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Economic and other Impacts of Solar-Powered Irrigation Pumps: An Empirical Study from Tamil Nadu

Alagappa University, Karaikudi, Tamil Nadu

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Economic and other Impacts of Solar-Powered Irrigation Pumps: An Empirical Study from Tamil Nadu

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The NABARD Research Study Series has been started to enable wider dissemination of research conducted/sponsored by NABARD on the thrust areas of Agriculture and Rural Development among researchers and stakeholders. The study titled 'Economic and other Impacts of Solar Powered Irrigation Pumps: An Empirical Study from Tamil Nadu' completed by Alagappa University, Karaikudi, Tamil Nadu is the forty-ninth in the series.

Groundwater is a dominant source of irrigation water in India. The share of groundwater irrigated area to the net irrigated area has increased from 29 percent to 60 percent during 1950-51 to 2021-22. However, the stage of ground water exploitation in some states is more than 100 percent. Hence, groundwater recharge in these states needs to be prioritized along with adoption of micro irrigation techniques. The adoption and use of Solar-powered Irrigation Pump (SIP) coupled with micro irrigation devices by farmers help in preventing exploitation of groundwater, saving of electricity consumption and thereby increase income of farmers and reduce global warming by reducing CO_2e emissions, etc.

This study aimed to understand the characteristics of farmers in Tamil Nadu who have installed solar powered irrigation pumps and estimate total reduction in CO_2 emission due to the installation of solar-powered irrigation pumps. The study also attempted to determine the net present worth and benefit-cost ratio for the investment made on the solar-powered irrigation pumps along with water and electricity saving achieved due to installation. The study was conducted in four districts namely Dindigul, Pudukkottai, Sivagangai and Virudhunagar of Tamil Nadu. A total of 304 sample farmers (152 solar pump-using farmers and 152 electric pump-using farmers) were selected from the four districts.

Hope this report would make a good reading and help in generating debate on issues of policy relevance. Let us know your feedback.

Kuldeep Singh
Chief General Manager
Department of Economic Analysis and Research

DISCLAIMER

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Executive Summary

To control the over-exploitation of groundwater and reduce the consumption of electricity, solar-powered irrigation pumps have been promoted with attractive subsidy schemes in India. Besides saving electricity consumption and its costs, the solar-powered irrigation pumps are expected to increase the income of farmers, reduce global warming by reducing CO2e emission, etc. Although the solar irrigation pumps (SIP) are expected to provide different benefits to the adopting farmers; their impact on cropping pattern, water saving, the productivity of crops, cost of cultivation, income from crops, etc., are not analysed in an in-depth manner using field survey data by the existing studies. An attempt was made in this study to find out the benefits of solar irrigation pumps including its economic viability. The summary of the study is presented below:

Objectives:

- To study the characteristics of the farmers who have installed solar-powered irrigation pumps.
- To study the cropping pattern of solar-powered irrigation pumps using farmers and the electric pumps using farmers.
- To estimate the water saving due to the installation of solar-powered irrigation pumps.
- To estimate the electricity-saving due to the installation of solar-powered irrigation pumps.
- To estimate the reduction in CO_2 emission due to the installation of solar-powered irrigation pumps.
- To assess the land lost in solar panels installation and its opportunity cost.
- To find out whether women in farm households are benefitted by the deployment of solar irrigation pumps.
- To study the cost of cultivation and income of farmers using solar-powered irrigation and electric pumps.
- To estimate the net present worth and benefit-cost ratio for the investment made on the solar-powered irrigation pumps, with and without subsidy.

Methodology:

The study was conducted in Tamil Nadu State covering four districts namely Dindigul, Pudukkottai, Sivagangai and Virudhunagar. A total of 304 sample farmers (152 solar pump-using farmers and 152 electric pump-using farmers) were selected from the four districts for this study. While the sample farmers using solar pumps were selected randomly, the electric pump-using farmers (located very close to the sample farmers of solar irrigation pump-using farmers) were selected as the non-solar pump-using sample farmers to minimise the variations in the agro-ecological factors between the two categories of farmers. The impact of solar irrigation pumps on different parameters was studied by making a comparative analysis between solar pump-using farmers and electric pump-using farmers. To evaluate the economic viability of solar pump investment, both the Net Present Worth (NPW) and the Benefit-Cost Ratio (BCR) were computed by utilising the discounted cash flow technique. The reference period of study was 2021-22.

Major Findings:

- The average gross irrigated area of the solar pump-using farmers before its installation was only 0.38 acre per household, which increased to 6.74 acres per household after the installation, which is an increase of about 18 times.

- The cropping pattern of solar pump-using farmers was changed completely after the installation of the solar pumps. Among the solar pump-using farmers, foodgrain crops accounted for about 89 percent of the cropped area before the installation of solar pumps, which reduced to about 29 percent after its installation.

- The average operating hours of pumps by the solar pump-using farmers was 6.85 hours per day, whereas the same was about 11.23 hours per day for the electric pump-using farmers. The difference between the two was about 39 percent.

- The total HP (horsepower) hours of water used was relatively less for almost all the crops cultivated by the solar pump-using farmers as compared to electric pump-using farmers. Among different crops, the highest water saving was found in coconut (42.60 percent) followed by sugarcane (33.08 percent). The solar pump farmers were also able to save a considerable amount of water in relatively more water-consuming crops like paddy, vegetables and maize.

- Farmers using solar pumps could save a substantial amount of electricity in their crops cultivation. The overall average calculated by taking into account all the crops considered for the analysis shows that the potential saving of electricity due to the adoption of solar pump was 783.68 kWh/acre. The electricity saving varied from about 1637 kWh/acre in sugarcane to about 45 kWh/acre in gingelly crop.

- The reduction of CO2e emissions due to the adoption of solar pumps was very high for different crops. The average reduction of CO2e emissions computed for all the crops was about 732 kg/acre, but it widely varied from crop to crop due to variations in the consumption of HP hours of water.

- The overall average cost of cultivation worked out for all the crops was a little higher (2.23 percent) for the solar pump-using farmers (Rs. 75,844/acre) as compared to the electric pump using farmers (Rs. 74,189/acre). Though no uniform pattern was observed in the cost of cultivation of different crops between the solar and electric pump-using farmers, the solar pump-using farmers spent relatively less cost for 6 out of 10 crops considered for the analysis.

- No uniform trend was observed in the productivity of crops cultivated by the two categories of farmers, but the solar pump-using farmers harvested higher yields per acre in important water-consuming crops namely paddy, coconut, sugarcane and vegetables. The productivity of paddy cultivated by solar pump-using farmers was about 3 percent higher over its counterpart electric pump-using farmers, while the same was higher by about 37 percent in vegetable crops.

- The average net income (in terms of cost A2+FL) computed for all the crops was about Rs. 1,08,434/acre for solar pump-using farmers, whereas the same was about Rs. 1,02,828/acre for electric pump-using farmers, a difference of about 5.45 percent. The net income from important crops like paddy, coconut, sugarcane, cotton and vegetable crops was relatively higher for the solar pump-using farmers as compared to the electric pump-using farmers. The net income realized by the solar pump-using farmers from paddy, which is one the largest crops cultivated by both the categories of farmers, was higher by about 4.34 percent over its electric pump using farmers.

- The capital cost for a 5 HP solar pump comes to Rs. 1,69,612 with subsidy, but it increases to Rs. 2,42,303 without subsidy. For 10 HP pumps, the capital cost increases from Rs. 3,07,741 with subsidy to Rs. 4,39,630 without subsidy. The farmers using solar pump received 70 percent of the capital cost as a subsidy.

- The Net Present Worth (NPW) of the investment estimated for one acre of holding with subsidy was marginally higher than without subsidy for all the HP size of pumps under different discount rates and life periods. At a 12% discount rate with 15-year life period, the NPW of solar pump investment for 5 HP pump was about Rs. 4,67,138/acre without subsidy, but the same was about Rs. 5,32,040/acre with subsidy. At a 12 percent discount rate, for 10 HP pumps with a 15-year of life period, the NPW was Rs. 3,65,625/acre without subsidy, but the same was about Rs. 4,83,383/acre with subsidy.

- The Benefit-Cost Ratio (BCR) also varies considerably when it was estimated with and without capital subsidy and with different life periods of solar pumps. The BCR of investment with subsidy was marginally higher than without subsidy options for all the size of pumps. For a 5 HP pumps, with a 15-year life period under without subsidy condition, the BCR was 1.58 at a 15% discount rate, but the same ratio was 1.75 under subsidy condition. For 10 HP pumps, with a 15-year life period, the BCR was 1.34 at a 15% discount rate, but it was 1.56 under subsidy condition. The value of BCR increases considerably when the estimate is made based on a 12% and 10% discount rate with a 25-year life period.

- The value of BCR increases considerably when the estimate was made considering the production cost and gross income realised from one hectare of land, instead of one acre of land. At a 10 percent discount rate with a 15-year life period under subsidy conditions, the estimated BCR was 1.89 for one acre of land, but the same increased to 2.25, when the estimate was made for one hectare of land. Under without subsidy condition too, the BCR value increased from 1.69 for one acre of land to 2.13 for one hectare of land.

- The year-wise computation of net present worth under different discount rates indicates that the farmers with one hectare of land could recover the entire capital cost of the solar pump from their income within two years when they use 5 HP and 7.5 HP pumps, whereas the 10 HP pumps owning farmers could recover the entire capital cost within three years, at a 10 percent discount rate under subsidy condition with 15-year life period.

Policy Recommendations:

- Though subsidy appears not to be a pre-requisite to improve the economic viability of solar pumps as per the study results, it is still needed to expand the widespread adoption of solar pumps particularly by the small and resource-poor farmers. Therefore, as demanded by the sample farmers, the adoption of solar pumps can be increased substantially, if 100 percent capital subsidy is given to the farmers. The subsidy can be phased out gradually when this climate-friendly irrigation technology covers an area adequate enough to expand subsequently on its own through the demonstration effect.

- The awareness about the subsidy schemes and the benefits of solar irrigation pumps is very poor among the farmers. The sample farmers were not even able to clearly tell the fixed capital cost of solar pumps and the subsidy that they received for the same. Therefore, both the central and state governments should make concerted efforts to increase awareness about solar pumps.

- A vast majority of the farmers using electric irrigation pumps have expressed that the availability of electricity free of cost is the main reason for not adopting the solar irrigation pump. The free of cost electricity supply also allows the farmers to exploit groundwater recklessly and use it inefficiently for crop cultivation. Therefore, the state governments that supply electricity free of cost can introduce judicious rationing of electricity supply for the farming sector to encourage the adoption of the solar irrigation pumps.

- Farmers have faced extraordinary delays in processing the application for sanctioning solar irrigation pump under the subsidy scheme. The multi-stakeholder survey conducted to understand the overall functioning of the solar pump scheme also reveals the same. Therefore, the central and state governments should fix a timeline for sanctioning the solar pumps from the date of receipt of the application so that the adoption can be increased speedily.

- By adopting drip method of irrigation, the solar irrigation pump using farmers are able to save water and increase productivity of crops. To encourage the adoption of the drip method of irrigation using solar irrigation pumps, innovative financing arrangements shall be provided to those farmers willing to adopt such a method of irrigation using solar pumps as recovery of investment is ensured within 2-3 years.

- As solar pump owners also use other water-efficient technologies such as micro-irrigation, the policymakers can think of introducing a new scheme integrating PMKSY-Per Drop More Crop and PM-KUSUM to accelerate the adoption of both micro-irrigation and the solar pumps.

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Abbreviations

BCR	Benefit-Cost Ratio
CACP	Commission for Agricultural Costs and Prices
CEA	Central Electricity Authority
CGWB	Central Groundwater Board
CI	Cropping Intensity
CO2e	Carbon Dioxide Equivalent
CSE	Centre for Science and Environment
EIP	Electric Irrigation Pumps
GCA	Gross Cropped Area
GIA	Gross Irrigated Area
GoI	Government of India
GoTN	Government of Tamil Nadu
GSM	Global System for Mobile
GW	Gigawatt
ha	hectare
HP	Horse Power
IIEC	International Institute for Energy Conservation
INDC	Intended Nationally Determined Contributions
kg	kilogram
kWh	kilowatt hour
mha	million hectares
MNRE	Ministry of New and Renewable Energy
MoSPI	Ministry of Statistics and Programme Implementation
NABARD	National Bank for Agriculture and Rural Development
NCF	National Commission on Farmers
NIA	Net Irrigated Area
NITI	National Institute for Transforming India
NPW	Net Present Worth
NSA	Net Sown Area
OBCs	Other Backward Communities
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan Yojana
Rs.	Indian rupees
SC	Scheduled Caste
SD	Standard Deviation
SIP	Solar-powered Irrigation Pumps
ST	Scheduled Tribes
VOP	Value of Output

CHAPTER **1**

Introduction

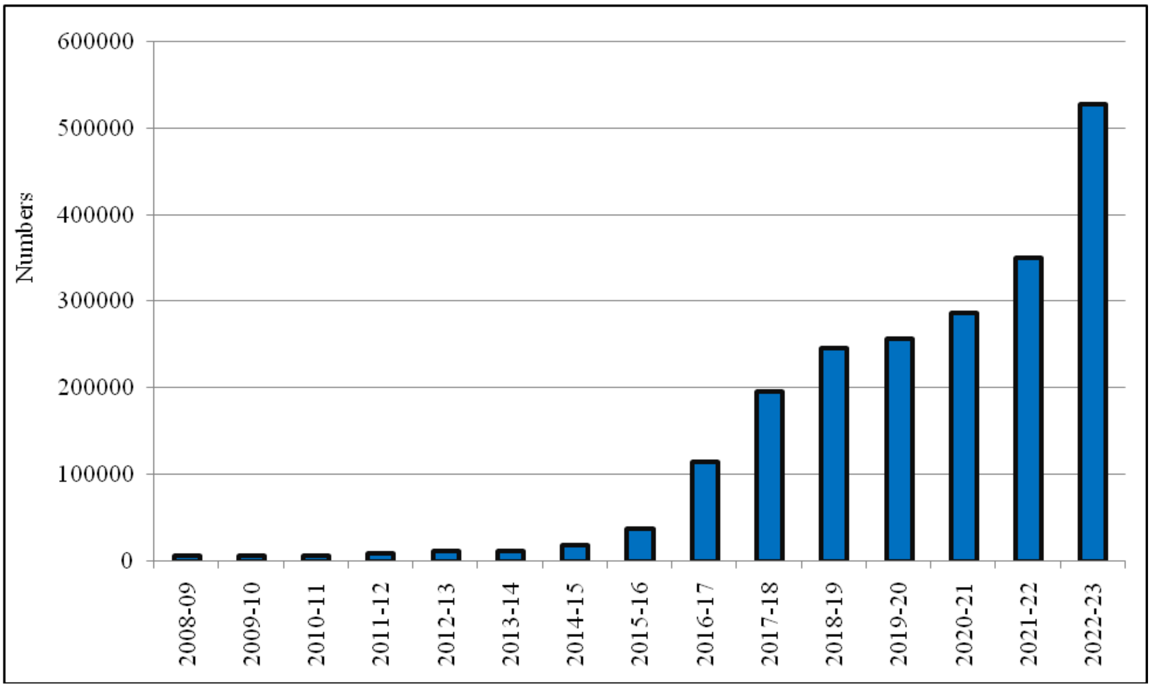
An Overview:

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. That is, the share of groundwater irrigated area to the net irrigated area has increased from 29 percent to 68 percent during the same period (MoAFW, 2022). 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 (Bardhan, 1973; Narayanamoorthy and Bhattarai, 2004) 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).

