INITIATIVE ON Transforming Agrifood Systems in South Asia

CGIAR

SoLAR Solar Irrigation for Agricultural Resilience

# Adaptation co-benefits of solar irrigation:

## Evidence from Bangladesh

Work Package 5, Research Note: 3
December 2022

## ABOUT THIS RESEARCH NOTE

The mitigation benefits of solar irrigation pumps (SIPs), when those SIPs replace diesel pumps, are well understood. What is not equally known are the adaptation co-benefits of SIPs. This brief evaluates the co-benefits of using SIPs instead of widely used diesel pumps for farmers in Bangladesh. It estimates the impact of access to SIP on household and crop levels outcomes for improving farmer livelihoods and food security. In doing so, it explores the potential pathways of these impacts.

## KEY STUDY FINDINGS

1. Access to solar irrigation has positive impacts on yields, value of outputs, and added value for dry season irrigated boro paddy.
2. These effects, particularly that of higher yields of boro paddy, are explained by a combination of three pathways:
    - The first and strongest pathway is the release of constraints related to water uses for SIP users with SIP irrigated plots receiving more water especially before transplanting and in the late vegetative stage of crop growth.
    - Second, SIP users benefit from lower costs of irrigation without any associated increase in other input costs.
    - The third pathway is a change in time allocation with SIP users spending less time on irrigation..

## BACKGROUND

In Bangladesh, groundwater irrigation supported by 1.34 million diesel pumps and 270,000 electric-run pumps is the backbone of the agricultural sector (GoB, 2019). Despite recent progress towards electrification (Varshney et al. 2023), the permits system for electricity connections and stringent institutional processes make access to the electricity grid constrained for many farmers. Diesel pumps therefore continues to provide access to groundwater but GHG emissions from the agricultural sector in Bangladesh for 2014–15 are 76.79 million tons (Mt) carbon-dioxide equivalent (CO2e) (Saptoka et al., 2021). In this context, solar irrigation is emerging as one of the ways for mitigating emissions from agriculture, while also providing other co-benefits..

# CONTEXT

In Bangladesh, since the early 1980s progress toward food security have been largely supported by an agri-food system relying on the access to groundwater irrigation and especially diesel pumps (Mukherji et al., 2021). Now, solar irrigation pumps are promoted by the government and donors to cut GHG emissions while maintaining strategic access to groundwater for food security and ensuring sustainable use of the groundwater resources.

The Infrastructure Development Company Limited (IDCOL), a Government-owned financial company, is the primary agency for financing and implementing SIPs in Bangladesh. They have installed nearly 1600 SIPs following a ‘fee-for-service’ model consistent with public-private partnership principles. Partner organizations, referred to as sponsors, buy the SIP and the related equipment by taking grants and loans from IDCOL. Approximately 50% of the cost is received as a grant by the sponsor and another 30% as a loan from IDCOL. The remaining amount, referred to as equity, has to be paid directly by the sponsor. The sponsor then operates the SIP and sells water to farmers in exchange for a fee. This fee is used to cover the operational costs (paid operator and maintenance costs) and mostly to recover the investment and to pay back the loan to IDCOL.

