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DOES RENEWABLE ENERGY INCREASE FARMERS' WELL-BEING? EVIDENCE FROM SOLAR IRRIGATION INTERVENTIONS IN BANGLADESH

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Abstract

As an alternative clean and climate-friendly energy source, renewable energy has gained increased importance in government policies, in particular regarding the use of sun power to operate irrigation projects. Researchers have found solar-power-based irrigation projects to be reliable, sustainable, and cost-effective, with higher rates of return, and recent studies have mostly focused on these outcomes. In the effort to ensure maximum electricity coverage in off-grid regions by 2041 and to achieve the global agenda of SDG 7, the Government of Bangladesh has recently prepared a draft policy to purchase unconsumed or surplus electricity from solar-run irrigation pumps (SIPs) across the country with the aim of promoting renewable energy, which further laid down the motivation for understanding the impacts of such interventions from the point of view of beneficiaries' well-being. Therefore, this paper particularly looks at the beneficial impacts of solar-powered irrigation using a recent survey of 1,000 solar-powered irrigation user and non-user farming households in selected regions of Bangladesh. Our regression results suggest that solar irrigation facilitates an adequate water supply and reduces the cost of production. However, the IV regression results suggest that SIPs do not significantly increase the agricultural return across all the seasons or plots. Overall, SIP adoption ensures reliability of the water supply (i.e., water adequacy) in addition to accessibility and affordability, implying longer-term implications for farmers' well-being.

Keywords: renewable energy, solar irrigation, agricultural productivity, farmers' well-being, Bangladesh

JEL Classification: Q15, Q16, Q42

Contents

1. INTRODUCTION

Renewable energy has been playing a complementary role in ensuring energy security in many countries. A diversity of green energy projects is available now all over the world. Among these projects, solar irrigation projects provide an attractive alternative to traditional irrigation practices in developing countries, especially in Asia and Africa, keeping in view the huge solar potential and the fact that a significant rural population lives in remote areas that require water for the irrigation of crops. Chandel, Naik, and Chandel (2015) identified solar-powered pumps as a reliable and economically viable alternative to electric and diesel water pumps for the irrigation of agricultural crops, but the large installation costs of solar water pumps require more incentives from the government to make the technology more attractive. Solar irrigation projects are now becoming prominent in the agricultural sector in Bangladesh. Being an agrarian and energy-scarce economy, people expect solar irrigation projects to exert enormous positive impacts on the economy. However, apart from its environmental and other beneficial aspects, our knowledge about their impact on agricultural production is still limited. Therefore, this paper aims to assess the impact of solar irrigation projects on agricultural production in Bangladesh.

Kelley et al. (2010) found solar-powered irrigation systems to be both technically and economically feasible when compared with the life cycle costs of diesel- and grid-based irrigation systems. Khan, Sarkar, and Islam (2013) conducted a feasibility analysis on the use of solar pumps for the purpose of irrigation in Bangladesh. They concluded that solar pumps are more profitable for a period of 5 or more years and that investment in solar pumps is less risky than investment in diesel engine operated pumps.

Several studies have suggested that solar irrigation systems produce economic benefits and have positive impacts on the environment and nutrition. Alaofè et al. (2016) conducted a study in Northern Benin, and their findings implied that solar-powered drip irrigation enhances diversity in crop production as well as dietary habits, thus offering both economic and nutritional benefits. Burney et al. (2010) also found that solar-powered irrigation increases food security. Suman (2018) constructed a report on the impacts of a solar irrigation pump program in the states of Andhra Pradesh and Chhattisgarh in India. The report suggested that the implementation of solar-powered irrigation systems has grossly increased the income of the farmers. It has also reduced the cost of irrigation and the wastage of water and caused a change in the cropping pattern in some areas. Another interesting finding in the report was that, due to the usage of the solar-powered irrigation system, the pressure on the general electrical grid has fallen, resulting in the exporting of surplus power to the grid. It has also increased both the quality and the quantity of the crops. Garg (2018) investigated the potential of solar-powered irrigation in India and pointed out that the implementation of solar-powered irrigation systems can lead to greater economic well-being by reducing the costs incurred for the use of coal and diesel for irrigation and can relax the burden of agricultural electricity subsidies from the government to some extent. Besides, it can result in a significant amount of foreign exchange savings in the process.

Solar irrigation systems are slowly gaining prominence in terms of usage in Bangladesh. The World Bank (2015) reported that solar-powered pumps have reduced the irrigation costs in Bangladesh. Islam, Sarker, and Ghosh (2017) suggested that solar irrigation may be an alternative way to increase the production of crops without creating extra pressure on grid power or diesel fuel and can help to keep the environment clean. They also found it to be cost effective and better suited to sustainable development in agriculture.

The purpose of this study is to estimate the impact of a solar irrigation project on agricultural productivity in Bangladesh as well as to identify other beneficial roles of solar irrigation projects, including energy consumption patterns in various irrigation modes, irrigation costs, and reliability of irrigation. The analysis uses primary data of 1,000 both solar and non-solar farmers from a survey conducted in 2018. Besides descriptive statistics on various aspects of solar irrigation, the study assesses its impact on agricultural production across seasons by applying probit and IV regressions.

The paper proceeds as follows. Section 2 discusses the green infrastructure for irrigation that is available in Bangladesh, with a focus on solar irrigation projects. Section 3 describes the sampling, data, and methodology. Section 4 provides descriptive results on various aspects of solar irrigation, including coverage, accessibility, reliability, and yield, and discusses the regression results on the determinants of access to solar irrigation and the impact of solar irrigation on crop production. Finally, section 6 provides concluding remarks and a few policy recommendations.

2. GREEN INFRASTRUCTURE FOR IRRIGATION: AN OVERVIEW OF SOLAR IRRIGATION PROJECTS

Solar irrigation systems are an innovative and environment-friendly solution for agro-based economies. The Infrastructure Development Company Limited (IDCOL), a public non-bank financial institution, implemented the solar irrigation program in Bangladesh. The program intends to provide rural off-grid areas with an irrigation facility. Solar irrigation systems reduce the dependence on fossil fuels and the demand for electricity from the national grid in irrigation seasons. The program also reduces carbon emissions and at the same time saves millions in foreign currency. Given its immense potential, the program aims to install solar PV-based irrigation systems in areas where there are possibilities to produce three types of crops throughout the year while ensuring safety from flooding, arsenic contamination, and saline water. To work toward this end, IDCOL has set a target to install 50,000 solar irrigation pumps by 2025. Up to December 2018, IDCOL had approved 1,429 solar irrigation pumps, of which 1,186 are already in operation, with a cumulative capacity of about 26.59 MWp. It expects the remaining pumps to become operational shortly. The World Bank, KfW, GPOBA, JICA, USAID, ADB, and BCCRF are supporting this initiative.