With the expansion of groundwater irrigated area, many changes have also taken place in the power sector of India as there is a close nexus between groundwater irrigation and 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 (CEA, 2021a). To woo the farmers, many states have introduced a flat-rate tariff system and 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 4618 kWh in 2018-19. The introduction of a flat-rate tariff system and 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 condition in 2529 blocks is in precarious condition (CGWB, 2021).

The Solar-powered Irrigation Pump (SIP) reportedly helps to reduce the exploitation of groundwater, save electricity consumption and its costs, increase income for farmers, reduce global warming by reducing CO2e emissions, etc. Though some consider the use of solar power as a threat to groundwater sustainability due to unregulated access to energy, this is not true always. Unlike electric pumps which can be operated 15-20 hours per day, the solar pumps can only be operated a maximum of 7-10 hours per day due to the non-availability of sunlight. Reduced operating hours of solar pumps ultimately help reducing the exploitation of groundwater. A few studies have shown that the adoption of solar pumps can reduce the exploitation of groundwater (Bassi, 2015; Shah, et al., 2018; CSE, 2019). Therefore, to control the over-exploitation of groundwater, reduce the consumption of electricity and phase out the diesel usage in irrigation pumps, solar-powered irrigation pumps have been promoted with attractive subsidy schemes by the centre and state governments. For instance, during 2014-15, under the National Solar Mission, the Government of India (through Ministry of New and Renewable Energy) announced a special scheme to install a minimum of 1,00,000 solar water pumps per year to reach a level of 10,00,000 pumps by 2020-21, with the support of State Nodal Agencies and the National Bank for Agriculture and Rural Development (NABARD). Many state governments have also introduced their own scheme with subsidy to promote the solar irrigation pump (Shah, et al., 2017; CSE, 2019; IIEC, 2022).

Figure 1.1: Installation of solar pumps in India, 2008-09 to 2021-23



In 2019, a very ambitious scheme namely PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) has been introduced 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)" (further details of the scheme can be seen from: https://www.india.gov.in/spotlight/pm-kusum-pradhan-mantri-kisan-urja-suraksha-evam-utthaan-mahabhiyan-scheme). As a result of effort taken by the centre and state governments, the number of SIP installed has increased from a mere 7,148 in 2008-09 to 5,26,859 in 2022-23 (see, **Figure 1.1**).

Given the benefits of solar-powered irrigation pumps, many studies have been carried out on various aspects. One of the biggest benefits of solar pump is that it helps to bring new irrigated area and therefore, a few studies have analysed its impact on cropping pattern, productivity of crops and income from crop cultivation (Kishore, et al., 2014 an 2017; Bassi, 2018; Gupta, 2019; Meena, et al., 2020). Since the solar pump is relatively a new technology, some studies have analysed their determinants including the adoption barriers (Kapoor and Dwivedi, 2017; Agarwal and Jain, 2018; Rathore, et al., 2018; Kumar, et al., 2019). While some have focused on the aspect of promoting solar power as a remunerative crop (Shah, et al., 2017), others have analysed Karnataka's solar pump 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 pumps (Mishra, et al., 2016; Nathan, 2014; Bassi, 2015; Sahasranaman, et al., 2021). The role of solar pump in groundwater exploitation including its management is also analysed by some studies (Shah et al., 2017 and 2018). 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. Comparative operational costs and benefits between diesel pumps and solar pumps have also been analysed by some studies (Kolhe, et al., 2002: Renjini et al., 2021; Hilarydoss, 2023). Solar pump involves a large amount of fixed investment and therefore, some studies have estimated the life cycle cost and benefit-cost ratio to find out the viability of such investment (Sahasranaman, et al., 2018; Pande, et al., 2003; Basi, 2015; Gautam and Singh, 2020; Mantri, et al., 2020; Sreedharan, et al., 2020; Verma, et al.,2020).

Despite the fact that the solar pump helps reducing the global warming by reducing the CO2e emission, studies have not attempted to estimate such reduction using survey data. Solar irrigation pumps save considerable amount of water and electricity, but studies have not analysed these benefits in detail. Though many have estimated the benefit-cost ratio for the investment made on solar pumps, studies are also seldom available on the economic viability of SIPs using properly designed discounted cash flow techniques covering field-level data collected from the farmers using solar pumps and electric pumps. The loss of land due to installation of solar panels and its opportunity cost and whether the deployment of solar pump anyway benefit the women who are the integral part of farming are also not studied so far. Solar-powered pump provide different kinds of benefits to the farmers and society, whereas electric pump provide different sets of benefits. Unless a comparative analysis is made using data collected from these two groups of farmers, it is difficult to judge whether the benefits generated from solar pumps outweigh the benefits of its counterpart electric pumps. Keeping this in view, an attempt has been made in this study to find out the benefits of solar irrigation pump including its economic viability, using field survey data collected from four different districts in Tamil Nadu state.

Objectives of the Study:

1. To study the characteristics of the farmers who have installed solar-powered irrigation pump.

2. To study the cropping pattern of solar-powered irrigation pumps using farmers and the electric pump using farmers.

3. To estimate the water saving due to the installation of solar-powered irrigation pump.

4. To estimate the electricity-saving due to the installation of solar-powered irrigation pump.

5. To estimate the reduction in CO2e emissions due to the installation of solar-powered irrigation pump.

6. To assess the land lost in solar panel installation and its opportunity cost.

7. To find out whether women in farm households are benefitted by the deployment of solar irrigation pump.

8. To study the cost of cultivation and income of farmers using solar-powered irrigation and electric pump.

9. To estimate the net present worth and benefit-cost ratio for the investment made on the solar-powered irrigation pump, with and without subsidy.

Study Area, Data and Method:

This study has been carried out using primary data collected from four districts of Tamil Nadu state. There are three plausible reasons for considering Tamil Nadu as a study area. First, Tamil Nadu is one of the important states in terms of using groundwater irrigation, which accounted for about 62 percent of its total net irrigated area in 2019-20. Second, the state also has a unique record of providing free electricity for irrigation pump 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 also very high in Tamil Nadu (8643 kwh) as compared to all India's average of about 4618 kWh in 2018-19. Third, 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 17 percent per annum (see, **Table 1.1**).[1] Because of these reasons, Tamil Nadu state becomes an obvious choice to carry out this study by using field survey data.

A total of 1000 farmers have installed solar pump using the government supported schemes in Tamil Nadu state during 2019-20, but the distribution of solar pumps is highly varied across the districts; from 05 in Perambalur district to 77 in Virudhunagar district. 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 solar pump 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 pump in relation to the state's average. Second, these four districts also have relatively less coverage of

[1] In many states, the number of solar pumps is exactly the same in 2008-09 and 2013-14. This stagnation in the adoption of solar pumps could be due to the absence of attractive subsidy schemes. This scenario has changed completely after the introduction of PM-KUSUM scheme, under which Tamil Nadu state provides 70-90% of capital subsidy for different categories of farmers.

irrigation (the irrigation and other agro-economic characteristics of the selected districts are explained in detail in chapter 2 of the report).

Table 1.1: Trends in adoption of solar pump by major states in India, 2008-09 to 2021-22

States	2008-09	2013-14	2021-23	Compound Annual Growth Rate (%)		
				2008-09 to 2013-14	2013-14 to 2022-23	2008-09 to 2022-23
Andhra Pradesh	613	613	34045	0	49.44	30.71
Bihar	139	139	2813	0.00	35.09	22.20
Chhattisgarh	93	240	119282	17.12	86.05	61.14
Gujarat	85	85	13981	0	66.58	40.52
Haryana	469	469	46260	0	58.27	35.81
Jharkhand	--	--	17231	--	--	--
Karnataka	532	551	7734	0.59	30.23	19.54
Madhya Pradesh	87	87	25138	0.00	76.23	45.90
Maharashtra	228	239	50623	0.79	70.84	43.36
Orissa	8	56	10856	38.31	69.34	61.75
Punjab	1821	1857	17446	0.33	25.11	16.26
Rajasthan	283	4501	113841	58.58	38.13	49.15
Tamil Nadu	829	829	8503	0	26.21	16.79
Uttar Pradesh	751	575	48695	-4.35	55.88	32.07
West Bengal	48	48	673	0	30.22	19.25
All India	7148	11626	526859	8.44	46.43	33.20

Source: MOSPI (*Statistical Year Book of India-various years) and* GOI *(Energy Statistics India-various years*).

As regards the sample selection, a total of 304 sample farmers have been selected for this study: 152 solar irrigation pump using farmers and 152 electric irrigation pump using farmers. These 152 solar pump using sample farmers account for 15% of the total solar pump installed in Tamil Nadu. The sample 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. The details of the sample selection from each district are presented in **Table 1.2**.

Table 1.2: Selection of sample farmers from four selected districts

Sl. No.	District's name	Total farmers installed solar pumps in 2019-20	Sample selected from		
			Solar pump farmers	Electric pump farmers	Total sample
1	Dindigul	47	35	35	70
2	Pudukkottai	40	30	30	60
3	Sivagangai	40	30	30	60
4	Virudhunagar	77	57	57	114
	Total	204	152	152	304

In addition to a sample survey, a multi-stakeholder consultation has also been done to understand the overall working condition of the solar pump including its promotional schemes. For this, a detailed consultation has been made with a total of 20 stakeholders; 2 sales executives and 3 Assistant Engineers working with the Agricultural Engineering Department from each selected district.

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 data has been collected from the sample farmers using a pre-tested interview schedule. The impact of solar irrigation pump on different parameters has been studied by making a comparative analysis between solar pump using farmers and electric pump using farmers. The impact analysis covers parameters such as area under cultivation (in acres), cropping pattern, area under irrigation (in acres), electricity use (in kWh), water use including its saving, hours of operation of solar/electric pumps, saving in electricity consumption (Rs/acre), productivity (quintal/acre) of major crops, cost of cultivation (Rs/acre), average net income (Rs/acre) from crops cultivation, cost-effectiveness of the solar pump investment (financial viability), etc.

Method followed for Determinants of Solar Pump Adoption:

As one of the objectives of the study is to find out the determinants of the adoption of solar irrigation pump, a logit regression analysis has been carried out to study the determinants. It is a known fact that the adoption of new technology in agriculture is determined by many social 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 dichotomous choice, essentially taking on value of 1 for 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 pump, a logit regression has been estimated using the variables that are expected to influence the adoption or non-adoption of solar pump. The reduced form of the logit regression model used for the estimate is given below:

$$Z = a + b_1AGE + b_2CI + b_3CMT + b_4EDU + b_5FAM + b_6FAS + b_7IRA + \mu \quad .... (1)$$

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)
CMT	= 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	= Gross 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 pump.

Method followed for Estimating CO2e Emissions:

Reduction in CO2e emissions is one of the biggest advantages of climate friendly solar irrigation pump. Therefore, an attempt is made to estimate the reduction in CO2e emissions based on the working hours of the pump. For estimating CO2e emissions based on the working hours of pump, a factor of 0.935 has been used, as the coal-fired power plant generates 0.935 kg of CO2e emissions for every unit of electricity generation in India (CEA, 2021).

Method followed for Estimating NPW and BCR:

One of the important issues pertaining to solar irrigation pump is whether its investment is economically viable for the farmers. This question arises because solar irrigation pump involves relatively large fixed investment. Past studies on this subject have conducted benefit-cost analysis without proper methodology, either relied on one or a few farmers adopting solar pumps or estimated output-input ratio without considering life period of solar pump, opportunity cost, depreciation factor, subsidy, etc. Therefore, in order to evaluate the economic viability of solar pump investment, both the Net Present worth (NPW) and the Benefit-Cost Ratio (BCR) have been computed by utilising the discounted cash flow technique.

The NPW is the difference between the sum of the present value of benefits and that of costs for a given life period of the solar pump and therefore, it collates the total benefits with the total costs covering items like capital and depreciation costs of the solar pump. In terms of the NPW criterion, the investment in solar pump can be treated as economically viable, if the present value of benefits is greater than the present value of costs. The BCR is also related to NPW as it is obtained just by dividing the present worth of the benefit stream with that of the cost stream. Generally, if the BCR is more than one, then the investment on that project can be considered economically viable. Obviously, a BCR greater than one implies that the NPW of the benefit stream is higher than that of the cost stream, which is also clearly detailed by Gittinger (1984). The NPW and BCR can be defined as follows:

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad \text{.. (2)}$$

$$BCR = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}} \quad \text{.. (3)}$$

Where,

B_t = benefit in year t

C_t = cost in year t

t = 1,2,3,…….n

n = project life in years
i = rate of interest (or the opportunity cost of the investment)

As reported earlier, fixed capital is required for installing solar pump and therefore, it is necessary to take into account the income and cost stream for the whole life span of solar pump investment. But, it is difficult to generate the actual cash flows for the entire life span of solar pump investment because of the absence of observed temporal information on benefits and costs. Therefore, certain realistic assumptions are employed to estimate the cash inflows and cash outflows for solar pump investment, which are:

1. The life period of the solar irrigation pump is considered as 5, 15 and 25 years, as the industry standard for most solar panels' life spans is 25 to 30 years.[2]

2. The cost of cultivation (production cost) and income (value of output) generated using the solar irrigation pump is assumed constant during the entire life period of the solar pump.

3. Differential rates of discount (interest rates) are considered to undertake the sensitivity of investment to the change in fixed capital cost. These are assumed at 10, 12 and 15 percent as alternatives representing various opportunity costs of capital.[3]

4. The crop cultivation technology is assumed constant for all crops during the entire life period of the solar irrigation pump.

Besides studying the determinants of the adoption of solar pump using logit regression and estimating the NPW and BCR, a comparison has been made between the solar pump using farmers and the electric pump using farmers in all the parameters relevant to the objectives of the study.

Organisation of the Study:

This study in total has four chapters including the introductory chapter. The profile of the study area, which includes demographic details, land use pattern, cropping pattern and irrigation coverage, is presented in chapter two. The core part of the study is chapter three which presents the detailed analysis about the impacts of solar-powered irrigation pump on various parameters including the economic viability using field survey data. The major findings and policy recommendations are presented in chapter four of the study report.

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[2] Though the industry standard for most solar panels' life spans is 25 to 30 years, it is not yet empirically proven in India, especially in solar pumps. Due to storms and cyclones, which are frequent visitors to Tamil Nadu, the panels may get affected, requiring complete replacement. Considering this, we have assumed a life period of 5 years as the worst scenario, 10 years as the medium scenario and the best possible scenario as 25 years for computing NPW and BCR.

[3] The data available from the Bank Bazzar website (www.bankbazzar.com) shows that the agriculture loan interest rate across various banks in India varies from 7.00-14.25 percent per annum (as of April 16, 2024), excluding the processing fee. Additionally, the farmers will be incurring a good amount of transaction costs to get the loan. Keeping this in view, discount rates are assumed as 10, 12 and 15 percent.

CHAPTER 2

Profile of the Study Area

Introduction:

As mentioned in the methodology section, this study has been carried out in four different districts of Tamil Nadu namely Dindigul, Pudukkottai, Sivagangai and Virudhunagar. It is always useful to understand the profile of the study area before analyzing the field data collected from the sample farmers. This chapter provides a bird-eye view of the study area, especially about the demographic details, irrigation details, land use pattern and cropping pattern. It is necessary to mention here that the boundaries of these four selected districts are connected to each other. Pudukkottai district's boundaries are connected with Sivagangai district, while the boundaries of Dindigul district and Virudhunagar district are connected with Sivagangai district. These districts are located in the southern-eastern part of Tamil Nadu. The general information on the state and the four districts is brought together in **Table 2.1** for the convenience of the readers.