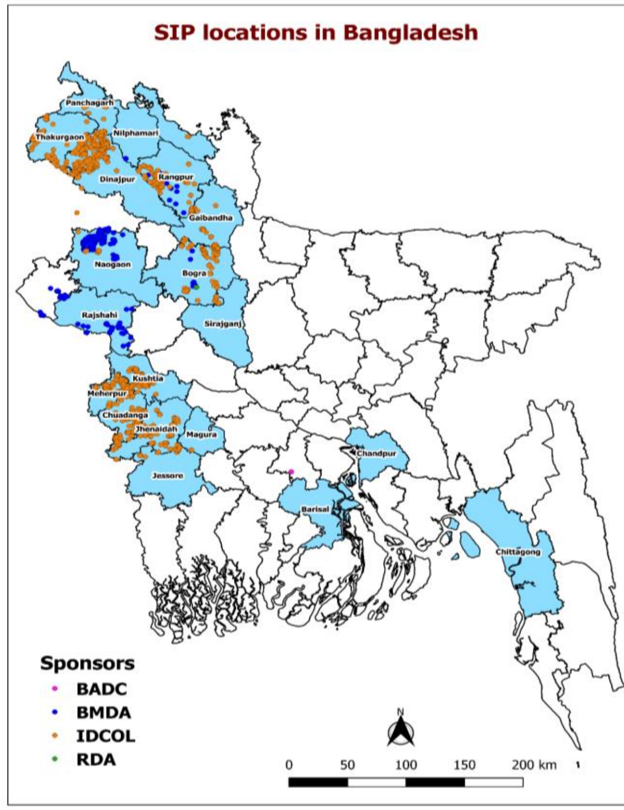



**Figure 1 – Solar Irrigation Pump (SIP) Locations in Bangladesh**

## OBJECTIVES

This brief analyses the impact of accessing solar irrigation pumps for farmers in Bangladesh. Beyond the initial objective of climate change mitigation, what are the co-benefits of using SIP for farmers? More specifically, what is the impact of access to SIP on farm-level (yields, profitability) and household-level (food security and diversity, wealth index) outcomes? What are the pathways at play which explain these outcomes (agricultural inputs and costs, time allocation, irrigation practices)?

## DATA AND METHODS

The research questions are answered based on the analysis of a household survey conducted among 900 households from 60 villages in July and August 2021. Out of the 60 villages, one third are treated villages (group A) in which IDCOL supported SIP are operational, one third are pipeline sites (group B) where it was already confirmed that IDCOL supported SIPs will become operational in 2022, and one third are control sites (group C) where SIPs are not operational and there were no plans to implement them either. Control villages (group C) were selected by matching with the pipeline villages (group B) on secondary and village level data which included variables like access to irrigation and informal water markets, agricultural practices, and quality of groundwater. Households in each village were selected by a proportional random sampling among SIP users (group A), future SIP users (group B), and village farmers (group C).

Matching and regression adjustment methods are used to estimate the Average Treatment Effects (ATE) and Treatment Effects on the Treated (ATT). Robustness checks for placement bias are addressed by considering inverse-probability-weighted (IPW) matching method and inverse-probability-weighted regression-adjustment (IPWRA) estimators at household and plot levels. Conditional independence, common support, balance and tests for multiple hypothesis are also checked and tested.

**Fig 2 – Enumerators on their way to conduct household surveys**

## STUDY FINDINGS

Starting with household-level Starting with household-level co-benefits (Table 1), the analysis shows that access to SIP's impact on food insecurity is negative, as expected, and significant for the ATE. Further, there is no significant effect of access to solar irrigation on food consumption and diversity and on the household wealth index.

The impact on the farm-level outcomes are then considered for the two main crops cultivated by the households in this region: *aman* paddy cultivated during the monsoon season and *boro* paddy cultivated in winder during the dry season (Table 1). We find no significant impact of access to SIP on outcomes related to *aman* cultivation. On the contrary, *boro* crops cultivated on plots irrigated from SIP produce significantly higher yields. The value of the output and the revenue generated per unit of land are also significantly higher for SIP-irrigated crops as compared to similar diesel-irrigated plots.

Still using regression analysis, we then explore three pathways that may explain the household and farm-level impacts of access to SIP which are previously identified (Figure 3). These pathways build on the literature as well as on qualitative evidence collected among SIP users. The effects may first be related to a **change in the irrigation practices** (Pathway A) once farmers irrigate from SIP instead of using their own diesel pump or buying water from the diesel pump owners.