Similar to the “fee-for-service model,” IDCOL finances the project under the “ownership model” based on a debt, grant, and equity ratio of 35%:50%:15%. The equity portion comes from the down payment (12%) of the farmers and the partner organizations’ (POs’) own sources (8%). The terms and conditions of the loan from IDCOL to the POs are the same as in the “fee-for-service” model. The financing mechanism of a pump under the “ownership model” is as follows:

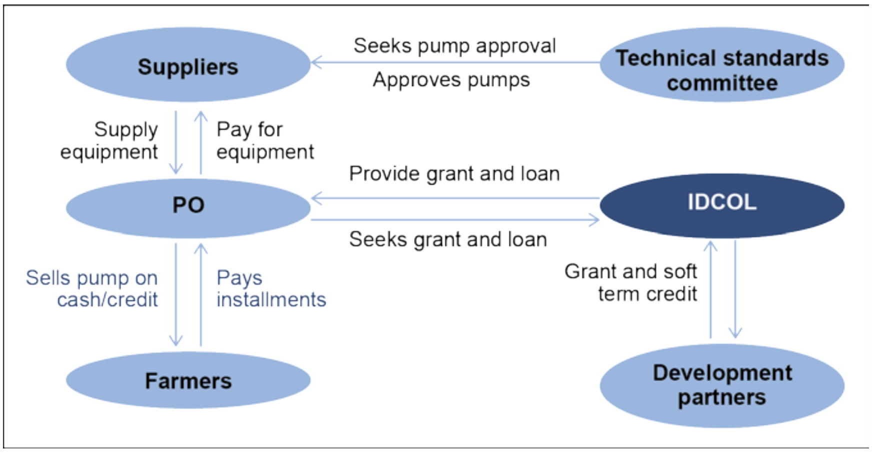
Table 1: Financing Structure under the "Ownership Model"

	Amount in USD
Pump price without subsidy [a]	13,271
Grant support (50%) [b]	6,635
Price to farmer [c = a – b]	6,635
Down payment by farmer (30% of c or 15% of a) [d]	1,991
Loan from PO to farmer [e = c – d]	4,645
IDCOL loan to PO (35% of a) [f]	4,645

Source: IDCOL.

Notably, the PO is expected to extend loans to farmers for a term of 5 years, whereas IDCOL's loan to the PO will be for 8 years. The average installment for investors will be $2,640 per year, whereas the yearly savings in the cost of diesel for investors will be about $2,655. Notably, investors remain at the break-even point throughout the repayment period of 5 years, but they will benefit once they have fully repaid the loan. Any private limited company/NGO/MFI is eligible to obtain financing from IDCOL to install solar irrigation pumps provided that IDCOL deems its financial strength to spend the required equity on the project, experience in activities of a similar nature, and so on to be suitable.

Figure 1: "Ownership Model" Structure for IDCOL Solar Irrigation Projects



Source: IDCOL.

3. SAMPLING DESIGN, DATA, AND METHODOLOGY

The purpose of the impact assessment study is to estimate the socio-economic benefits of solar irrigation for farmers who have adopted it compared with non-adopting farmers in selected locations. For this purpose, the study randomly selected and surveyed a total of 1000 households. Of the total sample, 500 farmers' households had adopted solar irrigation (i.e., treatment) and the remaining 500 households were non-adopting (i.e., control) farmers' households. Therefore, the pertinent question is: *are there any systematic differences between the adopters and the non-adopters of solar irrigation with regard to their basic characteristics?* In this paper, we attempt to find out whether adopters (i.e., treatment) and non-adopters (i.e., control) differ significantly on certain household characteristics. This indicates whether the treatment households are particularly different with regard to their demographic characteristics, level of education, employment and occupation pattern, access to housing, water, and sanitation, asset holdings, income, expenditure, and agricultural land use patterns.

We determined the sample size using the following sampling design formula, which provides the minimum required sample size:

$$n = z^2{}_{\alpha/2}\frac{p(1-p)}{d^2} \times f,$$

where p is the proportion of the required characteristics in the population based on hypotheses rather than observed facts, $z_{\alpha/2}$ is the value of the standardized percentile allowing α probability of bad samples, d is the allowable margin of error, and f is the design effect used for complex surveys involving multi-stage cluster sampling.

Conventionally, α can be taken as 0.05 and f can be taken as 1.5 to 2.0 for most socio-economic surveys in Bangladesh. For example, solar irrigation is new to many of the households, so, theoretically, $p = 0.5$ gives the safest sample size, since $p(1-p)$ takes the highest value in this case. A common choice for the value of the allowable margin of error is $d = 0.0025$. With $f = 2$ and considering the anticipated non-response rate of 5%, the above formula gave a total sample size (household) of 768. Considering the same number of sample households from the control areas, the finally decided sample size for solar irrigation interventions was 1000. The total sample taken consisted of 1000 households (500 treatment households; 500 control households). The division-wise survey data show that the majority of the treatment and control groups were from Khulna (52%), followed by Rangpur (38%). The smaller shares of respondents were chosen from Dhaka (2%), Chittagong (2%), and Rajshahi (6%).

Table 2: Distribution of Samples across Administrative Divisions

Division	**Treatment** (%)	**Control** (%)
Dhaka	2	2
Chittagong	2	2
Rajshahi	6	6
Khulna	52	52
Rangpur	38	38
N	500	500

In addition to the household survey, we conducted a community survey in 49 treatment villages and 50 control villages to control for village-level characteristics. The community survey included the basic village characteristics, access to various infrastructures, IGA activities, price of alternative fuels and consumers goods, and so on. In particular, we conducted one community survey in each of the villages where we conducted a household survey. Further, we carried out a pump owner survey in both treatment and control areas. Overall, we surveyed a total of 102 pump owners from both treatment and control areas.

4. EMPIRICAL RESULTS

This section presents the empirical results. First we discuss some descriptive statistics on various aspects of solar irrigation and then we employ several regression techniques to assess the impact of solar irrigation.