Table 2.1: Demographic and other details of Tamil Nadu state and four selected districts, 2011-12

Sl. No	Particulars	Tamil Nadu State	Dindigul District	Pudukkottai District	Sivagangai District	Virudhunagar District
1	Total population	72147030	2159775	1618345	1339101	1942288
	Male	36137975	1080938	803188	668672	967709
	Female	36009055	1078837	815157	670429	974579
	Rural	37229590	1351735	1301991	926256	962062
	Urban	34917440	808040	316354	412845	980226
	Percent of rural population	51.60	62.59	80.45	69.17	49.54
2	Literacy rate percentage					
	Total	80.09	76.30	77.19	71.67	72.02
	Male	86.77	84.20	85.56	78.71	78.57
	Female	73.14	68.30	69.00	64.65	65.51
3	Percentage of main workers by categories	85.00	87.10	84.10	74.35	89.90
3a	Total cultivators	12.90	14.00	27.50	22.74	6.02
3b	Agricultural labourers	29.20	35.10	40.10	32.18	21.96
3c	Household industry workers	4.20	1.10	1.80	2.36	3.71
3d	Other workers	53.70	35.60	30.60	42.72	68.31
4	Total number of villages	12524	361	497	521	600
5	Total number of towns	529	23	8	12	9

Sources: GoTN (2022), *Season and Crop Report of Tamil Nadu: 2021-22* and GoTN (2022), *Statistical Hand Book of Tamil Nadu: 2020-21*.

Population details of the Study Area:

Tamil Nadu has historically been an agricultural state and is one of the leading states of agricultural producers in India. As per the census 2011, it has 32 districts with a total population of 7,21,47,030 in which male and female population are 3,61,37,975 and

3,60,09,055 respectively. Among the 32 districts, Dindigul, Pudukkottai, Sivagangai and Virudhunagar have been chosen for the detailed analytical study. Among the four selected districts, the population size is relatively larger in Dindigul followed by Virudhunagar, Pudukkottai and Sivagangai. Though the male-female population ratio is more or less the same among the four districts, the share of the rural population is not the same. Close to 52 percent of the state's population lives in rural areas, whereas the same percentage is a little higher in 3 out of 4 districts. Among the four districts where from the primary data has been collected for the study, Pudukkottai district has a relatively higher rural population (80.45 percent), while Virudhunagar has a very less rural population (49.54 percent).

Literacy Rate of the Study Area:

As per the census data of 2011, the state's average literacy rate was 80 percent, which means 80 out of 100 persons of age more than 6 years are literate. As expected, the male literacy rate is relatively higher than the female literacy rate in all four selected districts. Though Pudukkottai district has a higher percentage of rural population, the average literacy rate and the female literacy rate are higher in Pudukkottai district as compared to the remaining three districts selected for the study.

Table 2.1 also presents the percentage of total main workers for all four districts, which varies from about 74 percent in Sivagangai district to about 90 percent in Virudhunagar district. The cultivators and agricultural labours together accounted for 42 percent for the whole of Tamil Nadu state. But, this share is not the same across the districts. Notably, the cultivators account for a larger proportion of the total main workers in Pudukkottai and Sivagangai districts (around 22 percent), whereas the same is much less in the other two districts.

Table 2.2: Source-wise irrigated area of Tamil Nadu state and four selected districts, 2021-22

Sl. No.	Particulars	Tamil Nadu State	Dindigul District	Pudukkottai District	Sivagangai District	Virudhunagar District
1	Canal	683806 (23.34)	5073 (5.50)	1063 (0.86)	7.00 (0.01)	--
2	Tank	410214 (14.00)	4296 (4.66)	60710 (49.26)	54028 (70.43)	22926 (41.66)
3	Well	1830779 (62.49)	81514 (88.35)	61472 (49.88)	22675 (29.56)	32099 (58.34)
3a	Tube well/Bore well	545846 (18.63)	16494 (17.88)	47253 (38.34)	7901 (10.30)	209 (0.38)
3b	Open well	1284933 (43.86)	65020 (70.47)	14219 (11.54)	14774 (19.26)	31890 (57.96)
4	Others	4703 (0.16)	1378 (1.49)	--	--	--
5	NIA	2929502 (100.00)	92261 (100.00)	123245 (100.00)	76710 (100.00)	55025 (100.00)
6	GIA	3893816	96316	136661	77246	61264
7	% of NIA/NCA	59.68	41.90	85.18	68.69	39.53
8	% of GIA/GCA	61.34	42.30	85.83	68.74	41.85
9	Normal rainfall (mm)	990	917	858	874	767
10	Actual rainfall in 2021-22 (mm)	1401	1174	1123	1145	862

Notes: NIA – net irrigated area; GIA – gross irrigated area; Figures in brackets are percentages to NIA
Source: GoTN (2022), Season and Crop Report of Tamil Nadu: 2021-22.

Irrigation Development:

Irrigation is the paramount factor in determining the agricultural development, without which the growth of agriculture will be less in any given region. Therefore, in order to analyse the true nature in agriculture of the study area, it is essential to understand the irrigation facility before getting into the details of the land use pattern and cropping pattern.

As per the data published in the *Season and Crop Report* 2021-22 of Tamil Nadu state (GoTN, 2022), the average normal rainfall of Tamil Nadu is 990.4 mm and the same for the four selected districts varies from 767.2 mm in Virudhunagar district to 917.3 mm in Dindigul district. The actual rainfall received during the year 2021-22 was relatively higher than the normal rainfall in all four selected districts. It is to be mentioned here that unlike other states in India, Tamil Nadu receives its major share of rainfall through north-east monsoon which starts during October and ends in mid-January.

Besides a difference in rainfall level between the state and the districts selected for the study, one finds a lot of differences in their irrigation profile as well (see, **Table 2.2**). Among the three major sources of irrigation, groundwater is the major source of irrigation for the state, accounting for about 62 percent of the net irrigated area (NIA) during 2021-22. This is somewhat different from the selected districts, where it varied from about 88 percent in Dindigul to about 30 percent in Sivagangai. Similarly, canal source of irrigation accounted for close to one-fourth of the net irrigated area in the state, but it accounted for a very meager percent in all the four districts. Among the four districts, tank irrigation accounted for 70.43 percent in Sivagangai district, followed by Pudukkottai (49.26 percent) and Virudhunagar district (41.66 percent). With this understanding of the availability of irrigation, let us now study the land use pattern and cropping pattern of the selected districts.

Land Use Pattern of the Study Area:

Table 2.3 presents the land utilization pattern of Tamil Nadu state and the selected four districts for the year 2021-22. The total geographical area of Tamil Nadu is 130.33 lakh hectares (lha), of which majority of the areas are utilized for non-agricultural uses, i.e., (16.93 percent). Further, an area of 4.57 lha is not able to be used for the agricultural activities and remains as a barren land. Despite having a higher irrigation ratio, close to 19 lakh hectares (14.30 percent) are reported as permanent fallow land in the state which is a surprising trend. The net sown area of the state accounts for only about 38 percent of the geographical area, which is relatively low by any standard. Besides, the forest area has shrunken to less than one-fifth of the total geographical area of Tamil Nadu.

As expected, the land use pattern of the four selected districts is different from the one which is observed at the state level. While the proportion of NSA to the geographical area is very low in Sivagangai district (26.66 percent), it is found to be relatively higher in Dindigul district, though a little less than the state's average of 37.67 percent. The area under fallow is very high in all four districts, accounting for about 21 percent in Dindigul district to as high as 38 percent in Virudhunagar district. One needs to carry out a detailed study to find out why the proportion of permanent fallow is very high in the four selected districts as well as in the whole of Tamil Nadu.

Table 2.3: Land use pattern of Tamil Nadu state and four selected districts, 2021-22 (area in hectares)

Sl. No	Particulars	Tamil Nadu State	Dindigul District	Pudukkottai District	Sivagangai District	Virudhunagar District
1	Total geographical area	13033116 (100.00)	626664 (100.00)	466329 (100.00)	418900 (100.00)	424323 (100.00)
2	Forest	2156574.00 (16.55)	138923.00 (22.17)	23535.00 (5.00)	16533.07 (3.95)	26466.00 (6.24)
3	Land not available for cultivation a) Barren uncultivable land	457234.00 (3.51)	36210.00 (5.78)	9863.00 (2.12)	4699.27 (1.12)	4525.00 (1.07)
4	b) Land put to non-agricultural uses	2206190.00 (16.93)	67342.00 (10.75)	137204.00 (29.42)	122664.29 (29.28)	75036.00 (16.62)
5	Cultivable waste	346365.00 (2.66)	8219.00 (1.31)	9192.00 (1.97)	17676.64 (4.22)	9400.00 (2.22)
6	Permanent pastures and other grazing lands	107640.00 (0.83)	6946.00 (1.11)	3471.00 (0.74)	1367.45 (0.33)	804.00 (0.19)
7	Land under miscellaneous tree crops and groves not included in net area sown	186068.00 (1.43)	7057.00 (1.13)	15492.00 (3.32)	7569.86 (1.81)	2035.00 (0.48)
8	Current fallows	800453.00 (6.14)	9323.00 (1.49)	14228.00 (3.05)	4123.04 (0.98)	8403.00 (1.98)
9	Other fallows	1863651.00 (14.30)	132459.00 (21.14)	108641.00 (23.30)	132596.40 (31.65)	162982.00 (38.41)
10	Net cultivated area	4908941.00 (37.67)	220186.00 (35.14)	144691.00 (31.03)	111670.10 (26.66)	139197.00 (32.80)
11	Area cultivated more than once	1439199.00	7537.00	14532.00	710.09	7184.00
12	Gross cultivated area	6348140.00	227723.00	159223.00	112380.19	146381.00

Note: Figures in brackets are percentages of the respective total geographical area.
Sources: GoTN (2022), *Season and Crop Report of Tamil Nadu: 2021-22*.

Cropping Pattern of the Study Area:

Cropping pattern can reflect the nature of the development of agriculture in any given region. Therefore, we have made a brief attempt to understand the cropping pattern of the study area. **Table 2.4** shows the cropping pattern in the state and the selected four districts for the year 2021-22. It is clear that paddy is the major crop cultivated in Tamil Nadu, accounting for about 35 percent of the gross cultivated area. Maize, pulses, groundnut, coconut, fruits are the other important crops in Tamil Nadu occupying about eight to ten percent of the cropped area.

The selected four districts show a fairly diversified cropping pattern with paddy, maize, pulses, groundnut, coconut and fruits as major crops. However, paddy accounting for a much higher proportion in the net cropped area as compared to the state’s average (about 69-75 percent as against the state average of about 35 percent) in districts such as Pudukkottai and Sivagangai. Besides, paddy, coconut and fruit crops accounted for a considerable share of cropped area in all the districts. It appears that paddy crop is predominantly cultivated in those districts (Pudukkottai and Sivagangai) where tanks are the major source of irrigation. Non-paddy crops were mostly cultivated in those districts (Dindigul and Virudhunagar) where groundwater is the major source of irrigation used for cultivating crops. This varied cropping pattern is not unexpected because it generally varies from region to region due to various reasons.

Table 2.4: Cropping Pattern of Tamil Nadu state and four selected districts, 2021-22 (area in hectares)

Sl. No.	Crops	Tamil Nadu State	Dindigul District	Pudukkottai District	Sivagangai District	Virudhunagar District
1	Paddy	2217269 (34.93)	12750 (5.60)	109299 (68.65)	84041 (74.78)	28965 (19.79)
2	Maize	400076 (6.30)	27649 (12.14)	1766 (1.11)	40 (0.04)	34320 (23.45)
3	Jowar (Cholam)	397223 (6.26)	49090 (21.56)	22 (0.01)	33 (0.03)	13506 (9.23)
4	Ragi	74434 (1.17)	11 (0.005)	26 (0.02)	196 (0.17)	49 (0.03)
5	Pulses	802100 (12.64)	16443 (7.22)	4661 (2.93)	1799 (1.60)	7291 (4.98)
6	Sugarcane	147993 (2.33)	1991 (0.87)	1875 (1.18)	1873 (1.67)	1207 (0.82)
7	Groundnut	372399 (5.87)	5591 (2.46)	11452 (7.19)	2220 (1.98)	4561 (3.12)
8	Coconut	457717 (7.21)	29347 (12.89)	12044 (7.56)	7787 (6.93)	10055 (6.87)
9	Chilli	53173 (0.84)	1662 (0.73)	383 (0.24)	3619 (3.22)	1563 (1.07)
10	Total Fruits	401942 (6.33)	30787 (13.52)	10106 (6.35)	7403 (6.59)	7671 (5.24)
11	Others	1023814 (16.13)	52402 (23.01)	7589 (4.77)	3375 (3.00)	37193 (25.41)
12	Gross Cultivated Area	6348140 (100.00)	227723 (100.00)	159223 (100.00)	112386 (100.00)	146381 (100.00)

Note: Figures in brackets are percentages of the respective GCA.
Source: GoTN (2022), Season and Crop Report of Tamil Nadu 2021-22.

On the whole, the analysis on the profile of the study area shows that the districts selected for the study are somewhat different in terms of their agro-economic characteristics. However, groundwater is the major source of irrigation for the selected districts.

CHAPTER **3**

Economic and Other Impacts of Solar Irrigation Pumps: An Analysis of Field Data

Introduction:

Although a few studies have analysed the impact of SIPs on different parameters in different crop cultivation, its impact has not been studied using large sample data collected from different locations. This section presents the analysis of the economic and other impacts of Solar-Powered Irrigation Pump (SIP) using field survey data collected from four districts of Tamil Nadu.

Characteristics of SIP and EIP Farmers:

As highlighted in the methodology section, the sample farmers for this study have been selected from four different districts adjoining each other located in Tamil Nadu state. The adoption of any new technology or new method in agriculture is not only determined by economic factors but also by the social and personal characteristics of the farmers. 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 who are not having electricity connections for operating the electric pumps in India, let us first understand the household characteristics of the farmers using SIP and EIP before getting into the other objectives of the study.

To study the household characteristics of the sample farmers, we have considered five parameters, which are the age of the farming head, experience of the farming head, education of the farming head, family size and community of the farmers. **Table 3.1** presents the household 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 of EIPs. Similar to age, the farming experience of SIP using farmers was less as compared to the farmers who adopted SIP. For instance, the average farming experience of SIP using farmers was 20.44 years, whereas the same was 25.41 years for EIP using farmers. 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 SIPs are 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 was from other backward communities (OBCs). The lands are mostly owned by OBC farmers in the study areas and therefore, the dominance of these community farmers in the adoption of solar pumps was expected one. The age, experience and education of the SIP using farmers appear to suggest that the young farmers with increased education are willing to adopt this new climate-friendly irrigation pump.

Table 3.1: Household characteristics of solar and electric pump using 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. Experience of farming head	Years	20.44	11.04	25.41	11.01	***
3. Education of farming head	Years	9.36	5.07	7.89	4.17	ns
4. Family size	Numbers	3.19	0.90	3.09	0.96	ns
5. Farmers belonging to SC	%	0.66	--	6.58	--	--
6. Farmers belonging to OBC	%	99.34	--	93.42	--	--

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

Landholding and Irrigation Details:

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 larger landholding generally have more resources and also have risk-bearing capacity as compared to the small size holders. Therefore, we have studied the landholding and the irrigation details of the sample farmers. **Table 3.2** shows that 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 to increase the gross income. It can be clearly seen from the data presented in **Table 3.2** that the groundwater is the main source of irrigation used for cultivating crops in both SIP and EIP using farmers. The groundwater area accounted for about 73 percent of the net cropped area of SIP using farmers, whereas the same accounted for about 89 percent of EIP category farmers. Similar to net cropped area and gross cropped area, there was also a significant difference in the gross irrigated area between the two categories of farmers, even after the installation solar pump. 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. Since the farmers with EIP are still better than SIP using farmers in terms of irrigation coverage and cropping intensity, a question may be asked whether the farmers shall rather choose EIP over SIP when choices are given. Farmers who have adopted SIP have just completed two years of crop cultivation, without incurring any cost on account of energy (electricity). Given the assured energy supply, there is a possibility that the cropping intensity and irrigated area might increase in the future. Whether the farmers would choose EIP over SIP in the future also depends upon the electricity tariff-rate policy followed by the state.