**Table 1 - Effect of SIP on household and farm-level outcomes**

| | | Household level outcomes | | | | Aman crop | | | Boro crop | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Food Consumption score (FCS) | Household Dietary Diversity Scale (HDDS) | Food Insecurity Experience Scale | Wealth Index | Yield (Kg/Acre) | Value of output per area (BDT/Acre) | Revenue (value of output-cost) per area (BDT/Acre) | Yield (Kg/Acre) | Value of output per area (BDT/Acre) | Revenue (profit-cost) per area (BDT/Acre) |
| ATE | | 2.157 | 0.298 | -0.168* | -0.049 | -8.98 | -493.282 | -64.043 | 92.283 | 2323.906 | 3362.722* |
| | | *0.124* | *0.235* | *0.067* | *0.575* | *0.891* | *0.76* | *0.97* | *0.292* | *0.257* | *0.086* |
| ATT | | 1.245 | 0.309 | -0.086 | -0.176 | -98.755 | -1684.7 | -1803.65 | 229.893** | 5775.578** | 6500.244*** |
| | | *0.552* | *0.235* | *0.43* | *0.061* | *0.33* | *0.453* | *0.499* | *0.029* | *0.014* | *0.003* |
| *Sample size* | *SIP* | *243* | *243* | *243* | *243* | *255* | *255* | *255* | *210* | *210* | *210* |
| | *Non SIP* | *600* | *600* | *600* | *600* | *441* | *441* | *441* | *297* | *297* | *297* |
| | *Total* | *843* | *843* | *843* | *843* | *696* | *696* | *696* | *507* | *507* | *507* |

Note: Results are presented here are from nearest neighbour propensity score matching. *P*-values in italic. *** stands for 1 percent of significance, ** for 5 per cent and * for 10 percent.

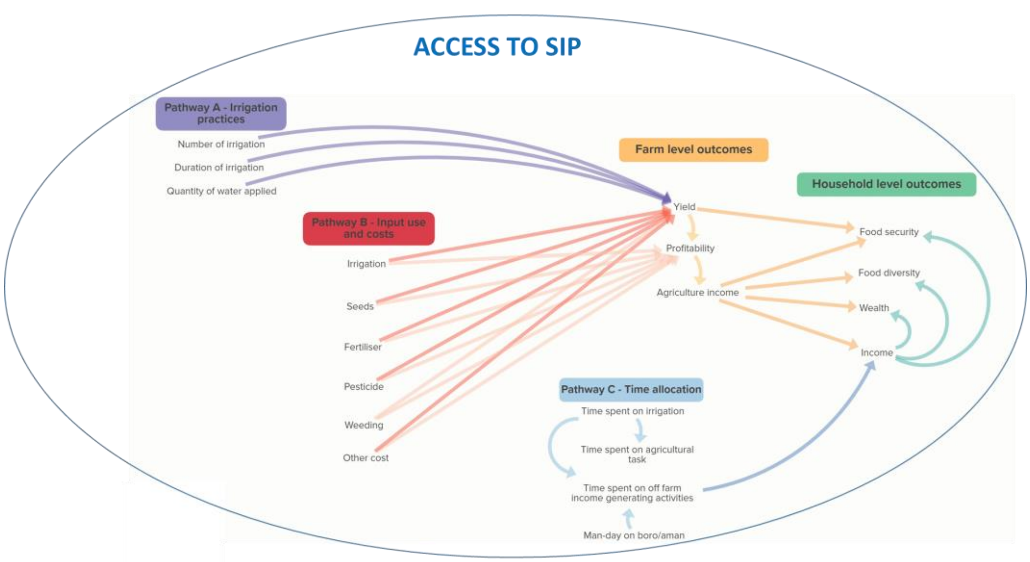
This pathway is confirmed since access to SIP has a positive and significant impact on the total number of purchased irrigations provided to the *boro* paddy crop (Table 2). With higher flow rates, the average irrigation duration from SIP is lower than those provided by diesel pumps. However, using the depth of water lying on the plot at the end of the irrigation as a proxy for the quantity of water applied, access to SIP has a positive impact on the quantity of water used throughout the season and, more significantly before transplanting and in the second vegetative stage of the crop. This result argues for carefully targeting the areas where solar irrigation development can be promoted in line with groundwater resource recharge (Shamsudduha et al., 2022).