4.1 Descriptive Results

4.1.1 Plot Cultivated

The descriptive statistics in Table 3 suggest that farmers who use solar irrigation (treatment) harvested in a significantly higher number of plots (3 vs 2.7 plots in Kharif-2 and 3.17 vs 2.8 plots in Rabi) and on more acres of land (1.35 vs 1.26 acres in Kharif-2 and 1.4 vs 1.3 acres in Rabi) compared with the group of non-solar irrigation users.[1] Solar irrigation appears to provide farmers with an opportunity to harvest in more areas and plots in relatively longer seasons, like Kharif-2 and Rabi, which also contributed to a higher yield, mainly due to cheaper irrigation opportunities with reliability and accessibility of irrigation water.

Table 3: Average Number of Plots, Area, and Yield

Category	Treatment	Control	Difference	p-Value
Panel A: Kharif-1 Season (mid-March to mid-July)				
Number of plots harvested	1.62	1.65	-0.03	0.76
Area (acres)	.71	.70	.01	0.8
Panel B: Kharif-2 Season (mid-July to mid-November)				
Number of plots harvested	3.00	2.69	0.31	0.00
Area (acres)	1.35	1.26	0.09	0.16
Panel C: Rabi Season (November to April)				
Number of plots harvested	3.17	2.80	0.36	0.00
Area (acres)	1.41	1.32	0.09	0.19

Source: BIDS Survey (2018).

4.1.2 Crop Production-Related Expenditure

The survey results suggest that, throughout all three seasons, the cost of solar irrigation was lower than that of other methods of irrigation that the control group used, in particular diesel-based irrigation. These results strongly support the argument of cost reduction through the use of solar irrigation, especially considering the fact that solar irrigation users harvest in a higher number of plots and on a greater area of land (see Table 4). In addition, because of this trend of a larger use of land among solar irrigation users (treatment), their overall input cost (pesticide, fertilizer, draft animals, power tillers, seeds, and hired labor) was also higher than that of non-solar irrigation users. As a result, the net return from the crop (rice and non-rice) harvest for the farmers who use solar irrigation was higher in all the seasons (except Kharif-2, but insignificantly) than for non-solar irrigation users (Table 4). One possible explanation for this finding could be that the cost of solar irrigation is lower and SIP users get adequate irrigation water, which resulted

[1] There are three harvesting seasons in Bangladesh, known as Kharif-1 (March/April to June/July), Kharif-2 (July/August to November/December), and Rabi (November/December to March/April). Rabi is the longest season and contributes the highest crop production.

in higher net return. Though this is not a causal relationship, we shall investigate the issue using regression techniques in section 4.3.

Table 4: Costs and Returns of Crop Cultivation

Category	Treatment	Control	Difference	p-value
Panel A: Kharif-1 Season (mid-March to mid-July)				
Irrigation cost (Tk per bigha)	1,106.1	1,250.89	–244.79	0.01
Total input cost (Tk per decimal on average)	192.67	204.61	11.94	0.60
Net return on rice (Tk per decimal on average)	138.47	140.76	–2.30	0.70
Net return on non-rice (Tk per decimal on average)	900.14	663.76	236.39	0.02
Panel B: Kharif-2 Season (mid-July to mid-November)				
Irrigation cost (Tk per bigha)	1,217.43	1,410.56	–193.13	0.00
Total input cost (Tk per decimal on average)	177.13	160.11	17.02	0.004
Net return on rice (Tk per decimal on average)	145.96	146.87	–0.91	0.70
Net return on non-rice (Tk per decimal on average)	1675.21	1,617.73	57.49	0.91
Panel C: Rabi Season (November to April)				
Irrigation cost (Tk per bigha)	2,472.91	4,129.73	–1,656.82	0.00
Total input cost (Tk per decimal on average)	244.47	233.44	11.02	0.14
Net return on rice (Tk per decimal on average)	147.09	149.17	–2.08	0.03
Net return on non-rice (Tk per decimal on average)	774.16	628.95	145.21	0.07

Source: BIDS Survey (2018).

4.1.3 Irrigation-Specific Information

Some of the characteristics of solar irrigation are discernible in Table 5. The survey findings suggest that, in all the seasons, the percentage of area covered with irrigation was slightly higher for the control groups than for the solar irrigation users (85.67% vs 92.05% in Kharif-1, 83.05% vs 86.02% in Kharif-2, and 95.89% vs 96.89% in Rabi). One interesting observation is that solar irrigation facilitates the coverage of a comparatively much longer distance between source and plot in every season (96.74 vs 74.51 in Kharif-1, 131.70 vs 82.83 in Kharif-2, and 138.03 vs 75.34 in Rabi). Solar irrigation projects provide irrigation facilities for a longer period in terms of the number of days in all the seasons, which might have contributed to the higher yield. On the other hand, solar irrigation appears to provide irrigation for relatively fewer hours in a day than diesel pumps, which may be due to its lower wastage of water (as it uses submersible pipes) than other modes of irrigation. A larger proportion of farmers using solar irrigation reported that they received adequate water than those using non-solar modes of irrigation, which is a testament to the increased efficiency in irrigation that the use of solar irrigation offers (Table 5).

Table 5: Availability, Utilization, Modes, and Intensity of Solar Irrigation

Category	Treatment	Control	Difference	p-value
Panel A: Kharif-1 Season (mid-March to mid-July)				
Area with irrigation available (%)				
Area with irrigation availed (%)	85.67	92.05	–6.38	0.01
Distance between irrigation plant and plot (ft)	96.74	74.51	22.23	0.06
Number of days irrigated (days)	4.91	4.23	0.68	0.02
Number of hours irrigated per day (hours)	1.82	1.73	0.09	0.45
Received adequate water (yes; %)	41.91	45.17	–3.26	0.25

continued on next page

Table 5 *continued*

Category	Treatment	Control	Difference	p-value
Panel B: Kharif-2 Season (mid-July to mid-November)				
Area with irrigation availed (%)	83.05	86.02	–2.97	0.03
Distance between irrigation plant and plot (ft)	131.70	82.83	48.87	0.00
Number of days irrigated (days)	8.65	7.49	1.17	0.00
Number of hours irrigated per day (hours)	1.74	1.90	–0.16	0.01
Received adequate water (yes; %)	76.13	71.90	4.24	0.01
Panel C: Rabi Season (November to April)				
Area with irrigation availed (%)	95.89	96.89	–1.00	0.15
Distance between irrigation plant and plot (ft)	138.03	75.34	62.69	0.00
Number of days irrigated (days)	32.91	27.89	5.02	0.00
Number of hours irrigated per day (hours)	1.94	2.00	–0.06	0.62
Received adequate water (yes; %)	87.61	77.89	9.72	0.00

Source: BIDS Survey (2018).