Table 3.2: Landholding and irrigation (acres/household) details of solar and electric pump using farmers

Particulars	Solar pumps			Electric pumps	% change over Electric pumps	Test of significance of mean value
	Average		% change			
	Before	After				
1. Total area owned	3.47 (1.63)	3.47 (1.63)	0.00	3.83 (2.11)	-9.40	***
2. Net cultivated area	3.12 (1.86)	3.47 (1.63)	11.22	3.76 (2.04)	-7.71	***
3. Gross cultivated area	3.12 (1.86)	7.28 (2.82)	133.33	8.21 (4.06)	-11.33	***
4. Solar pump irrigated area	--	6.35 (2.56)	--	--	--	--
5. Well-irrigated area	--	2.54 (1.03)	--	3.41 (1.81)	-25.51	ns
6. Other irrigated area	0.38 (1.14)	0.38 (1.14)	0.00	0.07 (0.40)	442.86	ns
7. Gross irrigated area	0.38 (1.14)	6.74 (2.81)	1673.68	7.93 (3.91)	-15.01	***
8. Cropping intensity	100	209.80	--	218.35	--	--
9. Percent of irrigated area (GIA/GCA)	12.30	92.56	--	96.54	--	--

Notes: *** - Significant difference either at 1%, 5%, 10% level; ns – Not significant; Figures in brackets are Standard deviation.
Source: Computed using field survey data.

Though the landholding and irrigation status were relatively better among the electric pump using farmers, a significant improvement was observed in the irrigation status of solar pump using farmers while comparing the data of pre and post-installation of solar pump. The lands were predominantly rainfed before the installation of SIP. The average gross irrigated area of the solar pump using farmers before its installation was only 0.38 acre per household, which increased to 6.74 acres per household after the installation, which is an increase of about 18 times. As a result, the gross cultivated area increased from 3.12 acres to 7.28 acres per household. With a substantial increase in the irrigated area, the cropping intensity increased from 100 percent to about 210 percent. The average irrigated area of the solar pump was 6.35 acres per household. All these clearly show that the installation of solar pumps has significantly improved the gross cultivated area by substantially increasing the irrigation coverage.

Cropping Pattern:

Though the cropping pattern of an area/district is determined by various agro-economic factors, the availability of irrigation plays a crucial role in determining it. Low-value non-commercial foodgrain crops are predominantly cultivated in un-irrigated rainfed areas, whereas high-value commercial crops are mostly cultivated in those areas where irrigation facilities are available. We have observed earlier that the installation of solar irrigation pump has increased the availability of irrigation to its adopters. Therefore, an attempt was made to study whether the cropping pattern has changed after the installation of solar pump irrigation.

Table 3.3: Cropping pattern of solar and electric pump using farmers (acres/household)

Crop's Name	Solar pumps		Electric pumps
	Before	After	
1. Paddy	2.78 (88.81)	1.86 (25.60)	1.90 (23.14)
2. Maize	--	0.13 (1.79)	0.28 (3.47)
3. Pulses	0.01 (0.31)	0.09 (1.24)	0.08 (0.96)
4. Groundnut	0.29 (9.26)	1.04 (14.29)	0.89 (10.82)
5. Gingelly	0.01 (0.31)	0.15 (2.06)	0.10 (1.24)
6. Coconut	0.02 (0.63)	1.37 (18.84)	2.07 (25.18)
7. Sugarcane	--	0.62 (8.47)	0.12 (1.44)
8. Cotton	0.02 (0.63)	0.43 (5.90)	0.37 (4.53)
9. Vegetable crops	--	0.45 (6.19)	0.75 (9.10)
10. Tree crops	--	1.13 (15.59)	1.65 (20.07)
11. Total foodgrains	2.79 (89.20)	2.08 (28.62)	2.26 (27.53)
12. Total non-foodgrains	0.34 (10.80)	5.19 (71.34)	5.95 (72.47)
13. GCA	3.12 (100)	7.28 (100)	8.21 (100)

Note: Figures in brackets are percentage to GCA (Gross Cropped Area).
Source: Computed using field survey data.

Table 3.3 presents the details of cropping pattern for solar pump (before and after the installation) as well as electric pump using farmers. It is clear from the table that the cropping pattern has completely changed after the installation of the solar pump. Among the solar pump using farmers, foodgrain crops accounted for about 89 percent of the cropped area before the installation solar pump, which reduced to about 29 percent after its installation. In other words, the share of the non-foodgrains area to the cropped area was only about 11 percent before the installation of the solar pump, but it increased to about 71 percent after the installation of solar pump. Interestingly, commercial crops such as coconut, sugarcane and cotton were not cultivated before the installation of solar pump, but these high-value crops were cultivated covering a good amount of area after the installation of solar pumps. What is more interesting is that the cropping pattern of the solar pumps using farmers was more or less the same as that of the farmers using electric pumps for irrigation. The share of the non-foodgrains area accounted for about 72 percent of the cropped area in both solar and electric pumps using farmers. This means that because of the installation of solar pumps, the farmers are not only able to change the cropping pattern substantially but also compete with the electric pump using farmers in terms of crop composition. On the whole, the analysis clearly suggests that the farmers are able to change the cropping pattern from low-value foodgrain crops to high-value non-foodgrains crops due to the installation of solar pump.

Factors Determining the Adoption of Solar Pumps:

After studying the household characteristics, landholding and irrigation details of the solar and electric pump using farmers, we have attempted to study the factors determining the adoption of solar irrigation pumps. This analysis was done to find out which is 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 considering seven social and agro-economic factors that are expected to determine the adoption of solar irrigation pumps.

Table 3.4 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 pump and the remaining three variables turned out to be negative in influencing such adoption. However, among the variables that turned out to be with 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 probability of adoption of solar pump would increase significantly when the education of the farmer increases. This was an expected result because the farmers' education plays a catalyst role in the adoption of any new technology in agriculture by allowing them to have outside contacts on both input and output markets, which is also proved by various studies (Tilak, 1993; Narayanamoorthy, 2000; Panda, 2015; 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 pump. Both the cropping intensity and the farm size are relatively higher among the non-adopters of solar pump (electric pump using farmers) and therefore, the regression coefficients of these variables turned out to be negative. The implication of the negative coefficients of farm size and cropping intensity is that the probability of adoption of solar pump would be less among those farmers with a high level of cropping intensity and farm size. Alternatively, one can also infer from these results that the probability of adoption of solar pump likely to be higher among those farmers having low levels of cropping intensity and farm size. As explained earlier, the cropping intensity of SIP using farmers is relatively less mainly due to two reasons; First, the operating hours of SIP are less as compared to EIP and second, less discharge of water from SIP as compared to EIP. The farm size of solar pump using farmers is relatively less probably due to the priority given to marginal and small farmers in providing solar pumps through government schemes. On the whole, the logit regression results suggest that the education of the farmer, cropping intensity and farm size are more likely to influence the adoption of solar irrigation pump.

Table 3.4: Logit regression results: factors influencing the adoption of solar pumps

Variables	Description of the variables	Co-efficient	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
Intercept		-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.

Ownership of Groundwater Structures:

In order to understand the impacts of solar pumps on different economic and other parameters, one needs to understand the groundwater structures owned by the SIPs and EIPs using farmers. Further, understanding more about the operating hours of pumps would also help analysing the water use pattern of the solar and electric pump using farmers, which is also one of the major objectives of the study. Therefore, an attempt is made to study the ownership pattern of groundwater structures including the operating hours of pumpsets of the sample farmers.

The details presented in **Table 3.5** show that there are differences in the ownership pattern of groundwater structures by the solar and electric pump using farmers. The farmers belonging to the category of electric pump owned a total of 163 pumps, whereas the solar pump using farmers owned a total of 152 pumps. Some of the farmers from the category of electric pump owned more than one electric pump and therefore, the number of electric pump comes to more than the total sample size. Against our expectation, the average horse power (HP) size of pumps was relatively higher (6.13) for the solar pump using farmers as compared to the electric pump using farmers (5.64). Except for a few farmers belonging to the category of electric pump, all other farmers were using 5 HP pumps, which is different from the solar pump using farmers where 56 out of 152 farmers were either using 7.5 HP pump or 10 HP pump. Therefore, the HP size of the pump is relatively higher for solar pump using farmers.

While studying the ownership pattern of groundwater structures, we have tried to get answers to two important questions namely (a) what were the per day operating hours of pumps? How much of the area was brought under irrigation due to the installation of solar pumps? It comes out from the analysis that the solar pump using farmers operated on an average of 6.85 hours per day, whereas the electric pump using farmers operated the pumps on an average of 11.23 hours per day, the difference between the two was about 39 percent. The reduced operating hours of solar pump would not only help to reduce the exploitation of groundwater but also reduce the consumption of electricity accounted under the category of agricultural sector.

Table 3.5: Operating hours of pumps and ownership of groundwater structures by solar and electric pump using farmers

Particulars	Solar pumps	Electric pumps
1. Total number of dug-wells	--	--
2. Total number of bore wells	152	163
3. Total number of diesel pumps	--	--
4. Total number of electric pumps	--	163
5. Total number of solar pumps	152	--
6. Average HP of pumps	6.13	5.64
7. Per day of operating hours of pumps	6.85	11.23
8. Gross area brought under irrigation due to installation of solar pumps (acres/household)	6.35	--

Source: Computed using field survey data.

There are reasons for the wide differences in the operating hours of pumps between the two categories of farmers. First, the solar pump cannot be operated during the nighttime because it requires adequate sunlight to run. Most of the time, the farmers are able to operate the solar pump only from 7.30 am to 4.30 pm. But, in the case of electric pumps, the availability electricity free of cost allows the farmers to operate the pumps for more hours, which not only increases the operating hours of pumps but also allows the farmers to operate the pumps inefficiently. Though there are differences in the operating hours of pump between the two categories of farmers, due to the installation of solar pump, the farmers were able to bring gross irrigated area amounting to 6.35 acres per household, which is a remarkable development.

Crop-wise Irrigated Area by Solar Pumps:

After studying the gross irrigated area brought by the solar pump, we have also studied the crop-wise irrigated area of the solar pump using farmers *vis-a-vis* electric pump using farmers. We have observed earlier that the operating hours of solar pumps are substantially less as compared to the electric pumps. This means that farmers may not be able to allocate more area for water-intensive crops because of constraints in operating the pumps throughout the day. By studying the crop-wise irrigated area of the solar pump using farmers, we can understand whether the farmers are efficiently allocating the area for different crops.

Crop-wise irrigated area presented in **Table 3.6** shows that the allocation of area for different crops is not the same between the solar and electric pump using farmers. Water-intensive crops such as paddy and vegetables have accounted for about 26 percent of the total irrigated area among the solar pump using farmers, whereas these same crops have accounted for about 22 percent among the electric pump using farmers. The farmers belonging to the solar pump category have also allocated relatively less area for crops like coconut and maize, which are the other important crops that require relatively less water for cultivation. Interestingly, the solar pump using farmers have allocated more area for the water-guzzling crop namely sugarcane as compared to the counterpart farmers belonging to the category of electric pump. Some enthusiastic farmers have started cultivating sugarcane aiming to harvest more profit after installing the solar pump and therefore, the share of sugarcane area is relatively higher among them. The allocation of relatively less area for water-intensive crops by the solar pump using farmers is not an unexpected one. Because of constraints in operating the solar pumps throughout the day, the farmers appear to prudently allocating the area for different crops. Overall, the solar pump using farmers have allocated relatively less area for foodgrain crops (about 19 percent) as compared to the electric pump using farmers (about 25 percent).

Table 3.6: Crop-wise irrigated area (acres/household) under solar and electric pumps

Crop's name	Total area under cultivation		Irrigated area	
	Solar pumps	Electric pumps	Solar pumps	Electric pumps
1. Paddy	1.86 (25.60)	1.90 (23.14)	1.01 (15.98)	1.58 (20.10)
2. Maize	0.13 (1.79)	0.28 (3.47)	0.11 (1.79)	0.27 (3.44)
3. Pulses	0.09 (1.24)	0.08 (0.96)	0.09 (1.42)	0.08 (1.02)
4. Groundnut	1.04 (14.29)	0.89 (10.82)	0.96 (15.15)	0.89 (11.32)
5. Gingelly	0.15 (2.06)	0.10 (1.24)	0.15 (2.43)	0.10 (1.27)
6. Coconut	1.37 (18.84)	2.07 (25.18)	1.37 (21.60)	2.07 (26.34)
7. Sugarcane	0.62 (8.47)	0.12 (1.44)	0.62 (9.76)	0.12 (1.53)
8. Cotton	0.43 (5.90)	0.37 (4.53)	0.43 (6.77)	0.36 (4.58)
9. Vegetable crops	0.45 (6.19)	0.75 (9.10)	0.45 (7.10)	0.75 (9.54)
10. Tree crops	1.13 (15.59)	1.65 (20.07)	1.13 (17.80)	1.65 (20.99)
11. Total foodgrains	2.08 (28.62)	2.26 (27.53)	1.21 (19.12)	1.93 (24.53)
12. Total non-foodgrains	5.19 (71.34)	5.95 (72.47)	5.12 (80.47)	5.93 (75.44)
13. Total of all crops	7.28 (100)	8.21 (100)	6.35 (100)	7.86 (100)

Note: Figures in brackets are percentage to total area under cultivation.
Source: Computed using field survey data.

Water Use Pattern and Water Saving:

It is understood from the above that the farmers using solar pump could operate their pumps only for about 6.85 hours per day as against the hours of 11.23 operated by the farmers using electric pumps. This reduced operation of pumps may have forced the farmers to follow the efficient water use pattern in crop cultivation. Therefore, after studying the cropping pattern, we turned our focus on the water use pattern. Particularly, we attempt to estimate the water saving due to the installation of the solar irrigation pump, which is one of the objectives of the study as well. Water use pattern (number of irrigation, hours required to irrigate one hectare of land, etc.,) of farmers varies with the source of irrigation. In canal irrigated area, it is usually determined by the irrigation authorities, whereas in the tank irrigated area, the pattern of water use is determined by the availability of water and the rainfall condition of the region. But, farmers themselves determine the pattern of water use in groundwater area as it is predominantly owned by them (Saleth, 2014). Government control on water use is negligible under the groundwater-irrigated condition. Since groundwater irrigation is essentially a private source, the pattern of water use is significantly different from that of the surface source of irrigation. Studies have shown that the efficiency of water use is significantly higher under groundwater irrigation when compared to canal and tank irrigation (Shah, 1993; Dhawan, 1988). Since the duration of the crop and other factors associated with crop cultivation are different from crop to crop, the water use pattern is expected to change widely from one crop to another. Water consumption is estimated based on the number of irrigation and the hours used for each turn of irrigation and therefore, one can expect a close relationship between the water use pattern and water saving in different crops.

