us briefly understand the demographic and agro-economic characteristics of the farmers using SIP and EIP. To study the social and agro-economic characteristics of the sample farmers, we have considered seven parameters. They are the age of the farming head, education of the farming head, family size of the sample household, farmer’s community, farm size, irrigated area, and cropping intensity.

Table 4 presents the characteristics of the sample farmers using SIP and EIP. It was expected that the average age of the farming head would be relatively less among the farmers using SIP as compared to the farmers using EIP. As expected, the average age of the farming head was found to be significantly less the than counterpart category EIP. The education of the farmers was also relatively better among SIP-using farmers (9.36) as compared to their counterpart farmers EIP (7.89). Though SIP is expected to be more useful to the resource-poor and marginalised community farmers, the survey shows that over 99 percent of SIP-using sample farmers were from other backward communities (OBCs).

TABLE 4. DEMOGRAPHIC AND AGRO-ECONOMIC CHARACTERISTICS OF SOLAR AND ELECTRIC PUMP FARMERS

Particulars		Unit	Solar-Pumps		Electric-Pumps		Test of significance of mean value
			Average	SD	Average	SD	
1.	Age of farming head	Years	49.63	10.17	51.84	11.51	***
2.	Education of farming head	Years	9.36	5.07	7.89	4.17	ns
3.	Family size	Numbers	3.19	0.90	3.09	0.96	ns
4.	Farmers belonging to SC/ST	%	0.66	--	6.58	--	--
5.	Farmers belonging to OBC	%	99.34	--	93.42	--	--
6.	Farm size	Acres	3.47	1.63	3.83	2.11	***
7.	Irrigated area (GIA/GCA)	%	8.17	21.18	97.07	8.52	***
8.	Cropping Intensity	%	100.00	33.91	218.35	57.38	***

Notes: *** - Significant difference either at 1% or 5% or 10% level; ns – Not significant; SD - Standard deviation.
Source: Computed using field survey data.

The landholding size of the farmer is an important factor, which plays a crucial role in determining the adoption of any modern technology in farming. Farmers with a larger landholding generally have more resources and also have risk-bearing capacity as compared to the small size holders. As expected, the landholding size of SIP using farmers was relatively less than its counterpart EIP using farmers. The average landholding size of SIP farmers was 3.47 acres, whereas the same was 3.83 acres for EIP farmers; the difference between the two is statistically significant as well. Irrigation is an important factor for agriculture without which sustained growth in the agricultural sector is difficult to achieve. Besides providing assured yield for crops, irrigation facility allows the farmers to cultivate high-value crops as well as multiple cropping, both of which help increase the gross income per hectare. Similar to farm size, there is also a significant difference in the gross irrigated area between the two categories of farmers. As a result of the difference in irrigation coverage, there is also a difference in the cropping intensity (CI) between the two categories of farmers. The average CI comes to about 209 percent for SIP farmers, whereas the same comes to about 218 percent for EIP-using farmers.

TABLE 5. LOGIT REGRESSION OF THE SURVEY DATA: FACTORS INFLUENCING THE ADOPTION OF SOLAR PUMPS

Variables	Description of the variables	Coefficients	Z statistic
1. Age	Years	0.2803	1.09
2. Cropping intensity	Percent	-0.0393	-1.35[b]
3. Community	Dummy (1 for others; 0 for SC/ST)	0.6285	0.03
4. Education	Years	0.5694	1.30[b]
5. Family size	Numbers	0.3418	0.19
6. Farm size	Acres	-0.7942	-1.76[a]
7. Irrigated area (GIA/GCA)	Percent	-0.0835	-1.21
Constant		-1.7471	-0.07
Number of observations		304	
Log likelihood		-3.9365	
Pseudo R^2		0.9813	

Note: *a* and *b* are significant level at 1 and 10 percent respectively.
Source: Computed using field survey data.

After studying the sample farmers' characteristics, we have attempted to study the factors determining the adoption of solar irrigation pumps. This analysis is done to find out the most important factor that determines the adoption of solar irrigation pumps. For this, as mentioned in the methodology section, a logit regression was estimated by treating the adoption behaviour of the farmers (1 for adopters; 0 for non-adopters) as a dependent variable with seven independent variables consisting of social and agro-economic factors that are expected to determine the adoption of solar irrigation pumps. Table 5 presents the estimated logit regression results. It is evident from the table that out of the seven variables included in the regression model, four variables turned out to be positive in influencing the adoption of solar pumps and the remaining three variables turned out to be negative in influencing such adoption. However, among the variables that turned out to have a positive sign of coefficient, the education of the farming head is the only variable that significantly influenced the adoption of solar pumps. This means that the increased education of the farmer is likely to help increase the adoption of solar pumps significantly more than any other factors considered for the analysis. This was expected because the farmers' education plays a catalyst role in the adoption of any new technology in agriculture not only due to their increased awareness about technology but also due to increased outside contacts on both input and output markets. A large number of studies have proved how important is farmers' education in adopting a new technology in crop cultivation and thereby improving their income (Shetty, 1968 Tilak, 1993; Foster and Rosenzweig, 1995; Narayanamoorthy, 2000; Singh, 2000; Panda, 2015; Paltasingh, 2016; Agarwal and Agarwal, 2017).