4.2 Reduction of Carbon Emissions

Based on the diesel use per acre of land, we estimated the carbon emissions of different types of pumps according to their longevity. Our estimation results suggest that, as the age of diesel pumps increases, their carbon emissions also increase. On average, diesel pumps emit 7.5 kg of carbon dioxide during the three seasons, amounting to 22.3484 kg per acre over the course of a year (Table 6). The variation in carbon emissions across seasons may be due to a reporting bias.

Table 6: Carbon Dioxide (CO_2) Emissions from Diesel Pumps

Category	**Pumps' Estimated Carbon Emissions** (kg)
Carbon emissions per acre (Kharif-1)	Control group
Pump age 1–5 years	5.988
Pump age 6–10 years	8.5492
Pump age 11–15 years	9.2728
Total average (A)	7.9367
Carbon emissions per acre (Kharif-2)	
Pump age 1–5 years	6.6732
Pump age 6–10 years	7.37
Pump age 11–15 years	8.2276
Total average (B)	7.426
Carbon emissions per acre (Rabi)	
Pump age 1–5 years	5.226
Pump age 6–10 years	7.2092
Pump age 11–15 years	7.6648
Pump age 16–25 years and above	7.8524
Total average (C)	6.9881
Overall (A + B + C)	22.3484

Note: We based this calculation on the conversion estimates from the US EPA Centre for Corporate Climate Leadership's 2016 report; that is, 1 liter of diesel burnt = 2.68 kg CO_2.

Source: Authors' calculations.

4.3 Regression Results

4.3.1 Determinants of Access to Solar Irrigation

Given the importance of households' access to a solar irrigation (SI) program, we examine here the determinants of households' access to IDCOL's SI program. We estimate the reduced-form equation as follows:

$$S_i = \alpha + \beta X_i + \varepsilon_i \quad (13)$$

where S_i is a household's SI adoption, X_i is a set of household- and village-level characteristics, and ε_i represents the unobserved random error term. β are unknown parameters requiring estimation.

Table 7: Determinants of Access to Solar Irrigation

Variables	(1) Kharif-1 Season	(2) Kharif-2 Season	(3) Rabi Season
Log (age)	–0.013	0.041	–0.078
	(0.025)	(0.082)	(0.126)
Marital status	0.018	–0.217	0.006
	(0.027)	(0.133)	(0.274)
Formal education	–0.005	–0.056	–0.150**
	(0.014)	(0.043)	(0.062)
House ownership	–0.001	0.026	0.050
	(0.005)	(0.016)	(0.032)
Log (land) (dec.)		0.024	0.124
		(0.126)	(0.157)
Access to sanitation	0.041***	–0.076	0.372**
	(0.012)	(0.080)	(0.162)
Log (total households in village)	–0.028	0.316**	0.479**
	(0.051)	(0.132)	(0.240)
Log (total population in village)	–0.008	–0.378***	–0.030
	(0.043)	(0.118)	(0.202)
Log (landless)	–0.042***	0.381***	0.184**
	(0.016)	(0.058)	(0.090)
Marginal land holders	0.041***	–0.063	0.105
	(0.014)	(0.043)	(0.089)
Small land holders	–0.011	–0.161***	–0.292***
	(0.018)	(0.054)	(0.080)
Medium land holders	0.024*	0.074*	–0.117
	(0.013)	(0.039)	(0.077)
Sponsor effect of SI	0.193***	0.225***	0.569***
	(0.040)	(0.054)	(0.047)
Village meeting effect of SI	0.023	0.195***	0.439***
	(0.021)	(0.070)	(0.052)
Peer effect of SI	0.026	0.573***	0.782***
	(0.021)	(0.037)	(0.033)
Advertising with a loudspeaker effect of SI	0.282	–0.184	
	(0.189)	(0.134)	
Pseudo-R^2	0.25	0.48	0.80
Observations	945	950	941

Note: Robust standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

Source: Authors' calculations.

We consider a household's adoption of SI as the outcome variable. Since the adoption of SI is a dummy variable, we apply the probit model to determine the factors that explain SI access. Table 6 reports the results. We consider the age, gender, and marital status of the owner, household size, agricultural land ownership, income, dwelling conditions, and some awareness-building factors, such as sponsors' meetings, advertising through loudspeakers, peer effects, and so on, as control factors. To assess the characteristics across harvesting seasons, we run several regressions based on the characteristics of SI adoption. The results suggest that some village characteristics, such as a larger population (households), access to sanitation, and land holding (medium sized), are some of the factors that determine SIP adoption in the locality. Apart from that, we find that the sponsor effect (the SI investor's own characteristics), meeting with villagers about SI, and the peer pressure effect are the key determinants of access to solar irrigation.

4.3.2 Impacts of Solar Irrigation

To assess the impact of irrigation on various aspects of crop production, our econometric model specification is as follows:

$$Y_{ijs} = \alpha X_{ij} + \beta V_j + \gamma I_{ijs} + \delta P_{ijs} + \lambda O_{ijs} + \varepsilon_{ijs}$$

Here, Y is the outcome, X is the household-level controls, V is the village-level controls, I is the dummy for the mode of irrigation (solar), P is the total plot size or plot fertility, and O is other inputs. Then we run a season-specific regression for the above equation for the Kharif-1, Kharif-2, or Rabi season. More specifically, Y_{ij} represents the seasonal (i.e., Kharif-1, Kharif-2, and Rabi) outcome for farm household i in village j; I indicates a dummy variable, that is, if the household uses solar irrigation in different seasons = 1 and otherwise = 0; X_{ij} denotes the household-level characteristics (e.g., age, marital status, formal education, house ownership, land ownership, and access to electricity, safe drinking water, and sanitation); V_j indicates the village-level characteristics, which include the village population, households in the village, total number of solar pump users, total number of diesel pump users, landless (below 0.5 acres), marginal land holders (0.5–1 acres), small land holders (1–2.5 acres), medium land holders (2.5–7.5 acres), and so on; α_1 represents the coefficients for seasonal solar irrigation use, household-level characteristics, and village-level characteristics, respectively, and ε_{ij} captures the error term.