Estimating the precise amount of water consumption at the farm level is very difficult. Water consumption per acre for any crop is determined by factors such as the HP of the pumps, the water level of the well, the capacity of the pump, the size of delivery pipes, the condition of the water extraction machineries, the distance between water source and field to be irrigated, quality of soil and terrain condition, etc. These factors could vary considerably across the farmers. Because of these difficulties, water consumption is measured in terms of HP hours of irrigation per acre. HP hours of water are computed by multiplying the HP of the pumps with hours of water used.

Now let us study whether solar pump using farmers are able to save water in different crop cultivation. **Table 3.7** presents the water use pattern in different crops by solar and electric pump using farmers. As expected, the water use pattern followed in different crops by these two categories of farmers is not the same. Although we could not see any perceptible differences in the number of irrigation given to each crop and the hours used for each turn of irrigation for different crops between the solar and electric pump using farmers, the total HP hours of water used is relatively less for almost all the crops (except pulses) for the solar pump using farmers as compared to the electric pump using farmers. This means that the solar pump using farmers are able to save a large quantity of water in cultivating different crops.

Among different crops, the highest water saving is found in coconut (42.60 percent) followed by tree crops (42.65 percent) and sugarcane (33.08 percent). The solar pump farmers are also able to save a considerable amount of water in relatively more water-consuming crops like paddy (about 15 percent), vegetables (15.51 percent) and maize (24.04 percent) as compared to the same crops cultivated by the electric pump using farmers. There are reasons why solar pump using farmers are able to save a considerable amount of water over their counterpart farmers. First, since the farmers are able to see water for the first time due to the installation of solar pumps in the rainfed area, after a long struggle and waiting, they give utmost care for managing the water efficiently. Second, unlike the electric pump using farmers, the solar pump using farmers are able to operate the pumps for only about 7 hours per day and therefore, they consider water as a very precious commodity. Third, many farmers from the solar pump category have constructed cement-lined channels for taking the water to the field, which reduces the leaching of water. Four, many solar pump using farmers are taking the water from pumps through a network of plastic pipes to the field, which helps reduce the evaporation and leaching of water to a large extent. Five, quite a few farmers in the category of solar pumps have also installed drip method irrigation, which also helps to reduce the water substantially.

Table 3.7: Water use pattern (per acre) in different crops by solar and electric pumps

Crop's Name	Particulars	Solar pumps	Electric pumps	Saving in % (Solar over Electric pumps)
1. Paddy	1. Number of irrigation	19.06	20.65	-7.70
	2. Hours required each turn of irrigation	5.00	6.15	-18.70
	3. Total HP hours of water used	554.95	651.88	-14.87
	4. HP of the pumpset	6.12	5.98	2.34
2. Maize	1. Number of irrigation	17.00	16.64	2.16
	2. Hours required each turn of irrigation	3.33	5.00	-33.40
	3. Total HP hours of water used	362.78	497.21	-27.04
	4. HP of the pumpset	6.67	6.68	-0.15
3. Pulses	1. Number of irrigation	5.88	4.82	21.99
	2. Hours required each turn of irrigation	4.00	3.82	4.71
	3. Total HP hours of water used	148.75	112.27	32.49
	4. HP of the pumpset	6.25	7.55	-17.22
4. Groundnut	1. Number of irrigation	15.34	17.08	-10.19
	2. Hours required each turn of irrigation	5.06	4.91	3.05
	3. Total HP hours of water used	430.65	504.84	-14.70
	4. HP of the pumpset	5.73	6.19	-7.43
5. Gingelly	1. Number of irrigation	3.19	3.56	-10.39
	2. Hours required each turn of irrigation	3.38	3.83	-11.75
	3. Total HP hours of water used	59.53	82.22	-27.60
	4. HP of the pumpset	5.63	6.44	-12.58
6. Coconut	1. Number of irrigation	23.05	24.19	-4.71
	2. Hours required each turn of irrigation	4.86	8.02	-39.40
	3. Total HP hours of water used	632.70	1102.26	-42.60
	4. HP of the pumpset	6.03	5.92	1.86
7. Sugarcane	1. Number of irrigation	96.87	120.00	-19.28
	2. Hours required each turn of irrigation	3.87	4.00	-3.25
	3. Total HP hours of water used	2183.17	3262.50	-33.08
	4. HP of the pumpset	6.17	7.50	-17.73
8. Cotton	1. Number of irrigation	18.76	18.53	1.24
	2. Hours required each turn of irrigation	3.94	5.37	-26.63
	3. Total HP hours of water used	430.45	436.21	-1.32
	4. HP of the pumpset	6.20	4.76	30.25
9. Vegetable crops	1. Number of irrigation	41.10	26.84	53.13
	2. Hours required each turn of irrigation	1.86	3.24	-42.59
	3. Total HP hours of water used	436.60	516.72	-15.51
	4. HP of the pumpset	6.42	4.88	31.56
10. Tree crops	1. Number of irrigation	36.30	35.19	3.15
	2. Hours required each turn of irrigation	3.37	7.39	-54.40
	3. Total HP hours of water used	724.72	1337.81	-45.83
	4. HP of the pumpset	6.48	5.39	20.22

Source: Computed using field survey data.

All these efficient water management practices followed by the solar pump using farmers are seldom followed by the electric pump using farmers mainly because of supply of electricity free of cost for agriculture purposes in Tamil Nadu. The provision of free electricity for all the categories of land-owning farmers appears to encourage the electric pump using farmers to exploit the groundwater as much as possible and also allows them to over-irrigate the crops, more than the required level. We have observed that many electric pump using farmers allow the pumps to run throughout the day irrespective of the water requirement for crops due to the availability of electricity free of cost. Because of all these reasons, the HP hours of water consumption is relatively higher among the electric pump using farmers as compared to the solar pump using farmers. On the whole, the installation of solar pump appears to have disciplined the farmers in terms of managing and efficiently using the irrigation water, which has become increasingly scarce in recent years in India.

Electricity Consumption and Saving:

In addition to water saving, solar irrigation pump also helps saving a substantial amount of electricity that is being used for lifting water from wells. Water consumption and electricity consumption are highly correlated and therefore, an analysis of electricity consumption by solar and electricity pump is also carried out. It is a well-known fact that due to the rapid energisation of pumps and widespread cultivation water-intensive crops, the consumption of electricity by the agricultural sector has increased manifolds since the independence. In India, on an average, pump that is used to lift water from wells consumes about 70 percent of electricity used for agricultural purposes (Sharma, 1994). Though the increased consumption of electricity indicates better growth of agriculture, many researchers argue that electricity is not used efficiently in agriculture due to various reasons (Kumar and Narayanamoorthy, 2020; Kumar, 2005). One of the options available for reducing the electricity use in agriculture is the solar irrigation pump. Preliminary-level studies related to solar irrigation pump have shown that this new climate-friendly irrigation technology is not only useful for reducing the consumption of water but also useful in electrical energy saving. It is understandable that along with the number of working hours of the pump, the consumption of electricity also reduced in solar irrigation pump.

We have observed in the preceding section that the HP hours of water used per acre in solar pump-irrigated crops are significantly less than the same crops irrigated using electric pumps. Consequently, it follows simply that the consumption of electricity also reduces significantly in solar pumps irrigated crops. In order to know the impact of solar pumps on potential electricity saving, we have estimated electricity consumption based on the hours of pump operation for both the solar and electric pumps irrigated crops. In order to estimate the quantum of electricity saved, we have assumed that for every hour of operation of pump, 0.750 kWh of power is used per HP, as assumed by Shah (1993). In order to estimate the electricity consumption per acre, we have simply multiplied HP hours of water with the assumed power consumption of 0.750/kWh/HP. It is to be mentioned here that since the solar pump does not consume electricity, its potential electricity consumption is estimated to compare with the pumps operated using electricity.

The estimated consumption of electricity (in kWh) presented in **Table 3.8** clearly depicts that farmers using solar pumps could save a substantial amount of electricity. The overall average calculated by taking into account all the crops considered for the analysis shows that the potential saving of electricity due to solar pump is 783.68 kWh/acre. The potential electricity saving varies from about 1637 kWh/acre in sugarcane to about 45 kWh/acre in gingelly. Farmers cultivating paddy, groundnut, coconut, cotton and vegetable crops could save 322-416 kWh of electricity per acre due to the adoption of solar irrigation pumps. The variation in potential electricity saving occurs due to variations in water consumption in terms of HP hours. It is worth mentioning here that the average potential electricity saving could go up to 976 kWh/acre, in case all the electric pump using farmers shit to solar pump irrigation. On the whole, the estimate on electricity consumption proves that besides saving water, solar pump also helps to save a substantial amount of electricity consumption.

Table 3.8: Estimate on electricity consumption and saving (per acre) in different crops due to solar pumps

Crop's Name	Solar pumps		Electric pumps		Electricity saving over electric pump (Kwh)
	HP hours of water use	Potential electricity consumption (Kwh)	HP hours of water use	Potential electricity consumption (Kwh)	
1. Paddy	554.95	416.21	651.88	488.91	-72.70
2. Maize	362.78	272.09	497.21	372.91	-100.82
3. Pulses	148.75	111.56	112.27	84.20	27.36
4. Groundnut	430.65	322.99	504.84	378.63	-55.64
5. Gingelly	59.53	44.65	82.22	61.67	-17.02
6. Coconut	632.70	474.53	1102.26	826.70	-352.17
7. Sugarcane	2183.17	1637.38	3262.50	2446.88	-809.50
8. Cotton	430.45	322.84	436.21	327.16	-4.32
9. Vegetable crops	436.60	327.45	516.72	387.54	-60.09
10. Tree crops	724.72	543.54	1337.81	1003.36	-459.82
11. Average all crops	1044.91	783.68	1301.37	976.03	-192.35

Source: Computed using field survey data.

CO2e Emission Reduction:

One of the major objectives of promoting solarised irrigation with a big incentive programme is to reduce carbon emissions. As the fossil fuel based electricity consumption in solar irrigation pump is zero, it helps to save huge amount of carbon emissions. Therefore, an attempt is made to estimate the CO2e emissions based on the potential saving of electricity due to solar pump irrigation in different crops. For estimating CO2e emissions based on the potential electricity saving, a factor of 0.935 is used as the coal-fired power plant generates 0.935 kg of CO2 for every unit of electricity generation in India (CEA, 2021).

Table 3.9: Estimate on reduction in CO2e emissions in different crops due to solar pumps

Crop's Name	Potential electricity saving (kwh/acre)	CO2e emission reduction (kg/acre)	Assumed factor (i.e., CO2e reduction in kg/kwh)
1. Paddy	416.21	389.16	0.935
2. Maize	272.09	254.40	0.935
3. Pulses	111.56	104.31	0.935
4. Groundnut	322.99	302.00	0.935
5. Gingelly	44.65	41.75	0.935
6. Coconut	474.53	443.69	0.935
7. Sugarcane	1637.38	1530.95	0.935
8. Cotton	322.84	301.86	0.935
9. Vegetable crops	327.45	306.17	0.935
10. Tree crops	543.54	508.21	0.935
11. Average all crops	783.68	732.74	0.935

Source: Computed using field survey data.

The estimate presented in **Table 3.9** shows that with the adoption of solar irrigation pump, a large quantity of CO2e emissions can be reduced in different crops. While the average reduction of emissions for all crops comes to about 732 kg/acre, it widely varies from crop to crop due to variations in the consumption of HP hours of water. Predictably, the highest reduction of carbon emissions of about 1531 kg/acre is observed in sugarcane which is a water-guzzling crop, whereas the lowest reduction is found in gingelly crop, which is a very less water consuming crop. In crops like paddy, groundnut, coconut, cotton and vegetables, the carbon emissions reduction is in the range of 301 to 389 kg/acre. The estimate suggests that the degree of reduction of carbon emissions is closely associated with the water consumption of the crops, meaning that large-scale adoption of solar pump irrigation in water-intensive crops like sugarcane, paddy, banana, etc., would help reducing the carbon emissions in a big way.

Crop-wise Cost of Cultivation:

One of the major objectives of the study is to find out whether or not the crops cultivated under the solar irrigation pumps are profitable. To study the profitability of crops more clearly, one needs to study the cost of cultivation and productivity of the crops, both of which are the core determinants of the income and profitability of the crops. While the cost of cultivation varies from crop to crop depending upon its duration and inputs use pattern, studies from India show that the cost of cultivation is found to be relatively higher among water-intensive crops like paddy, sugarcane, banana, wheat, etc., as compared to less-water consuming crops or rainfed crops (see, Narayanamoorthy, 2021, CACP, 2023). The availability of irrigation also allows the farmers to adopt the required inputs for crops, which ultimately increases the cost of cultivation.

It was observed earlier that both the solar and electric pump using farmers have cultivated different crops. Let us study whether any perceptible differences exist in the cost of cultivation of different crops between the two categories of farmers. Before going into the analysis of the cost of cultivation, it is to be mentioned here that the cost of cultivation used in this study refers to cost A2+FL.[4] **Table 3.10** presents the cost of cultivation for different crops for both solar and electric pump using farmers. As expected, the cost of cultivation varies from crop to crop in both the categories of farmers. The overall average cost of cultivation worked out for all the crops is a little higher (2.23 percent) for the solar pump using farmers (Rs. 75,844/acre) as compared to the electric pump using farmers (Rs. 74,189/acre). While we do not see any uniform pattern in the cost of cultivation of different crops between the solar and electric pump using farmers, the solar pump using farmers have spent relatively less cost for 6 out of 10 crops presented in the table. Interestingly, the solar pump using farmers have incurred relatively less cost for growing the two most important water-intensive crops namely paddy (1.19 percent) and sugarcane (7.13 percent) as compared to the electric pump using farmers. While we could not observe any particular reason for the variations in

[4] The Commission for Agricultural Costs and Prices (CACP), of Ministry of Agriculture, Government of India, has been using nine different cost concepts for calculating the cost and income of different crops in India. Of this, A2+FL is used for cost calculation in this Study. Cost A2+FL includes all actual expenses in cash and kind incurred in production by the owner, rent paid for leased-in land and the imputed value of family labour. The profit mentioned in this study is the difference between gross income (obtained by multiplying yield with the prevailing per tonne selling price) and cost A2+FL. Since the total cost is calculated by considering only the variable costs and not the fixed cost components like interest rate and depreciation, it should be appropriately called as farm business income instead of profit or net income.

the cost of cultivation between the two categories of farmers, most farmers from the solar pump category have mentioned that they adopt all the inputs for crops equivalent to that of the counterpart electric pump using farmers because of availability of assured irrigation.

Table 3.10: Crop-wise cost of cultivation (Rs/acre) by solar and electric pumps irrigated crops

Crop’s Name	Solar pumps	Electric pumps	% increase (solar over electric pumps)
1. Paddy	26927	27248	-1.19
2. Maize	26111	25277	3.30
3. Pulses	6438	6773	-4.95
4. Groundnut	35800	36244	-1.23
5. Gingelly	7107	6533	8.79
6. Coconut	49543	49886	-0.69
7. Sugarcane	76156	82000	-7.13
8. Cotton	44322	45965	-3.57
9. Vegetable crops	73777	71766	2.80
10. Tree crops	45565	45218	0.77
Average of all crops	75844	74189	2.23

Source: Computed using field survey data

Productivity of Crops:

Following the analysis of the cost of cultivation, we have studied the productivity of crops to find out whether any difference exists between the crops cultivated by solar and electric pump using farmers. Generally, the productivity of a crop is directly related to the amount of use of yield-increasing inputs besides the source of irrigation. The productivity of canal irrigated crops is found to be higher than that of the tank irrigated crops. Similarly, the productivity of crops that are cultivated using groundwater irrigation is much higher than that of the canal and tank irrigated crops (Dhawan, 1988; Vaidyanathan, *et al.*, 1994). It was observed earlier that the difference in cost of cultivation in most of the crops is very minimal between the two categories of farmers. This means that both categories of farmers have applied more or less the same amount of inputs for cultivating different crops and have used groundwater irrigation uniformly for cultivating different crops. With this understanding, let us now study the productivity of different crops.