As expected, two of the agro-economic factors namely cropping intensity (which is the ratio of gross cropped area to net cropped area referred to in percentage in the analysis) and farm size have negatively and significantly influenced the adoption of solar pumps. Both the cropping intensity and the farm size are relatively higher among the non-adopters of solar pumps (electric pump-using farmers) and therefore, the regression coefficients of these variables turned out to be negative. The negative coefficient of farm size implies that the farmers with a large holding are less likely to adopt the solar irrigation pump. This is plausible as most of the large farmers may already own more than one electric pump and therefore, they may not be willing to adopt the new climate-friendly irrigation pump unless the government puts restrictions on using electric pumps beyond certain hours. The negative coefficient of cropping intensity suggests that those farmers with a high level of cropping intensity are less likely to adopt solar irrigation pumps. This is because the farmers with high levels of cropping intensity must be following intensive crop cultivation with assured irrigation infrastructure, where the incentive for adopting solar pumps is very minimal. Looking at it differently, one can also infer from the negative coefficients of ASH and CI that those farmers having low levels of cropping intensity and farm size are more likely to adopt solar irrigation pumps. The other variable that turned out to have with negative coefficient (though not significant) is the percentage of irrigated area to cropped area. This means that the probability of adoption of solar pumps is less among the farmers with high coverage of irrigated area to cropped area. This was expected because solar pumps may not be needed for those farmers who already have high a percentage of irrigated area. On the whole, the logit regression results estimated using field survey data suggest that the education of the farmer, cropping intensity and farm size are more likely to influence the adoption of solar irrigation pumps.

IV

CONCLUSION AND POLICY POINTERS

Besides saving electricity, the climate-friendly solar-powered irrigation pump is expected to reduce the exploitation of groundwater, save electricity costs, and increase income for farmers, reduce global warming by reducing CO_2 emission, etc. Therefore, solar-powered irrigation pumps have been promoted with an attractive subsidy scheme by the government of India with the support of state governments. Though the adoption of solar pumps has increased since 2013-14, the level of adoption of such pumps per thousand hectares of cropped area is not appreciable in many states in India. In this study, an attempt has been made to find out the determinants of the adoption of solar pumps using both macro and micro-level data. The macro-level analysis carried out using the results estimated by a multiple regression covering data from 17 major states shows that the electricity tariff dummy is likely to positively and significantly influence the adoption of solar pumps, while the share of the non-foodgrains area to the cropped area appears to negatively and significantly determine its adoption.

The micro-level analysis carried out using logit regression by utilising sample survey data collected from 304 farmers covering four districts of Tamil Nadu shows that the farmers with increased education are likely to adopt solar irrigation pumps than the farmers with low levels of education. The logit regression results also suggest that the farmers with increased cropping intensity and large farm size are less likely to adopt solar irrigation pumps. Our in-depth inquiry conducted among the sample farmers using electric pumps reveals that the supply of electricity free of cost is one of the important reasons for the non-adoption of solar pumps. Similar to this, the macro-level analysis also reveals that the electricity tariff policy followed by the state is one of the important factors in determining the adoption of solar pumps. The adoption rate of solar pumps is relatively higher in those states where electricity is not supplied free of cost. Therefore, there is a need to tweak the tariff rate on electricity supplied for agricultural purposes to increase the adoption of solar pumps. Given the reduced income realised by the farmers, the policymakers can think of providing electricity supply free of cost up to certain hours per day or per month so that the adoption of solar pumps can be increased. Following the data periodically released by the Central Groundwater Board, in all those areas where groundwater exploitation is very high, the supply of electricity free of cost can be stopped fully to encourage the adoption of solar pumps.

The analysis of field survey data suggests that the education of the farmers plays a decisive role in increasing the adoption of solar pumps. Our field survey also reveals that the poor awareness about the usefulness of solar pumps including the incentive schemes available for the same acts as the stumbling block in adopting the solar pumps. Even the adopters have a poor understanding of the capital cost of the solar pumps and the level of subsidy available for the same. Therefore, since the adoption of solar pumps is still in the nascent stage in India, a well-conceived awareness programme with a big budgetary allocation needs to be formulated to spread the importance of solar pumps among every farming household in India. It appears from the analysis of field survey data that the farmers having high levels of irrigated area are less likely to adopt the solar pumps. To encourage the adoption of solar pumps among these farmers, the government can bring an act imposing a condition that all additional pumps to be installed by the farmers must be with solar power. No doubt that the increased adoption of solar pumps will not only help reduce the rising climate-associated disasters but also reduce the increased requirement of electricity including its costs.

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