4.3.2.1 Impact on the Adequacy of Water

Table 8 represents the impacts of adopting solar irrigation on achieving adequate water for the purpose of irrigation. We used OLS regressions across seasons to determine whether solar irrigation provides an adequate amount of irrigation water compared with diesel-based irrigation. We measured the adequacy of irrigation in terms of three variables: the hours per day during which the land receives irrigation water; the number of days for which irrigation is available in a season; and the interaction between these two to obtain the number of hours for which land receives irrigation in a season. We report the regression results for all the seasons. The results suggest that solar irrigation provides irrigation water for a higher number of days but a lower number of hours, indicating its adequacy and reliability. The reason is that diesel pumps might provide water for a smaller number of days and a greater number of hours just to save the diesel cost, which may not be efficient.

Table 8: Impact of SIP on the Adequacy of Irrigation Water

	Kharif-1		
	(5)	**(6)**	**(7)**
Variables	**Log (No. of Days Irrigation Was Used per Season)**	**Log (No. of Hours Irrigation Was Used per Day)**	**Log (No. of Hours Irrigation Was Used per Season)**
Solar irrigation	0.323***	–0.240**	0.082
	(0.080)	(0.097)	(0.123)
Plot fertility	–0.037	–0.204**	–0.234**
	(0.073)	(0.090)	(0.112)
Distance between source of irrigation and plot (ft)	–0.000	–0.001*	–0.001
	(0.000)	(0.000)	(0.001)
Plot type	–0.135**		
	(0.058)		
Age	0.001	0.001	0.001
	(0.003)	(0.004)	(0.005)
Marital status	0.020	–0.151	–0.099
	(0.106)	(0.190)	(0.260)
Formal education	–0.010	0.052	0.023
	(0.072)	(0.091)	(0.111)
House ownership	–0.667***	–0.643***	–1.409***
	(0.101)	(0.108)	(0.147)
Land ownership	0.000	0.001***	0.001**
	(0.000)	(0.000)	(0.000)
Access to safe drinking water	–1.507***	0.409***	–0.960***
	(0.096)	(0.095)	(0.123)
Access to sanitation	–0.037	0.196	0.139
	(0.294)	(0.243)	(0.432)
Total households in village	–0.001**	0.002***	0.001
	(0.000)	(0.001)	(0.001)
Total people in village	–0.000	–0.000	–0.000
	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	0.000	–0.001*	–0.000
	(0.000)	(0.000)	(0.001)
Landless	0.003**	–0.005***	–0.002
	(0.001)	(0.001)	(0.002)
Landowner (marginal)	0.117*	–0.070	0.063
	(0.070)	(0.094)	(0.115)
Landowner (small)	–0.017	–0.014	0.010
	(0.116)	(0.140)	(0.176)
Landowner (medium)	–0.022	0.022	–0.011
	(0.081)	(0.094)	(0.130)
Constant	3.461***	0.865*	3.875***
	(0.509)	(0.476)	(0.682)
Observations	328	328	328
R-squared	0.166	0.196	0.104

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Table 8 *continued*

Variables	Kharif-2		
	(8) Log (No. of Days Irrigation Was Used per Season)	**(9)** Log (No. of Hours Irrigation Was Used per Day)	**(10)** Log (No. of Hours Irrigation Was Used per Season)
Solar irrigation	0.259***	–0.146***	0.114
	(0.057)	(0.048)	(0.072)
Plot fertility	–0.231***	–0.121***	–0.351***
	(0.052)	(0.042)	(0.061)
Distance between source of irrigation and plot (ft)	–0.000	–0.001***	–0.001***
	(0.000)	(0.000)	(0.000)
Plot type	0.038		
	(0.049)		
Age	0.001	–0.000	0.001
	(0.002)	(0.002)	(0.002)
Marital status	–0.107	–0.034	–0.143
	(0.149)	(0.085)	(0.174)
Formal education	–0.112**	0.099**	–0.011
	(0.053)	(0.046)	(0.064)
House ownership	–0.086	–0.253	–0.352*
	(0.246)	(0.194)	(0.194)
Land ownership	0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)
Access to safe drinking water	–0.052	–0.458	–0.519***
	(0.345)	(0.393)	(0.149)
Access to sanitation	–0.104	0.162	0.054
	(0.154)	(0.118)	(0.207)
Total households in village	–0.001***	0.001***	0.000
	(0.000)	(0.000)	(0.000)
Total people in village	–0.000	–0.000**	–0.000***
	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	0.001***	–0.001***	0.001*
	(0.000)	(0.000)	(0.000)
Landless	0.003***	–0.002***	0.000
	(0.001)	(0.001)	(0.001)
Landowner (marginal)	0.352***	–0.192***	0.154**
	(0.054)	(0.047)	(0.068)
Landowner (small)	0.154**	0.137**	0.283***
	(0.067)	(0.061)	(0.074)
Landowner (medium)	–0.064	–0.043	–0.102*
	(0.051)	(0.045)	(0.057)
Constant	0.387	1.349***	1.877***
	(0.504)	(0.446)	(0.413)
Observations	821	821	821
R-squared	0.366	0.264	0.196

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Table 8 *continued*

	Rabi		
	(11)	**(12)**	**(13)**
Variables	**Log (No. of Days Irrigation Was Used per Season)**	**Log (No. of Hours Irrigation Was Used per Day)**	**Log (No. of Hours Irrigation Was Used per Season)**
Solar irrigation	0.324***	–0.118**	0.205***
	(0.042)	(0.046)	(0.061)
Plot fertility	–0.173***	–0.080**	–0.251***
	(0.038)	(0.039)	(0.053)
Distance between source of irrigation and plot (ft)	0.000	–0.001***	–0.001***
	(0.000)	(0.000)	(0.000)
Plot type	0.045		
	(0.038)		
Age	0.005***	–0.002	0.003
	(0.002)	(0.002)	(0.002)
Marital status	–0.130	–0.034	–0.166
	(0.089)	(0.105)	(0.107)
Formal education	–0.027	0.032	0.008
	(0.041)	(0.044)	(0.058)
House ownership	–0.008	–0.106	–0.129
	(0.288)	(0.226)	(0.425)
Land ownership	–0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)
Access to safe drinking water	0.184	–0.216	–0.043
	(0.207)	(0.283)	(0.340)
Access to sanitation	–0.187***	0.086	–0.100
	(0.060)	(0.113)	(0.117)
Total households in village	–0.001***	0.001***	–0.000
	(0.000)	(0.000)	(0.000)
Total people in village	0.000	–0.000**	–0.000
	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	0.000	–0.000	0.000
	(0.000)	(0.000)	(0.000)
Landless	0.001	–0.002***	–0.001*
	(0.000)	(0.001)	(0.001)
Landowner (marginal)	0.115**	–0.106**	–0.002
	(0.045)	(0.041)	(0.059)
Landowner (small)	–0.025	0.088	0.052
	(0.056)	(0.055)	(0.074)
Landowner (medium)	0.217***	–0.047	0.180***
	(0.038)	(0.037)	(0.049)
Constant	2.406***	1.013**	3.586***
	(0.386)	(0.397)	(0.554)
Observations	958	958	958
R-squared	0.277	0.206	0.168

Note: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Authors' calculations.

