**Solar Pump Irrigation in Bangladesh: Current Status, Future Prospects and Key Challenges**

**ABSTRACT**

Solar pump Irrigation (SPI) has gained popularity in Bangladesh as a sustainable substitute for conventional diesel and grid-connected pumps. This shift is driven by the need to enhance energy security, reduce greenhouse gas emissions, and mitigate the environmental impact of irrigation practices. Overall, this study aimed to address the present condition, challenges and opportunities associated with the use of solar pump irrigation in Bangladesh. Data were collected from various articles of indexed journals, organizational reports, research reports, and mass media publications. In Bangladesh, there are 8 divisions, 64 districts, 5556614 ha irrigated agricultural land, and 16.5 million farmers. At present, SPI is operating in 5 divisions and more than 25 districts, covering about 1% of total irrigated agricultural land and reaching approximately 125,000 farmers. On the way to expanding solar pump irrigation poses several challenges including high initial costs, limited technical expertise, slow progress toward government targets, the need for continued investment in infrastructure, inadequate policy frameworks, and concerns related to water scarcity and climate change. Initiative taken to reduce these challenges, the country can enhance agricultural productivity, promote sustainable practices, and contribute to a greener future.

# **Keywords:** Solar pump irrigation, prospect, challenges, renewable energy, Bangladesh agriculture

# **1. INTRODUCTION**

The prevailing irrigation practices in Bangladesh heavily rely on diesel-powered pumps, with 83% of the 1.57 million irrigation pumps being diesel-operated, consuming around 1 million tons of diesel annually and emitting 7 million tons of carbon dioxide, contributing to environmental degradation (Akter & Bari, 2022; Hossain et al., 2015b). The government's initiative, announced in 2023, aims to replace all diesel pumps with Solar Pump Irrigation (SPI) to mitigate greenhouse gas emissions, enhance energy security, and reduce the nation's dependence on expensive diesel fuel (Mitra et al., 2024). Although grid-connected pumps account for a portion of irrigation, they face challenges such as frequent load shedding and low voltage, hindering optimal irrigation levels (Islam et al., 2022a). The reliance on traditional manual methods results in time-consuming practices, excessive water usage, and significant water losses due to over-irrigation (Khan, 2021). Additionally, the escalating groundwater depletion rate of 2 meters per year threatens irrigation sustainability, leading some regions to limit access to groundwater for food production and drinking water (Biswas & Hossain, 2013). The most used irrigation method in Bangladesh is surface irrigation and shallow tube wells (STWs), which have experienced a significant increase in usage since their import liberalization after the 1988 floods and 1990 cyclones, leading to a tripling of the total irrigated area from 1.7 million hectares in 1985-86 to 5.6 million hectares in 2018-19, with a notable rise in STW irrigated area from 34% to 54%. On the other hand, the proportion of surface-water irrigated areas decreased from 48% to 27% during the same period, and the share of area under traditional and gravity flow methods substantially decreased (Islam et al., 2022a; Mitra et al., 2023). Despite the predominant use of diesel pumps, there is a growing interest in alternative and sustainable technologies like solar pumps to address environmental concerns and improve the efficiency of irrigation practices in Bangladesh (Hossain et al., 2015b).

A Solar Pump Irrigation (SPI) utilizes solar energy through photovoltaic panels to power water pumps, offering a sustainable and environmentally friendly alternative for agricultural irrigation, reducing reliance on diesel and grid electricity, particularly beneficial in off-grid or remote areas (Joy et al., 2023; Prutzer et al., 2023). The history of solar pump irrigation in Bangladesh dates back to the early 2000s when the government and various organizations started promoting solar-powered irrigation systems as a sustainable and environmentally friendly alternative to traditional diesel engine-operated pumps (Khan, 2021). The introduction of solar pump irrigation aimed to address the challenges associated with conventional irrigation practices, such as the high cost of diesel and the environmental impact of diesel-powered pumps (Biswas & Hossain, 2013). In the 1980s, the testing of Photovoltaic (PV) solar pumps for low-lift small-scale irrigation at the Bangladesh Agricultural Research Institute (BARI) in Gazipur marked the initial exploration of solar pump irrigation technology in the country (Hossain et al., 2015b).