**Table 2 - Pathway A – Change in irrigation practices and water allocation, winter season *boro* rice crop**

| | | Number of own irrigations | Number of purchased irrigations | Total number of irrigations | Average duration of one irrigation per area | Total depth of water applied | Depth of water applied before transplanting | Depth of water applied vegetative stage 1 | Depth of water applied vegetative stage 2 | Depth of water applied mid-season stage | Depth of water applied late season stage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ATE | | -8.696*** | 9.272*** | 0.576 | -49.249*** | 156.232 | 97.814* | -85.042 | 154.374* | 0.203 | -7.501 |
| | | 0 | 0 | 0.544 | 0 | 0.502 | 0.078 | 0.13 | 0.079 | 0.996 | 0.81 |
| ATT | | -9.348*** | 9.243*** | -0.105 | -58.755*** | -4.099 | 17.191 | -43.559 | -51.39 | 41.112 | 30.1 |
| | | 0 | 0 | 0.815 | 0 | 0.98 | 0.472 | 0.395 | 0.387 | 0.466 | 0.371 |
| *Sample size* | *SIP* | *210* | *210* | *210* | *210* | *210* | *210* | *210* | *210* | *210* | *210* |
| | *Non SIP* | *297* | *297* | *297* | *297* | *297* | *297* | *297* | *297* | *297* | *297* |
| | *Total* | *507* | *507* | *507* | *507* | *507* | *507* | *507* | *507* | *507* | *507* |

Note: Results are presented here are from nearest neighbour propensity score matching. P-values in italic. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

**Fig 3 - Pathways to co-benefit of SIP access**



The second pathway relates to how the inputs are being allocated by farmers to their plots and to the costs of these inputs (Pathway B). We find that while the cost of irrigation is significantly lower for SIP users both for their *aman* and *boro* crops (Fig 4), this saved cost is not necessarily reinvested in other inputs (Table 3) and instead contributes to higher value added.