4.3.2.2 Impact on the Cost of Production

In Table 9, we assess the impacts of the adoption of solar irrigation on the cost of production in the Kharif-2 and Rabi seasons across plots. Except for plot 5 in the Rabi season, the impact of SIP is negative though insignificant in other plots. For the Kharif-2 season, the impact is also insignificant. The results provide an indication that solar-powered irrigation reduces the cost of production marginally though insignificantly.

4.3.2.3 Impact on Crop Returns

Though solar-powered irrigation does not have a significant impact on the reduction of the cost of production, it is still worth investigating whether the adequacy and reliability of irrigation water make any improvement in the crop pattern that might increase the crop return. It is notable that access to SI might suffer from endogeneity biases and, to overcome any such unobserved selection biases, we run IV regression models in this section. Table 10 reports the second-stage IV regression results for the Rabi season across plots (the results for the Rabi season are reported because this is the biggest rice-harvesting season and requires the most irrigation water). Following the results in Table 7, we consider advertisement/publicity that attracts adoption, knowledge from pump owners/sponsors, knowledge from village meetings, knowledge from friends/neighbors, knowledge from circulating through a loudspeaker, and the distance of the plot from the irrigation plant as instruments that are associated with access to SI but not necessarily with agricultural production. The tests indicate that the instruments are valid and satisfy the identification restrictions.

In Table 10, we report the impacts of solar irrigation on Rabi production using plot-wise information. We report the results for three plots only, mainly to save space. Although our primary focus is on the impacts of solar irrigation interventions (through adoptions) in Bangladesh, our discussions extended beyond accessibility and affordability, and the impacts on reliability (i.e., water adequacy) and the well-being of the beneficiaries through productive income are profound. We found evidence of a significant increase in rice production when associating the adoption of solar irrigation with the adequacy of water, though the marginal effects are negative. Besides water adequacy, the number of irrigation days per season and land ownership significantly improve crop production, in particular rice, during the Rabi season. However, the finding on ownership of land based on land sizes (e.g., landless, marginal, small, and large) does not exhibit consistently robust returns across all plots. In sum, solar-powered irrigation does not have a significant impact on crop returns

Table 9: Impact of SIP on the Cost of Production

	Kharif-2		
	(1)	(2)	(3)
Variables	Log (per Decimal Cost of Production) Plot 1	Log (per Decimal Cost of Production) Plot 2	Log (per Decimal Cost of Production) Plot 3
Solar irrigation	0.018	0.018	–0.004
	(0.025)	(0.025)	(0.032)
Plot fertility	–0.062**	–0.043*	–0.020
	(0.024)	(0.025)	(0.029)
Distance between source of irrigation and plot (ft)	0.000	0.000	–0.000
	(0.000)	(0.000)	(0.000)
Age	0.001	0.001	–0.001
	(0.001)	(0.001)	(0.001)
Marital status	–0.133	–0.068	–0.057
	(0.096)	(0.048)	(0.069)
Formal education	0.066**	0.060**	0.059**
	(0.028)	(0.024)	(0.028)
House ownership	0.091	0.176	0.051
	(0.066)	(0.110)	(0.065)
Land ownership	0.000	–0.000	0.000
	(0.000)	(0.000)	(0.000)
Access to safe drinking water	0.212	0.149	0.096*
	(0.129)	(0.103)	(0.052)
Access to sanitation	–0.164*	–0.227*	–0.140**
	(0.088)	(0.127)	(0.068)
Total households in village	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Total people in village	–0.000	–0.000*	–0.000
	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Landless	0.001**	0.000	0.001*
	(0.000)	(0.000)	(0.001)
Landowner (marginal)	–0.026	0.010	–0.047
	(0.025)	(0.029)	(0.034)
Landowner (small)	0.048	–0.027	0.000
	(0.036)	(0.030)	(0.036)
Landowner (medium)	0.012	0.040*	0.047
	(0.026)	(0.022)	(0.029)
Constant	4.843***	4.858***	5.133***
	(0.207)	(0.165)	(0.169)
Observations	803	670	418
R-squared	0.105	0.080	0.083

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Table 9 *continued*

	Rabi				
	(4)	**(5)**	**(6)**	**(7)**	**(8)**
Variables	**Log (per Decimal Cost of Production) Plot 1**	**Log (per Decimal Cost of Production) Plot 2**	**Log (per Decimal Cost of Production) Plot 3**	**Log (per Decimal Cost of Production) Plot 4**	**Log (per Decimal Cost of Production) Plot 5**
Solar irrigation	–0.039	–0.031	–0.053	–0.061	–0.183**
	(0.032)	(0.034)	(0.035)	(0.051)	(0.071)
Plot fertility	–0.023	–0.038	–0.077**	–0.158***	–0.285***
	(0.028)	(0.029)	(0.031)	(0.054)	(0.095)
Distance between source of irrigation and plot (ft)	0.000**	0.000*	–0.000	–0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age	–0.001	–0.001	–0.000	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)
Marital status	0.073	0.023	0.084	0.127*	–0.175
	(0.079)	(0.055)	(0.088)	(0.069)	(0.180)
Formal education	0.072**	0.028	0.004	0.035	–0.033
	(0.033)	(0.029)	(0.032)	(0.055)	(0.094)
House ownership	0.081	0.116	–0.118	–0.509***	
	(0.183)	(0.167)	(0.096)	(0.155)	
Land ownership	–0.000**	–0.000***	–0.000***	–0.000**	–0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to safe drinking water	–0.099	0.012	–0.062	–0.143	–0.287**
	(0.280)	(0.075)	(0.086)	(0.095)	(0.123)
Access to sanitation	–0.126*	–0.098	–0.086*	0.188	0.267
	(0.070)	(0.072)	(0.049)	(0.141)	(0.371)
Total households in village	0.000*	0.001***	0.000	0.000	0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Total people in village	–0.000*	–0.000***	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	0.000	0.000***	–0.000**	–0.001**	–0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Landless	0.000	–0.000	0.001	0.001	0.001
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Landowner (marginal)	0.104***	0.079***	0.116***	0.018	–0.134
	(0.030)	(0.030)	(0.035)	(0.058)	(0.128)
Landowner (small)	0.118***	0.049	–0.032	–0.042	0.103
	(0.043)	(0.044)	(0.043)	(0.078)	(0.147)
Landowner (medium)	–0.107***	–0.069**	–0.038	–0.002	–0.072
	(0.032)	(0.031)	(0.039)	(0.058)	(0.111)
Constant	4.894***	5.004***	5.330***	5.737***	5.869***
	(0.309)	(0.198)	(0.166)	(0.216)	(0.578)
Observations	912	784	508	275	109
R-squared	0.162	0.141	0.153	0.110	0.251