Table 3.11: Productivity of crops (quintals/acre) irrigated by solar and electric pumps

Crop’s Name	Solar pumps	Electric pumps	% increase (solar over electric pumps)
1. Paddy	20.63	19.98	3.25
2. Maize	25.98	26.06	-0.31
3. Pulses	4.36	5.11	-14.68
4. Groundnut	14.42	15.09	-4.44
5. Gingelly	3.73	3.79	-1.58
6. Coconut (numbers)	6884.32	6798.57	1.26
7. Sugarcane	863.27	834.33	3.47
8. Cotton	13.76	13.29	3.54
9. Vegetable crops	93.86	68.18	37.67
10. Tree crops	341.00	358.40	-4.85

Source: Computed using field survey data.

Though the data presented in **Table 3.11** does not show any uniform pattern in the productivity of crops cultivated by the two categories of farmers, the solar pump using farmers have harvested higher yield per acre in most of the important water-consuming crops such as paddy, coconut, sugarcane and vegetables. While the productivity of paddy cultivated by solar pump using farmers is about 3 percent higher over its counterpart farmers, the same is higher by about 37 percent in vegetable crops. Besides, the solar pump using farmers have also harvested relatively higher yield in cotton over than their counterpart farmers who cultivated the same crop with electric pumps. With no big differences in the cost of cultivation of different crops cultivated by the two categories of farmers, there could be two main reasons for the increased productivity of crops by solar pump using farmers. First, since the solar pump using farmers have cultivated the irrigated crops extensively for the first time, they have followed all good practices for cultivating the crops. Second, the lands that are used by the solar pump farmers have not been used extensively for cultivating crops so far for want of irrigation and therefore, these fresh lands could have responded very well to the yield-increasing inputs as compared to the lands that have been used more intensively for many years by the electric pump using farmers.

Cost and Income Pattern:

One of the serious problems encountered by the Indian farmers for the last two decades or so has been the increased cost of cultivation and reduced profitability.[5] It is obvious that no new technology would be adopted by the farmers unless it is economically viable to them. If a new technology helps to save water or cost of cultivation without increasing productivity or value of output in crop cultivation, then that technology would not be adopted extensively. Similarly, if a crop technology promotes only resource conservation without augmenting productivity, then it would not get an adequate response from farmers. Therefore, there is a need to study whether crops cultivated using solar irrigation pump generate more income for farmers than that of crops cultivated using electric pumps. We have observed earlier that the productivity of most crops cultivated using solar pumps is relatively higher than the same crops cultivated using electric pumps. Given this, one can hypothesis that the income of the crops cultivated using solar pumps could be higher than the crops cultivated using electric pumps.

Before getting into the details of crop income, it is necessary to mention how the value of output and profit is calculated in the study. As mentioned earlier, the cost of cultivation used in the study refers to cost A2+FL, the definition of which is mentioned elsewhere in the study. The value of output (VOP) is computed by multiplying the productivity of crops with its price (per quintal) received from the market by the sample farmers. The net income (farm business income) is calculated by deducting the value of output from the cost of cultivation per acre. The net income computed using cost A2+FL for different crops is presented in **Table 3.12**.

[5] The issue of high-cost and low-productivity in the farm sector has also been echoed by the economists of our country in the very first meeting of the NITI (National Institute for Transforming India) Aayog chaired by the Prime Minister Shri Narendra Modi at New Delhi on February 6, 2015 (see, The Hindu, February 7, 2015, p. 1). The same issue has also been underlined by many credible studies including the National Commission on Farmers (NCF, 2006) and the Expert Group on Agricultural Indebtedness (GOI, 2007). Policymakers at various levels have been contemplating for a fresh push for agricultural growth.

It is evident from the table that the value of output as well as the net income obtained in most of the crops by the farmers who have cultivated crops using solar pump is relatively higher than its counterpart electric pump using farmers. The average net income computed by taking the data of all the crops comes to about Rs. 1,08,434/acre for solar pump farmers, whereas the same is about Rs. 1,02,828/acre for electric pump using farmers, indicating a difference of about 5.45 percent between the two categories of farmers. As observed in the productivity of crops, the net income from important crops like paddy, coconut, sugarcane, cotton and vegetable crops are relatively higher for the solar pump using farmers as compared to the electric pump using farmers. The net income realized by the solar pump using farmers from paddy, which is one of the major crops cultivated by both the categories of farmers, is higher by about 4.34 percent over its electric pump using farmers. Similarly, the net income from sugarcane, which is another important crop cultivated largely by both categories of farmers, is also considerably higher (10.33 percent) for solar pump using farmers than its counterpart farmers using electric pump. Because of increased productivity in vegetable crops, the solar pump using farmers are able to harvest higher net income from its cultivation too.

Table 3.12: Cost and income (Rs/acre) pattern of solar and electric pump irrigated crops

Crop's Name	Solar pumps			Electric pumps			% increase in net income (solar over electric)
	Cost of Cultivation	Value of Output	Net Income	Cost of Cultivation	Value of Output	Net Income	
1. Paddy	26927	41983	15056	27248	41678	14430	4.34
2. Maize	26111	66246	40135	25277	66458	41181	-2.54
3. Pulses	6438	39274	32836	6773	45949	39176	-16.18
4. Groundnut	35800	61492	25692	36244	64355	28111	-8.61
5. Gingelly	7107	20508	13401	6533	20827	14294	-6.25
6. Coconut	49543	82612	33069	49886	81583	31697	4.33
7. Sugarcane	76156	215817	139661	82000	208583	126583	10.33
8. Cotton	44322	78417	34095	45965	75768	29803	14.40
9. Vegetables	73777	222457	148680	71766	193220	121454	22.42
10. Tree crops	45565	207436	161871	45218	223725	178507	-9.32
11. Average of all crops	75844	184278	108434	74189	177017	102828	5.45

Source: Computed using field survey data.

One might be interested to know how could the net income from most of the crops cultivated by solar pump using farmers is considerably higher than that of the electric pump using farmers. A few reasons can be attributed to the increase in net income. First, the productivity of most of the important crops is higher for solar pump using farmers. Second, the cost of cultivation of important crops is relatively lower for solar pump using farmers. Third, the solar pump using farmers have allocated more share of cropped area for non-foodgrain commercial crops, which could have also helped to realize higher net income from their crop cultivation. The net income of crops such as maize, pulses, groundnut and gingelly cultivated by the solar pump using farmers is lower due to relatively less productivity and increased cost of cultivation in some crops as compared to that of the electric pump using farmers. On the whole, though there are variations in the net income among different crops, the overall average of all crops shows that the net income per acre realized by the solar pump using farmers is higher than that of the electric pump using farmers.

Land Lost and its Opportunity Cost:

Farmers lose some amount of cultivable land due to the installation of solar pumps/solar panels, which ultimately reduces the income realized by the farmers in cultivating different crops. Therefore, after studying the cost and income pattern of the sample farmers, we have attempted to estimate the loss of land and its opportunity cost (loss of income) of the solar pump using farmers. The land requirement for installing solar pump varies depending on the pump size and the cell size of the panel used. All the sample farmers in the study area have used solar panel cell size of 72 (6.77 feet long x 3.39 feet width), which requires 22.95[6] square feet of land for installing each solar panel. The number of panels required for 5 HP, 7.5 HP and 10 HP pump are 15, 20 and 22 respectively. Following the requirement of panels and HP of the pump, the total loss of land is worked out, which varies from 344 square feet for 5 HP pump to 505 square feet for 10 HP pumps.

It was observed earlier that the solar pump using farmers have cultivated different crops and the income realised by them is different as well. Therefore, the opportunity cost of land is estimated separately for each crop. The opportunity cost of the land lost is worked out based on the net income realised in different crops per acre by the farmers. That is, the opportunity cost is estimated by multiplying the net income per square foot of land with the loss of land for each crop. The estimate presented in **Table 3.13** shows that the opportunity cost (net income) varies considerably from crop to crop.

Table 3.13: Land lost due to solar panel installation and its opportunity cost (Rs/acre)

Name of the Crops	5 HP Pumps (344 Sq.ft. Area Lost)	7.5 HP Pumps (459 Sq.ft. Area Lost)	10 HP Pumps (505 Sq.ft. Area Lost)	ALL (390.36 Sq.ft. Area Lost)
1. Paddy	118.90	158.65	174.55	134.89
2. Maize	316.95	422.91	465.29	359.57
3. Pulses	259.31	346.00	380.67	294.18
4. Groundnut	202.89	270.72	297.85	230.18
5. Gingelly	105.83	141.21	155.36	120.06
6. Coconut	261.15	348.45	383.38	296.27
7. Sugarcane	1102.92	1471.63	1619.12	1251.24
8. Cotton	269.25	359.27	395.27	305.46
9. Vegetable crops	1174.15	1566.67	1723.68	1332.04
10. Tree crops	1278.32	1705.67	1876.60	1450.22
11. Average of all crops	856.32	1142.59	1257.10	971.48

Note: The opportunity cost of land is estimated based on the net income realised by the solar pump using farmers.
Source: Computed using field survey data.

The average opportunity cost worked out by taking into account the average net income of all the crops comes to Rs. 862/acre for 5 HP pumps, which increases to Rs. 1,150/acre for 7.5 HP pump and further to Rs. 1,265/acre for 10 HP pump using farmers. Among different crops cultivated by the solar pump using farmers, the loss of net income (opportunity cost) is found to be relatively high in tree crops followed by vegetable and

[6] The average 72-cell solar panel size measures 3.25 feet by 6.42 feet, for which the land requirement comes to 20.865 square feet. However, such a requirement of land increases to 22.95 square feet for each panel while fixing the panel with aluminium feeding at the field.

sugarcane. The overall net income per acre realised by the farmers in these crops is very high and therefore, the opportunity cost is also very high in these crops. Unexpectedly, the opportunity cost of land for cultivating paddy, which is a heavy water-intensive crop, is the lowest (about Rs. 118/acre for 5 HP pump and Rs. 175/ acre for 10 HP pump) among the major crops cultivated by the solar pump using farmers, implying that the farmers would be losing more income, if paddy is cultivated extensively using solar irrigation pumps. On the whole, though the overall average opportunity cost of land lost due to the installation of solar pump is close to Rs. 1000/acre, it accounts not even one percent of the net income realised by the solar pump using farmers from different crops cultivation per acre per annum.

Benefits to Women:

It is clear from the above that the introduction of solar irrigation pump has increased the productivity and the net income of the major crops. Studies have confirmed that the availability of irrigation also changes the participation of women in agriculture and other activities. Though quantifying the benefits to women due to the installation of solar pump is very difficult, we have asked the respondents a perception-based qualitative question as to whether women in farm households benefit from the deployment of solar irrigation pumps. Most of the farmers have accepted that the installation of solar pump one way or the other benefits the women. The important benefits listed by the respondents are:

- Women farmers can operate the solar pump easily, which is not possible in diesel pump.
- Women used to spend considerable amount of time fetching the water for drinking and domestic purposes earlier, which has reduced due to solar pump.
- Women are able to work on their own farm contributing to crop cultivation, instead of going for wage work earlier.
- Since the solar pump works only during daytime, women farmers are able to manage irrigation works without any fear and other security issues.
- By working on their own farm, work time flexibility for women has increased.
- The stress faced by the women has reduced substantially by working on their own farm.
- With the availability of water from solar pump, the women are able to rear quality milch animals that help to contribute more to the household income.

Besides these, the sample farmers have expressed that the women in their households are able to cook food patiently for their families and also eat food in time because of working at their own farms.

Economic Viability of Solar Pumps:

One of the important issues about to solar irrigation pump is whether its investment is economically viable. This question arises because the solar irrigation pump involves relatively a large fixed investment. Past studies on this subject have conducted benefit-cost analysis without proper methodology, either relied on a few farmers adopting solar irrigation pump or estimated output-input ratio without considering the life period of solar pump, opportunity cost, depreciation factor, subsidy, etc. Therefore, as mentioned in the methodology section, an attempt is to find out the economic viability of the solar pump investment. In order to evaluate the economic viability of solar pump investment, both the Net Present worth (NPW) and the Benefit-Cost Ratio (BCR) are computed by utilising the discounted cash flow technique.

Though the methodology followed for estimating the NPW and BCR was explained in detail under the methodology section, we briefly present it again here for quick understanding. The NPW is the difference between the sum of the present value of benefits and that of costs for a given life period of the solar pump and therefore, it collates the total benefits with the total costs covering items like capital and depreciation costs of the solar pump. In terms of the NPW criterion, the investment in the solar pump can be treated as economically viable, if the present value of benefits is greater than the present value of costs. The BCR is also related to NPW as it is obtained just by dividing the present worth of the benefit stream with that of the cost stream. Generally, if the BCR is more than one, then the investment on that project can be considered economically viable. Obviously, a BCR greater than one implies that the NPW of the benefit stream is higher than that of the cost stream, which is also clearly detailed by Gittinger (1984).

Relative Economics of Solar Irrigation Pumps:

Before analysing the NPW and BCR, let us briefly understand the relative economics of farmers using 5 HP, 7.5 HP and 10 HP solar pumps. **Table 3.14** presents details of production cost (cost of cultivation), gross income (value of output) and net income (farm business income) for different pump size using farmers. It is necessary to mention here again that while calculating profit, the total cost is calculated by considering only the variable costs but not the fixed cost components like interest rate and depreciation. As reported earlier, for calculating per acre net income, the total cost of cultivation has been subtracted from the total income realised from the cultivation of crops. The gross income is calculated by multiplying the total yield with the price received by the farmers for their crop output.

Since we attempt to estimate NPW and BCR for 5 HP, 7.5 HP and 10 HP pump using farmers separately, let us understand how the capital cost varies among different pumps. As expected, the fixed capital cost increases along with HP size of the solar pump. While the capital cost for 5 HP pump comes to Rs. 1,69,612 with a subsidy, it increases to Rs. 2,42,303 without a subsidy. Similarly, the capital cost increases from Rs. 3,07,741 to Rs. 4,39,630 without a subsidy for 10 HP pump. The solar irrigation pump is capital-intensive in nature and therefore, the farmers using solar pump have received 70 percent of the capital cost as a subsidy through PM-KUSUM scheme, which is implemented jointly by the central and Tamil Nadu state governments.[7]

[7] The Government of Tamil Nadu has made some changes in PM-KUSUM scheme to accelerate the adoption of solar pumps. Instead of 60 percent of capital subsidy under PM-KUSUM, the state gives a capital subsidy of 70 percent (40 percent from the state + 30 percent from the central). The state also allows the farmers to install 10 HP pumps. More details on the modified scheme being implemented can be seen from Tamil Nadu's government orders: GO (MS) No. 96 and GO (MS) No. 164.

Table 3.14: Fixed cost, production cost, gross income details of solar irrigation pumps

Sl. No.	Particulars	5HP pumps	7.5 HP pumps	10 HP pumps	All average
1.	Number of farmers	96	43	13	152
2.	Capital cost with subsidy (Rs)	169612	244698	307741	240684
3.	Capital cost without subsidy (Rs)	242303	349569	439630	343834
4.	Production cost (Rs/acre)	75162	78930	70673	75844
5.	Production cost (Rs/ha)	185649	194958	174563	187335
6.	Gross income (Rs/acre)	175513	204539	181988	184278
7.	Gross income (Rs/ha)	433517	505211	449511	455167
8.	Net income (Rs/acre)	100351	125609	111315	108434
9.	Net income (Rs/ha)	247868	310253	274948	267832

Source: Computed using field survey data.