**Fig 4 - Cost of irrigation for boro (BDT/Acre)**

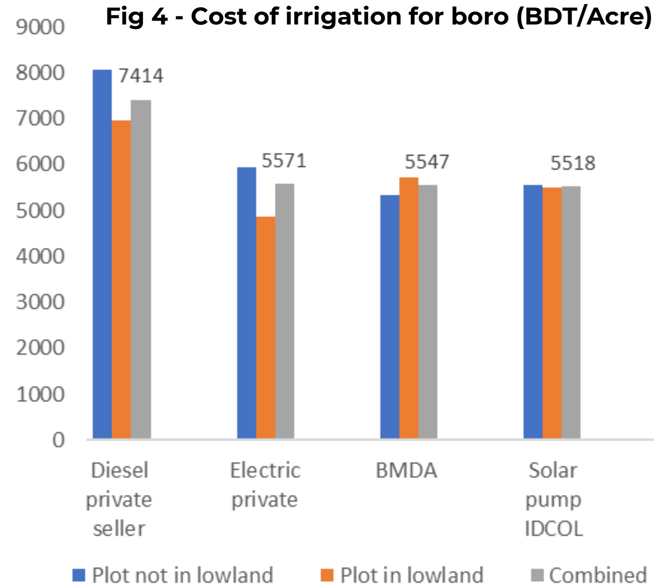



**Table 3 - Pathway B – Reallocation of inputs and costs**

| | | Aman crop | | | | Boro crop | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost of seeds per area (BDT/Acre) | Cost of pesticide per area (BDT/Acre) | Cost of fertilizer per area (BDT/Acre) | Cost of weeding per area (BDT/Acre) | Cost of seeds per area (BDT/Acre) | Cost of pesticide per area (BDT/Acre) | Cost of fertilizer per area (BDT/Acre) | Cost of weeding per area (BDT/Acre) |
| ATE | | 17.767 | 20.612 | -131.004 | 22.168 | 172.143 | -470.26 | -453.885 | -88.302 |
| | | *0.728* | *0.949* | *0.583* | *0.813* | 0.083 | 0.123 | 0.118 | 0.549 |
| ATT | | 134.083* | 232.571 | 230.017 | 72.712 | 21.864 | -491.569 | -296.874 | 153.065 |
| | | *0.054* | *0.744* | *0.622* | *0.518* | 0.779 | 0.014 | 0.296 | 0.423 |
| *Sample size* | *SIP* | *255* | *255* | *255* | *255* | *210* | *210* | *210* | *210* |
| | *Non SIP* | *441* | *441* | *441* | *441* | *297* | *297* | *297* | *297* |
| | *Total* | *696* | *696* | *696* | *696* | *507* | *507* | *507* | *507* |

Note: Results are presented here are from nearest neighbour propensity score matching. P-values in italic. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

**Table 4 - Pathway C – Change in time allocation**

| | | Household level | | | |
|---|---|---|---|---|---|
| | | Individual time spent on irrigation (hour/day) | Individual time spent on farm (hour/day) | Individual time spent off farm (hour/day) | Adoption of off-farm livelihoods |
| ATE | | -0.56** | -0.098 | -0.152 | 0.015 |
| | | *0.011* | *0.68* | *0.335* | *0.71* |
| ATT | | -0.708*** | -0.064 | -0.121 | -0.025 |
| | | *0.001* | *0.765* | *0.64* | *0.628* |
| *Sample size* | *SIP* | *243* | *243* | *243* | *243* |
| | *Non SIP* | *600* | *600* | *600* | *600* |
| | *Total* | *843* | *843* | *843* | *843* |

Note: Results are presented here are from nearest neighbour propensity score matching. P-values in italic. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

Finally, the third possible pathway is the reallocation of time by the farmers and their household members (Pathway C). First, with the fee-for-service model, SIP users spend less time on irrigation during the peak time of the dry season. Second, we don't identify any impact of SIP access on time spent on off-farm activities or the adoption of other income-generating activities which would have positively impacted the wealth of the household for example.

## CONCLUSION AND RECOMMENDATION

The empirical results from this analysis suggest that beyond its effect on climate change mitigation, access to solar irrigation has co-benefits at the household and farm level for farmers in Bangladesh. At the household level, access to SIP tends to reduce food insecurity. At the farm level, access to SIP increases the yield, the value of output and the value added for *boro* paddy, the main income-generating and water-intensive crop grown in the region. These effects derive from three pathways that have been tested: changes in irrigation practices, changes in time allocation, and changes in input uses and costs. Out of the three and in the relatively short time since the adoption of solar irrigation for the beneficiaries, the change in irrigation practices seems to be the stronger pathway to explain higher yields of *boro* paddy for SIP users.

In the Bangladeshi context, where the development of solar irrigation remains costly and relatively slow and while the benefits from omitted emissions are under-valued (Rennert et al., 2022), these results argue for a more accurate and comprehensive measurement of the benefits associated with solar irrigation. It also positions solar irrigation as one of the only mitigation strategies without trade-off and instead with co-benefits for farmers' adaptation to climate change and shocks.