Note: Robust standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

Source: Authors' calculations.

Table 10: Impacts of Solar Irrigation on Rabi Crop Returns

	Plot 1		
Variables	**Log (Net Return per Decimal)**	**Log (Net Rice Return per Decimal)**	**Log (Net Non-rice Return per Decimal)**
Solar irrigation	0.557	–0.504**	9.571***
	(0.392)	(0.250)	(3.384)
Adequacy of water * solar irrigation	–0.618	0.408*	–9.420***
	(0.384)	(0.245)	(3.324)
Adequacy of water (1 = yes, 2 = no)	0.420***	0.010	1.012
	(0.149)	(0.105)	(0.621)
Total hours of irrigation per season	–0.000		
	(0.001)		
Type of land (1 = high, 2 = medium, 3 = low)	–0.017	0.017	–0.132
	(0.038)	(0.026)	(0.280)
Distance between source of irrigation and plot (ft)	0.000	0.000	0.001
	(0.000)	(0.000)	(0.001)
No. of irrigation days per season	–0.008***	0.003*	0.125***
	(0.002)	(0.002)	(0.040)
Hours of irrigation per day	0.014	0.005	0.063
	(0.028)	(0.003)	(0.081)
Plot fertility	–0.042	–0.002	–0.189
	(0.045)	(0.032)	(0.282)
Age of farmer	–0.000	–0.000	–0.013
	(0.002)	(0.001)	(0.012)
Marital status	0.023	–0.024	1.904*
	(0.135)	(0.094)	(1.062)
Formal education	–0.015	–0.043	–0.131
	(0.048)	(0.033)	(0.276)
House ownership	0.005	0.071	–0.331
	(0.216)	(0.157)	(1.052)
Land ownership	0.000	0.000**	–0.001
	(0.000)	(0.000)	(0.001)
Access to safe drinking water	–0.186	0.067	–0.800
	(0.289)	(0.207)	(1.479)
Access to sanitation	–0.089	0.026	–1.141*
	(0.116)	(0.082)	(0.619)
Total households in village	–0.000	0.000	0.000
	(0.000)	(0.000)	(0.002)
Total people in village	0.000	–0.000	–0.000
	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	0.000	–0.000	0.000
	(0.000)	(0.000)	(0.001)
Landless	–0.000	–0.000	0.004
	(0.001)	(0.000)	(0.005)
Landowner (marginal)	0.000	–0.000	0.002
	(0.000)	(0.000)	(0.002)
Landowner (small)	0.003***	0.000	–0.005
	(0.001)	(0.001)	(0.005)
Landowner (medium)	–0.003***	–0.000	–0.006
	(0.001)	(0.001)	(0.006)
Constant	6.231***	5.713***	6.166**
	(0.437)	(0.299)	(2.520)
Observations	907	748	159
R-squared	0.077	–0.009	–0.333

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Table 10 *continued*

	Plot 2		
Variables	**Log (Net Return per Decimal)**	**Log (Net Rice Return per Decimal)**	**Log (Net Non-rice Return per Decimal)**
Solar irrigation	–1.067**	–0.864***	0.859
	(0.486)	(0.300)	(3.315)
Adequacy of water * solar irrigation	0.990**	0.790***	–1.013
	(0.474)	(0.297)	(3.294)
Adequacy of water (1 = yes, 2 = no)	–0.199	–0.203*	–0.143
	(0.151)	(0.113)	(0.276)
Total hours of irrigation per season	0.001*		
	(0.001)		
Type of land (1 = high, 2 = medium, 3 = low)	–0.020	–0.020	0.008
	(0.035)	(0.024)	(0.131)
Distance between source of irrigation and plot (ft)	0.000	–0.000	0.001*
	(0.000)	(0.000)	(0.001)
No. of irrigation days per season	–0.006***	0.003	0.141***
	(0.002)	(0.002)	(0.025)
Hours of irrigation per day	–0.053**	–0.021**	–0.044
	(0.023)	(0.010)	(0.043)
Plot fertility	–0.073*	–0.083***	0.175
	(0.043)	(0.029)	(0.150)
Age of farmer	0.000	0.000	0.002
	(0.002)	(0.001)	(0.006)
Marital status	0.096	0.031	0.987*
	(0.121)	(0.075)	(0.599)
Formal education	0.048	0.027	0.106
	(0.046)	(0.030)	(0.153)
House ownership	0.133	0.145	–0.659
	(0.255)	(0.169)	(0.847)
Land ownership	0.000	0.000***	–0.000
	(0.000)	(0.000)	(0.000)
Access to safe drinking water	–0.039	–0.005	
	(0.259)	(0.154)	
Access to sanitation	0.059	0.093	0.593
	(0.116)	(0.079)	(0.369)
Total households in village	0.000*	0.000	0.002**
	(0.000)	(0.000)	(0.001)
Total people in village	–0.000***	–0.000	–0.000**
	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	–0.000	–0.000	–0.001
	(0.000)	(0.000)	(0.001)
Landless	–0.000	–0.000	0.000
	(0.001)	(0.000)	(0.003)
Landowner (marginal)	0.001**	0.001**	0.001
	(0.000)	(0.000)	(0.001)
Landowner (small)	0.002*	–0.001	–0.003
	(0.001)	(0.001)	(0.003)
Landowner (medium)	–0.003***	0.000	–0.007**
	(0.001)	(0.001)	(0.004)
Constant	6.231***	5.906***	4.720***
	(0.408)	(0.270)	(1.183)
Observations	779	601	178
R-squared	0.010	–0.154	0.296