Similar to fixed capital cost, we have also observed some differences in the production cost, gross income and net income of the farmers using different sizes of solar pump. The production cost per acre or per hectare is relatively higher for the farmers owning 5 HP pump as compared to the farmers owning 10 HP pump. However, the gross income and the net income are also relatively lower for the farmers owning 5 HP pump as compared to the farmers owning 10 HP pump. Both the gross income and the net income per acre are relatively higher for the farmers owing 7.5 HP pump as compared to the other two groups of farmers. A relatively high-value cropping pattern followed by the farmers owning 7.5 HP pump could have helped them to harvest relatively higher productivity and thereby higher net income per acre.

NPW and BCR for Solar Investment:

The solar irrigation pump using farmers have realised a good amount of net income per acre, but it cannot yet be taken as a conclusive indicator of the comparative advantage of solar pumps. The life-period of a solar pump is one of the important variables that determine per acre net income. Since solar pump is a capital-intensive irrigation infrastructure, the initial investment needed for installing solar pump is commonly believed to be the main deterrent to the widespread adoption of solar pump. Is this true? How important is the government subsidy for the economic viability of investment in solar pump?

Though adopters of solar pump have received subsidy for installing solar pump, both NPW and BCR are estimated for with subsidy and without subsidy scenarios. This is done to assess the potential role that subsidy could play in the adoption of solar pump. Both NPW and BCR are also estimated for one acre of holding and also for one hectare of holding to see how they differ between these two categories of farm size. **Tables 3.15 to 3.17** present the estimates of NPW and BCR computed under different scenarios. As expected, the NPW of the investment with subsidy is marginally higher than under without subsidy scenario for all the HP size of pumps. For instance, at a 12% discount rate with 15 years life period, the NPW of solar pump investment for 5 HP pump is about Rs.

4,67,138/acre without subsidy, but the same increases to Rs. 5,32,040/acre with subsidy. Similarly, for 10 HP pumps with 15-year of life period at a 12 percent discount rate, the NPW comes to Rs. 3,65,625/acre without subsidy, but it increases to Rs. 4,83,383/acre with subsidy. The same kind of trend also emerges when one computes NPW considering one hectare of land. This means that the subsidy provides substantial additional benefits to solar irrigation pump using farmers.

Similar to NPW, the BCR also shows considerable variations when estimated with and without capital subsidy and also with different life periods of solar pumps. The BCR of investment with subsidy is marginally higher than without subsidy options for all three different capacities of the pumps. For 5 HP pump, with a 15-year life period under without subsidy condition, the BCR is 1.58 at a 15% discount rate, but it increases to 1.75 under with subsidy condition. Similarly, for 10 HP pump, with a 15-year life period, the BCR is 1.34 at a 15% discount rate, but it increases to 1.56 under with subsidy condition. The BCR increases considerably for all the capacities of the pump when the estimate is made based on 12% and 10% discount rate with 25-year life period. While the positive role that subsidy plays in improving the economic viability of solar pump investment is evident from BCR, at the same time it is also very clear from BCR estimates using discount rates at 15% 12% and 10% that investment in the solar pump is economically viable for farmers even without subsidy. However, the discounted cash flow analysis shows that the investment in solar pump with 5-year life period at a 15 percent discount rate without subsidy is not financially viable to the one-acre holding farmers as the estimated BCR comes to only 0.99. This implies that the farmers owning one-acre of land should not adopt the solar pump with 10 HP as the capital cost for such pump size is much larger than 5 HP pump. In any case, this is not a worrying sign as the solar irrigation pump is normally expected to work efficiently for more than 20 years.

Table 3.15: Estimate on NPW and BCR for one acre and one hectare of land with 5 HP solar pumps

Subsidy category	Life period (years)	Discount rate (%)	For 1 acre		For 1 hectare	
			NPW (Rs)	BCR	NPW (Rs)	BCR
With subsidy	5 Years	10	226218	1.52	785422	1.92
		12	210305	1.50	742069	1.90
		15	188905	1.47	683403	1.89
	15 Years	10	609088	1.84	1731111	2.11
		12	532040	1.80	1536756	2.09
		15	439303	1.75	1301887	2.06
	25 Years	10	756701	1.90	2095715	2.14
		12	635631	1.86	1792623	2.12
		15	501198	1.79	1454767	2.08
Without subsidy	5 Years	10	160135	1.32	719339	1.78
		12	145402	1.30	677167	1.76
		15	125695	1.27	620194	1.74
	15 Years	10	543005	1.69	1665028	2.02
		12	467138	1.64	1471853	1.99
		15	376093	1.58	1238677	1.96
	25 Years	10	690618	1.77	2029632	2.07
		12	570728	1.71	1727721	2.03
		15	437988	1.63	1391557	1.99

Source: Computed using field survey data.

We have also compared the BCR estimated considering the production cost and gross income realised from the one acre of land with that of the one hectare of land to see how it differs between the two. It is evident from the values presented in **Tables 3.15 to 3.17** that the BCR estimated for the one hectare of land is very high as compared to such BCR estimated with one acre of land. For instance, at a 10 percent discount rate with 15-year life period under subsidy conditions, the estimated BCR comes to 1.89 for the one acre of land, but it increases to 2.25 for the one hectare of land. Similarly, under without subsidy conditions too, the BCR value increases from 1.69 for the one acre of land to 2.13 for the one hectare of land. The differences in the estimate of BCR occur due to a variation in the density of the fixed capital between the one-acre and one-hectare land. This suggests that though the investment in the solar pump is economically viable for the farmers owning one acre of land, the return from every rupee of investment in the solar pump would be higher for those farmers owning one hectare of land.

Table 3.16: Estimate on NPW and BCR for one acre and one hectare of land with 7.5 HP solar pumps

Subsidy category	Life period (years)	Discount rate (%)	For 1 acre		For 1 hectare	
			NPW (Rs)	BCR	NPW (Rs)	BCR
With subsidy	5 Years	10	253703	1.49	953652	1.99
		12	234311	1.47	899914	1.98
		15	208279	1.44	827237	1.95
	15 Years	10	732937	1.89	2137359	2.25
		12	637023	1.84	1894614	2.23
		15	521700	1.77	1601386	2.18
	25 Years	10	917702	1.98	2593730	2.30
		12	766686	1.92	2214880	2.27
		15	599172	1.83	1792743	2.22
Without subsidy	5 Years	10	158366	1.26	858315	1.81
		12	140676	1.24	806279	1.79
		15	117087	1.21	736045	1.77
	15 Years	10	637600	1.69	2042022	2.13
		12	543388	1.64	1800979	2.10
		15	430507	1.56	1510193	2.05
	25 Years	10	822365	1.80	2498393	2.20
		12	673051	1.72	2121246	2.15
		15	507980	1.62	1701551	2.09

Source: Computed using field survey data.

How many years are needed to recover the capital costs of installing solar irrigation pump is an important decision point for farmers as well as banks that finance solar investments. The year-wise computation of net present worth under different discount rates suggests that the farmers with one hectare of land could recover the entire capital cost of the solar pump from their income within two years when they use 5 HP and 7.5 HP pump, whereas the 10 HP owning farmers could recover the entire capital cost within three years, at 10 percent discount rate under subsidy condition with 15-year life period.

This finding disproves the general belief that the capital cost recovery for solar pump investment takes more time. However, in order to have a more definite answer to the economic and social viability of solar pump investment, there is a need for social rather than private cost-benefit evaluation being estimated here. A comprehensive evaluation can be done by incorporating the social benefits in the form of water-saving, electricity-saving, CO2e emissions reduction, additional irrigated area, etc. Be that as it may, the BCR under different discount rates indicates that solar pump investment remains economically viable under with and without subsidy at different discount rates with a life period of more than 5 years. There is no doubt that the subsidy given for installing solar pump not only encourages its adoption but also help realising higher income from every rupee of investment in this new climate-friendly and climate-resilience irrigation technology.

Table 3.17: Estimate on NPW and BCR for one acre and one hectare of land with 10 HP solar pumps

Subsidy category	Life period (years)	Discount rate (%)	For 1 acre		For 1 hectare	
			NPW (Rs)	BCR	NPW (Rs)	BCR
With subsidy	5 Years	10	142207	1.26	762506	1.81
		12	126497	1.24	716358	1.79
		15	105545	1.21	654069	1.77
	15 Years	10	566907	1.69	1811514	2.13
		12	483383	1.64	1597867	2.09
		15	383300	1.56	1340124	2.04
	25 Years	10	730647	1.79	2215952	2.19
		12	598291	1.72	1881689	2.14
		15	451957	1.62	1509706	2.08
Without subsidy	5 Years	10	22308	1.03	642607	1.61
		12	8739	1.01	598600	1.59
		15	-9141	0.99	539382	1.56
	15 Years	10	447008	1.48	1691615	1.98
		12	365625	1.42	1480109	1.94
		15	268614	1.34	1225438	1.87
	25 Years	10	610748	1.59	2096053	2.06
		12	480533	1.51	1763931	2.00
		15	337270	1.40	1395020	1.92

Source: Computed using field survey data.

Multi-Stakeholders Survey:

Besides carrying out a detailed survey covering 304 sample farmers (152 solar pump farmers and 152 electric pump farmers), a multi-stakeholders survey was also carried out to understand the overall functioning of the solar irrigation pump including the schemes that are being operated by the government. Although detailed discussions were made at different time points with many government officials and the dealers who have installed the solar irrigation pumps in the four selected districts during the course of the sample survey, an in-depth discussion was made with five stakeholders from each district (2 sales executives and 3 Assistant Engineers working with the Agricultural Engineering Department). That is, an in-depth discussion/survey was made with a total of 20 officials from the four selected districts.

Since we aim to get an overall understanding of the functioning of the solar irrigation pumps from the stakeholders, we have asked the following specific questions to get their view points and perceptions:

1. What is your overall view about solar irrigation pump?
2 What is your view about the subsidy schemes operated for solar pump?
3 What would you suggest to improve the adoption of solar pump irrigation?

The excerpts of the multi-stakeholder survey are summarised in **Table 3.18**. The message that we received from question number 1 on the overall view about the solar irrigation pump is that the solar pumps are working well and no major complaints were received from the farmers using solar pump, which is also reflected during the course of survey conducted among the sample farmers. Almost all the stakeholders have mentioned that a local service centre for solar pump would help the farmers to attend the minor repairs and problems quickly.

Table 3.18: A Summary of multi-stakeholder survey results

Key questions floated	Summary of responses
1 What is your overall view about solar pump irrigation?	1. Solar panel service center needed at a block level. 2. GSM (Global System for Mobile Communications) technology enables farmers to easily operate the solar pump wherever they go. 3. To generate more power from the solar panel, it needs to be cleaned on a regular basis. 4. More space is needed to install the solar panels/pumps. 5. No major complaints received from the solar pump using farmers.
2 What is your view about the subsidy scheme operated for solar pump irrigation?	1. The subsidy scheme followed presently works well. 2. The capital cost of solar pump is very high without subsidy. 3. Solar pump benefits mostly the resource poor marginal and small farmers. 4. A subsidy of 100 percent will help increase the adoption level of solar pump at a large scale.
3 What would you suggest to improve the adoption of solar pump irrigation?	1. The government should create more awareness about the benefits of solar pumps. 2. The government should provide 100% subsidy to small and marginal farmers. 3. The processing period of the application for sanctioning the solar pump needs to be reduced. 4. A judicious rationing of free electricity supply to electric pump will encourage the adoption of solar pump.

Source: Multi-stakeholders survey.

On the question of a subsidy scheme, most of the stakeholders have expressed that the adoption of solar irrigation pump cannot be increased without a subsidy scheme because of the higher requirement of fixed capital cost. While there is no denying the fact that the scheme helps largely the marginal and small farmers, the adoption of solar irrigation can be increased substantially, if a 100 percent subsidy is provided to the farmers. No one reported anything about the involvement of any corruption and influence peddling in sanctioning the solar irrigation pump to the farmers because of the practice of transparent method followed in sanctioning the solar pump.

A few important messages have also emerged from the multi-stakeholder survey on the question of how to increase the adoption of solar irrigation pump at a large scale. As we expected, almost all the stakeholders opined that there is a need to increase awareness among the farmers about the benefits of solar irrigation pump as many farmers have very little understanding about the various benefits of this new climate-friendly irrigation pump. While suggesting a 100 percent subsidy for the marginal and small farmers, the stakeholders have expressed that the time required to process the application for sanctioning the solar pump has to be reduced substantially to increase the adoption of solar pump. Some have mentioned that the electricity supply free of cost to electric pump owning farmers by the Tamil Nadu state discourages the farmers from adopting the solar irrigation pump. Therefore, instead of providing round the clock supply of electricity free of cost, a judicious rationing of free electricity supply would help increase the adoption of solar irrigation pump.

To conclude, the analysis carried out using the sample survey data clearly shows that due to the adoption of solar irrigation pump, the farmers are able to increase the irrigated area, change the cropping pattern from low-value to high-value crops, save water and electricity consumption, reduce the CO_2e emissions, increase the productivity of major crops and net income of different crops. Though the requirement of fixed capital cost for solar irrigation pump is very high, the investment made on the solar pump is economically viable at different discount rates with over 10-year life period under with and without subsidy conditions.

CHAPTER **4**

Major Findings and Recommendations

Introduction:

The solar-powered irrigation pumps are expected to reduce the exploitation of groundwater, save electricity consumption and its costs, increase the income of farmers, reduce global warming by reducing CO2e emission, etc. Therefore, to control the over-exploitation of groundwater and reduce the consumption of electricity, solar-powered irrigation pumps have been promoted with attractive subsidy schemes in India. Given the benefits of Solar-Powered Irrigation Pump (SIP), a few studies have been carried out covering different aspects. Even though solar pumps help in reducing global warming by reducing CO2e emissions, studies have not attempted to estimate its reduction using survey data. Studies are also seldom available on the economic viability of SIPs using properly designed discounted cash flow methodology covering field-level data collected from the farmers using solar pumps and electric pumps. The loss of land due to installation of solar panels and its opportunity cost have also not been studied so far. Solar-powered pumps provide different kinds of benefits to farmers and society, whereas the electric pumps provide different sets of benefits. Unless a comparative analysis is made using data collected from these two groups of farmers, it is difficult to judge whether the benefits generated from solar pump outweigh the benefits of its counterpart electric pump. In this study, therefore, an attempt was made to find out the benefits of solar irrigation pump including its economic viability, using field survey data collected from a total of 304 sample farmers (152 solar pump using farmers and 152 electric pump using farmers) covering four districts of Tamil Nadu state. The major findings and recommendations of the study are presented in this section.

Major Findings of the Study:

1. The household characteristics of the sample farmers using SIP and EIP are not the same. The average age of the farming head using SIP was found to be significantly less as compared to EIP using farmers. Similar to age, the farming experience of the solar pump using farmers was less as compared to the electric pump using farmers. The level of education was relatively better among SIP using farmers (9.36) as compared to EIP using farmers. The survey also reveals that over 99 percent of SIP using sample farmers were from other backward communities (OBCs).

2. The landholding size of SIP using farmers was relatively smaller than its counterpart EIP using farmers. The average landholding size of SIP using farmers was 3.47 acres per household, whereas the same was 3.83 acres per household for EIP using farmers.