# REFRENCES


Mukherji, A.; Buisson, M.C.; Mitra, A.; Sarkar, A.; Yashodha. 2022. Sonar Bangla Revisited: Groundwater development and agrarian change in Bangladesh and West Bengal since the 1970s. IWMI-ACIAR. https://www.aciar.gov.au/project/wac-2020-182

GoB (2019), Minor Irrigation Survey Report 2017-18, Ministry of Agriculture, Government of Bangladesh, Bangladesh Agricultural Development Corporation (BADC). Dhaka, Bangladesh. http://badc.portal.gov.bd/sites/default/files/files/badc.portal.gov.bd/page/c23bdffd_22fd_4f15_8fc4_b1fc7a91a36a/2020-09-01-14-15-bbb411c861df9a62fdafcccbd8025192.pdf

Rennert, K., Errickson, F., Prest, B.C., Rennels, L., Newell, R.G., Pizer, W., Kingdon, C., Wingenroth, J., Cooke, R., Parthum, B. and Smith, D., 2022. Comprehensive evidence implies a higher social cost of CO2. Nature, 610(7933), pp.687-692. doi: 10.1038/s41586-022-05224-9

Sapkota, T.B., Khanam, F., Mathivanan, G.P., Vetter, S., Hussain, S.G., Pilat, A.L., Shahrin, S., Hossain, M.K., Sarker, N.R. and Krupnik, T.J., 2021. Quantifying opportunities for greenhouse gas emissions mitigation using big data from smallholder crop and livestock farmers across Bangladesh. Science of the Total Environment, 786, p.147344. doi: 10.1016/j.scitotenv.2021.147344

Shamsudduha, M., Taylor, R.G., Haq, M.I., Nowreen, S., Zahid, A. and Ahmed, K.M.U., 2022. The Bengal Water Machine: Quantified freshwater capture in Bangladesh. Science, 377(6612), pp.1315-1319. doi: 10.1126/science.abm4730

Varshney, D.; Banerjee, A.; Chakraborty, S.; Mukherji, A. 2022. The energy-irrigation nexus in Bangladesh: implications of rapid rural electrification on informal groundwater markets. New Delhi, India: International Water Management Institute (IWMI). CGIAR Initiative on Transforming Agrifood Systems in South Asia (TAFSSA); Solar Irrigation for Agricultural Resilience (SoLAR). 10p.

## AUTHORS
**Marie-Charlotte Buisson**: International Water Management Institute
**Archisman Mitra:** International Water Management Institute
**Thierry Hounsa:** Department of Economics, University of Oxford
**Ahasan Habib:** NGO Forum for Public Health
**Aditi Mukherji**: International Water Management Institute

## SUGGESTED CITATION
Buisson, M.-C.; Mitra, A.; Hounsa, T.; Habib, A.; Mukherji, A. 2022. *Adaptation co-benefits of solar irrigation: evidence from Bangladesh*. New Delhi, India: International Water Management Institute (IWMI). CGIAR Initiative on Transforming Agrifood Systems in South Asia (TAFSSA); Solar Irrigation for Agricultural Resilience (SoLAR). 9p.

## FUNDING ACKNOWLEDGEMENT
We would like to thank the Swiss Agency for Development and Cooperation (SDC) and all funders who supported this research through their contributions to the CGIAR Trust Fund: https://www.cgiar.org/funders/

**To learn more, please contact:**
m.buisson@cgiar.org

**To learn more about TAFSSA, please contact:**
**t.krupnik@cgiar.org**; **p.menon@cgiar.org**

## ABOUT TAFSSA
TAFSSA is a CGIAR regional integrated initiative to support actions that improve equitable access to sustainable healthy diets, improve farmers' livelihoods and resilience, and conserve land, air, and water resources in South Asia. For more details about the initiative see https://www.cgiar.org/initiative/20-transforming-agrifood-systems-in-south-asia-tafssa/

## ABOUT SoLAR
Solar Irrigation for Agricultural Resilience (SoLAR) is a South Asia regional initiative involving Bangladesh, India, Nepal, and Pakistan, implemented by IWMI and funded by the Global Programme of SDC. The project aims to support the climate-compatible development of energy and water systems in rural South Asia for resilient livelihoods. For more details see: https://solar.iwmi.org/

## ABOUT CGIAR
CGIAR is a global research partnership for a food secure future. Visit https://www.cgiar.org/research/cgiar-portfolio to learn more about the initiatives in the CGIAR research portfolio