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Table 10 *continued*

	Plot 3		
Variables	**Log (Net Return per Decimal)**	**Log (Net Rice Return per Decimal)**	**Log (Net Non–rice Return per Decimal)**
Solar irrigation	–1.743**	0.068	–0.217
	(0.763)	(0.370)	(0.141)
Adequacy of water * solar irrigation	1.685**	–0.083	0.000
	(0.754)	(0.370)	(0.000)
Adequacy of water (1 = yes, 2 = no)	–0.285	0.157	–0.189
	(0.214)	(0.120)	(0.256)
Total hours of irrigation per season	0.001		
	(0.001)		
Type of land	0.084*	0.047	0.249**
(1 = high, 2 = medium, 3 = low)	(0.044)	(0.029)	(0.104)
Distance between source of irrigation	–0.000*	–0.000	–0.001
and plot (ft)	(0.000)	(0.000)	(0.000)
No. of irrigation days per season	–0.003	0.005***	0.122***
	(0.002)	(0.002)	(0.030)
Hours of irrigation per day	–0.052	0.002	–0.055
	(0.033)	(0.014)	(0.041)
Plot fertility	0.018	–0.030	0.233*
	(0.052)	(0.033)	(0.140)
Age of farmer	–0.001	0.001	–0.006
	(0.002)	(0.001)	(0.005)
Marital status	–0.008	0.033	0.343
	(0.155)	(0.093)	(0.456)
Formal education	–0.080	0.019	–0.186
	(0.054)	(0.033)	(0.141)
House ownership	0.165	0.114	
	(0.383)	(0.208)	
Land ownership	0.000*	0.000**	0.000
	(0.000)	(0.000)	(0.000)
Access to safe drinking water	–0.043	–0.073	–0.047
	(0.311)	(0.208)	(0.619)
Access to sanitation	0.064	0.032	
	(0.151)	(0.082)	
Total households in village	0.001**	–0.000	0.002***
	(0.000)	(0.000)	(0.001)
Total people in village	–0.000**	0.000	–0.000***
	(0.000)	(0.000)	(0.000)
Total diesel pump users in village	–0.000	0.000**	0.000
	(0.000)	(0.000)	(0.001)
Landless	0.000	–0.000	0.007***
	(0.001)	(0.001)	(0.003)
Landowner (marginal)	0.001**	0.001	0.001
	(0.001)	(0.000)	(0.001)
Landowner (small)	0.001	0.000	–0.006*
	(0.001)	(0.001)	(0.003)
Landowner (medium)	–0.003**	–0.001	–0.005*
	(0.001)	(0.001)	(0.003)
Constant	6.069***	5.410***	5.252***
	(0.572)	(0.344)	(0.883)
Observations	500	374	126
R-squared	–0.107	0.143	0.458

Note: Standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

Source: Authors' calculations.

5. CONCLUSION

The purpose of the impact assessment study is to assess the benefits of solar irrigation compared with the non-solar-based irrigation that farmers use in selected locations. The cost of solar irrigation is relatively lower than that for diesel irrigation. The results suggest that farmers harvest in a higher number of plots and areas due to solar irrigation, which indicates better accessibility and affordability of solar irrigation. However, the aspect that we found to be crucial in our analysis is reliability through water adequacy. Therefore, the reliability, accessibility, and affordability features of solar irrigation prompted farmers to harvest in more areas and plots in relatively longer seasons, like Kharif-2 and Rabi, which contributed to a higher yield, enhancing farmers' well-being as well. A noteworthy point is that we did not find a similar better outcome of solar irrigation across the plots, which may be due to various issues, including cost aspects. Therefore, from the policy perspective, inconsistencies in our findings indicate further scope for cost reduction, contributing to the longer-term agricultural income potential of the farmers. We can also translate this into vulnerability reduction due to price shocks contributing to the longer-term well-being of the farmers from the demand-side perspective. From the supply-side perspective, multiple use of SIP pumps, selling of surplus solar electricity, and so on, could help SIP owners reduce the cost of solar irrigation, which will also enhance the welfare of the farmers.

Solar irrigation is free from carbon emissions and therefore it has a positive impact on the environment. Based on the diesel use per acre of land, we estimated the carbon emissions from different types of pumps based on their longevity. Our estimation results suggest that, as the age of the diesel pumps increases, their carbon emissions also increase. On average, diesel pumps emit 7.5 kg of carbon dioxide in the three seasons, amounting to 22.3484 kg per acre over the course of a year.

Finally, solar irrigation provides an opportunity to irrigate a larger amount of land due to reliability, affordability, and accessibility, though it has not yet contributed positively enough to higher returns from harvesting. Moreover, it is free from carbon emissions and therefore contributes to reducing air pollution. More awareness-building efforts are necessary in this regard so that more farmers can benefit. Multiple benefits of solar irrigation projects are achievable. During the off-season, farmers can use solar electricity for other income-generating purposes as well as to supply electricity to households.

Though the financing for investments in SIP is now provided by IDCOL on an equity–grant–ownership basis, a market-based financing solution involving spillover revenue sharing could be a viable option for private sectors. For this reason, the government can explore the possibilities of green bond or green credit guarantee schemes based on spillover benefits (Hossain, Yoshino, and Taghizadeh-Hesary, 2019). Our findings on SIP adoption strongly emphasize the continuation and upgrading (including scaling up) of the existing initiatives of the sponsors, including arrangements regarding village meetings and peer effect action plans. Apart from renewable energy financing, it is necessary to take into account groundwater level depletion and arsenic contamination for longer-term sustainability. To ensure comprehensiveness from the maximum coverage point of view to fulfill the targets of the global sustainability agenda (i.e., SDG 7), gender inclusiveness could be explored further from both the program (in particular through non-user farming households) and the policy perspective in the medium to long term. Therefore, as an alternative clean and climate-friendly energy source, proper policy guidelines with more inclination toward market-based solutions can make solar irrigation projects a very lucrative option for agrarian economies like Bangladesh.

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