3. The main source of irrigation used for cultivating crops by both SIP and EIP using farmers is groundwater. The groundwater area accounted for about 73 percent of the net cropped area of SIP using farmers, whereas the same accounted for about 89 percent for EIP using farmers.

4. A significant difference was observed in the net cropped area, gross cropped area as well as in the gross irrigated area between the two categories of farmers. There was also a difference in the cropping intensity (CI) between the two categories of farmers. The average CI was about 209 percent for SIP using farmers, whereas the same was about 218 percent for EIP using farmers.

5. The average gross irrigated area of the solar pump using farmers before its installation was only 0.38 acre per household, which increased to 6.74 acres per household after the installation, an increase of about 18 times. As a result, the gross cultivated area of SIP using farmers increased from 3.12 acres to 7.28 acres per household. The cropping intensity increased from 100 percent to about 210 percent. The average gross irrigated area of the solar pump was 6.44 acres per household.

6. The cropping pattern of the solar pump (before and after the installation) and electric pump using farmers was not the same. The cropping pattern of SIP using farmers was changed completely after the installation of the solar pump. Among the solar pump using farmers, foodgrain crops accounted for about 89 percent of the cropped area before the installation of solar pumps, which reduced to about 29 percent after its installation. Commercial crops such as coconut, sugarcane and cotton were not cultivated before the installation of solar pumps, but these high-value crops were cultivated covering a good amount of area after the installation of solar pumps. After the installation of the solar pump, the cropping pattern of the solar pumps using farmers was more or less the same as that of the farmers using electric pump.

7. The logit regression estimated to find out the determinants of solar irrigation pump reveals that among the variables that turned out to be with a positive sign of coefficient, the education of the farming head was the only variable that significantly influenced the adoption of solar pumps. Two of the agro-economic factors namely cropping intensity and farm size were negative and significantly influenced the adoption of solar pump. The logit regression results suggest that factors such as education of the farmer, cropping intensity and farm size are more likely to influence the adoption of solar irrigation pumps.

8. There were differences in the ownership pattern of groundwater structures by the solar and electric pump using farmers. The electric pump using farmers owned a total of 163 pumps, whereas the solar pump using farmers owned a total 152 pumps. The average horsepower (HP) size of the pump was relatively higher (6.13) for the solar pump using farmers as compared to electric pump using farmers (6.64). Except for a few farmers belonging to the category of electric pumps, all other farmers were using 5 HP size pumps, which is different from the solar pump using farmers where 56 out of 152 farmers were either using 7.5 HP pump or 10 HP pump.

9. The average operating hours of pumps by the solar pump using farmers was 6.85 hours per day, whereas the same was about 11.23 hours per day for the electric pump using farmers. The difference between the two was about 39 percent.

10. The allocation of irrigated area for different crops was not the same between the solar and electric pump using farmers. Water-intensive crops such as paddy and vegetables accounted for about 26 percent of the total irrigated area among the solar pump using farmers, whereas these same crops accounted for about 22 percent among the electric pump using farmers. The solar pump using farmers allocated more area for the water-guzzling crop namely sugarcane as compared to the counterpart farmers belonging to the category of electric pump. Overall, the solar pump using farmers allocated relatively less irrigated area for foodgrain crops (about 19 percent) as compared to the electric pump using farmers (about 25 percent).

11. The water use pattern followed in different crops by solar and electric pump using farmers was totally different. Although no perceptible differences were found in the number of times each crop was irrigated and the hours used for each turn of irrigation for different crops between the solar and electric pump using farmers, the total HP hours of water used was relatively less for almost all the crops (except pulses) cultivated by the solar pump using farmers as compared to electric pump using farmers. Among different crops, the highest water saving was found in coconut (42.60 percent) followed by tree crops (42.65 percent) and sugarcane (33.08 percent). The solar pump farmers were also able to save a considerable amount of water in relatively more water-consuming crops like paddy (about 15 percent), vegetables (15.51 percent) and maize (24.04 percent) as compared to the same crops cultivated by the electric pump using farmers.

12. The estimate on the consumption of electricity (in kWh/acre) reveals that farmers using solar pumps could save a substantial amount of electricity in different crop cultivation. The overall average calculated by taking into account all the crops considered for the analysis shows that the potential saving of electricity due to the solar pump was 783.68 kWh/acre. The potential electricity saving varied from about 1637 kWh/acre in sugarcane to about 45 kWh/acre in gingelly. Farmers cultivating paddy, groundnut, coconut, cotton and vegetable crops could save 322-416 kWh of electricity per acre due to the adoption of solar irrigation pumps. The estimate also shows that the average potential electricity saving could go up to 976 kWh/acre, in case all the electric pump using farmers shift to solar pump irrigation.

13. The reduction of CO2e emissions estimated based on the potential electricity saving was very high for different crops. The average reduction of CO2e emissions computed for all the crops was about 732 kg/acre, but it widely varied from crop to crop due to variations in the consumption of HP hours of water. The highest reduction of carbon emissions of about 1531 kg/acre was observed in water-guzzling sugarcane crop, whereas the lowest reduction was found in the gingelly crop (about 42 kg/acre), which is less water-consuming.

14. The cost of cultivation varies from crop to crop for both solar and electric pump using farmers. The overall average cost of cultivation worked out for all the crops was a little higher (2.23 percent) for the solar pump using farmers (Rs. 75,844/acre) as compared to the electric pump using farmers (Rs. 74,189/acre). Though no uniform pattern was observed in the cost of cultivation of different crops between the solar and electric pump using farmers, the solar pump using farmers spent relatively less cost for 6 out of 10 crops considered for the analysis. The solar pump using farmers incurred relatively less cost for growing the two most important water-intensive crops namely

paddy (1.19 percent) and sugarcane (7.13 percent) as compared to the electric pump using farmers.

15. No uniform trend was observed in the productivity of crops cultivated by the two categories of farmers, but the solar pump using farmers harvested higher yields per acre in important water-consuming crops namely paddy, coconut, sugarcane and vegetables. The productivity of paddy cultivated by solar pump using farmers was about 3 percent higher over its counterpart farmers, while the same was higher by about 37 percent in vegetable crops. The solar pump using farmers also harvested relatively higher yield of cotton over its farmers who cultivated the same crop using electric pumps.

16. The average net income (in terms of cost A2+FL) computed for all the crops was about Rs. 1,08,434/acre for solar pump using farmers, whereas the same was about Rs. 1,02,828/acre for electric pump using farmers, a difference of about 5.45 percent. The net income from important crops like paddy, coconut, sugarcane, cotton and vegetable crops was relatively higher for the solar pump using farmers as compared to the electric pump using farmers. The net income realized by the solar pump farmers from paddy, which is one the largest crops cultivated by both the categories of farmers, was higher by about 4.34 percent over its electric pump using farmers. The net income from sugarcane, which is another important crop cultivated largely by both categories of farmers, was also considerably higher (10.33 percent) for solar pump farmers than its counterpart farmers using electric pump.

17. The loss of land due to the installation of solar pump was worked out based on the panel size used by the farmers for different HP-size pumps. All the sample farmers in the study area were using solar panel cell size of 72 (6.77 feet long x 3.39 feet wide), which requires 22.95 square feet of land for installing each solar panel. The number of panels required for 5 HP, 7.5 HP and 10 HP pump are 15, 20 and 22 respectively. Following the requirement of panels and HP of the pump, the loss of land was worked out, which varied from 344 square feet for 5 HP pump to 505 square feet for 10 HP pumps.

18. The opportunity cost (net income) of land lost (due to installation of the solar pump) estimated by taking into account the average net income of all the crops was Rs. 862/acre for 5 HP pumps, Rs. 1,150/acre for 7.5 HP pump and Rs. 1,265/acre for 10 HP pump using farmers. Among different crops cultivated by the solar pump using farmers, the loss of net income (opportunity cost) was found relatively high in tree crops followed by vegetables and sugarcane. The opportunity cost of land for cultivating paddy, which is a heavy water-intensive crop, was the lowest (about Rs. 118/acre for 5 HP pump and Rs. 175/ acre for 10 HP pump) among the major crops cultivated by the solar pump using farmers.

19. Most of the farmers have accepted that the installation of solar pump benefits the women one way or the other. The important benefits listed by the respondents are: (a) Women farmers can operate the solar pump easily, which is not possible with diesel pump; (b) Women used to spend a considerable amount of time fetching water for drinking and domestic purposes earlier that has reduced now due to solar pump; (c) Women are able to work on their own farm contributing to crop cultivation, instead of going for wage work earlier; (d) Since the solar pump works only during day time, women farmers are able to manage the irrigation work without any fear and other

security issues; (e) By working on their own farm, work time flexibility for women has increased. (f) Stress faced by the women has reduced substantially by working on their own farm; (g) Women are able to rear quality milch animals due to the availability of water from solar pump.

20. The HP size of the solar pump determines the requirement of fixed capital cost. The capital cost for a 5 HP pump comes to Rs. 1,69,612 with subsidy, but it increases to Rs. 2,42,303 without subsidy. For 10 HP pumps, the capital cost increases from Rs. 3,07,741 with subsidy to Rs. 4,39,630 without subsidy. The farmers using solar pumps received 70 percent of the capital cost as a subsidy through PM-KUSUM scheme, jointly implemented by the central and Tamil Nadu state government.

21. The NPW of the investment estimated for one acre of holding with subsidy was marginally higher than without subsidy for all the HP size of pumps under different discount rates and life periods. At a 12% discount rate with a 15-year life period, the NPW of solar pump investment for 5 HP pump was about Rs. 4,67,138/acre without subsidy, but the same was about Rs. 5,32,040/acre with subsidy. At a 12 percent discount rate, for 10 HP pumps with a 15-year of life period, the NPW was Rs. 3,65,625/acre without subsidy, but the same was about Rs. 4,83,383/acre with subsidy.

22. The BCR also varies considerably when it was estimated with and without capital subsidy and with different life periods of solar pumps. The BCR of investment with subsidy was marginally higher than without subsidy options for all the size of pumps. For 5 HP pumps, with a 15-year life period under without subsidy condition, the BCR was 1.58 at a 15% discount rate, but the same ratio was 1.75 under with subsidy condition. For 10 HP pumps, with a 15-year life period, the BCR was 1.34 at a 15% discount rate, but it was 1.56 under with subsidy condition. The value of BCR increases considerably when the estimate is made based on a 12% and 10% discount rate with a 25-year life period.

23. The investment in solar pump with 5-year life period at a 15 percent discount rate without subsidy was not financially viable to the one-acre holding farmers, as the estimated BCR was only 0.99. This suggests that the farmers owning one acre of land should not adopt solar pump with 10 HP as the capital cost for such a pump size is much larger than 5 HP pump.

24. The value of BCR increases considerably when the estimate was made considering the production cost and gross income realised from one hectare of land, instead of one acre of land. At a 10 percent discount rate with a 15-year life period under subsidy conditions, the estimated BCR was 1.89 for the one acre of land, but the same increased to 2.25, when the estimate was made for one hectare of land. Similarly, under without subsidy condition too, the BCR value increased from 1.69 for one acre of land to 2.13 for one hectare of land.

25. The year-wise computation of net present worth under different discount rates indicates that farmers with one hectare of land could recover the entire capital cost of the solar pump from their income within two years when they use 5 HP and 7.5 HP pump, whereas the 10 HP pumps owning farmers could recover the entire capital cost within three years, at a 10 percent discount rate under subsidy condition with a 15-year life period.

Recommendations:

Though the study shows that solar irrigation pump generates many economic and other benefits to the farmers, the following recommendations may be considered to increase the adoption of solar irrigation pumps on a large scale:

1. The study reveals that the solar irrigation pump helps to save water and electricity besides increasing the income of the farming household. The climate-friendly irrigation pump also helps to reduce global warming by reducing the CO2e emissions. Though subsidy appears not to be a pre-requisite to improve the economic viability of solar pumps as per the study results, it is still needed to expand the widespread adoption of solar pump, in particular, by the small and resource poor farmers. The Tamil Nadu state government gives 90 percent of capital subsidy for SC/ST farmers to encourage the adoption of solar pumps. Therefore, as demanded by the sample farmers, the adoption of solar pump irrigation can be increased substantially, if a 100 percent capital subsidy is given to the farmers willing to adopt this new irrigation pump. From the point of view of public policy, the study result indicates that subsidy can be phased out gradually when this climate-friendly irrigation technology covers to an area adequate enough to expand subsequently on its own through the demonstration effect.

2. Though there are no major complaints received from the sample farmers about the functioning of solar pumps, many farmers demand establishment of service centre at block level so that they can repair the pumps quickly without any delay as and when required.

3. Awareness about subsidy schemes and the benefits of solar irrigation pump is very poor among farmers. The sample farmers were not even able to clearly tell the fixed capital cost of solar pump and the subsidy that they received for the same. Therefore, both the central and state governments should make concerted efforts to increase awareness about the solar pump through TV advertisements and other means to accelerate the adoption of such pumps.

4. About 63 percent of the sample farmers using electric irrigation pump have expressed that the availability of electricity free of cost is the main reason for not adopting the solar irrigation pump. The free of cost electricity supply also allows the farmers to exploit the groundwater recklessly and use it inefficiently for crop cultivation. Therefore, the state governments that supply electricity free of cost can introduce judicious rationing of electricity supply for the farming sector to encourage the farmers to adopt the solar irrigation pump. Alternatively, the governments can explore the possibility of repurposing the electricity subsidy to top-up the capital subsidy on solar pumps.

5. Many farmers have expressed that they have faced extraordinary delays in processing the application for sanctioning solar irrigation pump under the subsidy scheme. The multi-stakeholder survey conducted to understand the overall functioning of the solar pump scheme also reveals the same. Therefore, the central and state governments should fix a timeline for sanctioning the solar pump from the date of receipt of the application so that the adoption can be increased speedily. The introduction of a

single window system or a Special-Purpose Vehicle for accelerating the implementation procedure of the solar pump may help reduce the delay in processing the application.

6. Some of the solar irrigation pump using farmers have adopted drip method of irrigation for cultivating different crops. By adopting the drip method of irrigation, they are also able to save water and the increase productivity of crops. Therefore, to encourage the adoption of drip method of irrigation using solar irrigation pump, innovative financing arrangements shall be provided to those farmers willing to adopt such a method of irrigation using solar pump as recovery is ensured within 2-3 years.

7. As solar-pump owners also use other water-efficient technologies such as micro-irrigation, the policymakers can think of introducing a new scheme integrating PMKSY-Per Drop More Crop and PM-KUSUM to accelerate the adoption of both micro-irrigation and the solar pumps.

8. Since one of the objectives of solar pump schemes is to reduce the over-exploitation of groundwater, the adoption of solar irrigation pump may be made mandatory for the farmers living in areas which are classified as over-exploited districts/taluks/blocks by the Central Groundwater Board.

The benefits of solar irrigation pumps appear to be a win-win proposition for both the individual farmer and the society at large. The expansion of groundwater irrigated area through solar pumps without electricity consumption helps farmers to cultivate high-value crops, increase productivity as well as the net income from the crop cultivation. The reduced exploitation of groundwater, zero consumption of electricity and substantial reduction in CO_2e emissions could benefit the society in a big way by reducing the public cost. There are possibilities that the increased use of solar irrigation pumps by smallholders may also help them to come out from the clutches of poverty permanently. An increased use of solar pumps will also help reduce global warming by reducing the use of fossil fuel, as envisaged by the United Nations' Climate Change Conference COP23. Therefore, the central and state governments must make a concerted effort to increase awareness about climate-friendly solar irrigation pump so that the solar pump can reach every nook and corner of India.

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