Despite facing challenges such as high initial costs and limited technical expertise, the government and various organizations have initiated efforts to promote the use of solar pump irrigation, including the "Solar Irrigation Pump Project" launched in 2014 (Islam et al., 2022b). As of March 2023, the progress towards the government's target of solar pump irrigation installations has been slow, with only 150 pumps installed out of a target of 2000 by June 2022 (Islam et al., 2022b). However, the increasing demand for sustainable and efficient irrigation practices is anticipated to drive the continued growth of solar pump irrigation in Bangladesh (Islam et al., 2022a). The Infrastructure Development Company Limited (IDCOL) is a pioneer in developing the Solar Pump Irrigation (SPI) business model in Bangladesh. IDCOL has financed around 84% of the installed capacity in solar pumps. SPI account for about 8% of the total solar capacity installed in the country (Mitra et al., 2023b). The country has set a target to install 10,000 SIPs by the year 2027 (Islam & Hossain, 2022a). Other organizations like Barind Multipurpose Development Authority (BMDA), Bangladesh Agricultural Development Corporation (BADC), and Bangladesh Rural Electrification Board (BREB) have also promoted solar irrigation pumps in the country (Anonymous, 2021). The present study will investigate the current status of SIP in the context of area coverage by SIP against demand. In addition, the challenges and prospects of SIP in Bangladesh agriculture will also be explored in the study.

# **2. METHODOLOGY**

The study mostly relied on secondary data. Related articles from various peer-reviewed journals, organizational reports, and mass media reports were used to prepare the article. We considered the publications and reports on the last 10 years (from 2015 to 2024) to emphasize the recent information. Google scholar, PubMed and various websites were searched to collect data and information. Solar pump irrigation, renewable energy, fossil fuel in irrigation, and Bangladesh agriculture were the keywords for searching. We finalized the research articles and reports for use in the study in two consecutive stages. In the first stage, all papers and reports were collected with direct and indirect relevance to the study. In the second stage, the articles and publications are considered to have direct relevancy and good indexed journals. In addition, we used reports from various related organizations such as Infrastructure Development Company Limited (IDCOL), Sustainable and Renewable Energy Development Authority (SREDA), Bangladesh Bureau of Statistics (BBS), Bangladesh Rural Electrification Board (BREB), Bangladesh Power Development Board (BPDB) etc. Besides collecting data from various secondary sources, we also had some informal discussions with the key people of the sectors involved in the solar pump irrigation program in Bangladesh (Kabir and Rainis, 2013). This was done to cross check and common understanding of the collected data. After data collection, we stored, organized, and presented data based on the objectives of the study.

# **3. RESULT AND DISCUSSION**

## The objectives of the study are to highlight the present status of Solar Pump Irrigation (SPI) regarding irrigation area coverage and providing support to the farmers, the prospect of SPI, and the challenges to expanding SPI for sustainable agricultural development of Bangladesh. This section presented an overview of the findings based on these objectives.

## **3.1 Present status of using solar pump irrigation in Bangladesh**

Bangladesh has made great strides in the past several years in the use of SPI, and a number of organizations have played a major role in this technology's broad acceptance. The Infrastructure Development Company Limited (IDCOL) has become a key organization leading Bangladesh’s effort to mainstream solar pumps. Approximately 40,000 farmers have benefited from the 1,969 SPI that IDCOL has successfully constructed in 25 districts as of 2021, covering 16,000 hectares of land (Table 1). IDCOL plans to build 50,000 SPI by 2030, with an installed capacity of 46.98 MW, demonstrating the increasing acceptance of solar irrigation pumps as a sustainable alternative (IDCOL, 2023).

**Table 1.** Number of SPI installed in Bangladesh by different organizations and their respective capacity

|  |  |  |
| --- | --- | --- |
| **Organization** | **Quantity** | **Installed Capacity** |
| IDCOL | 1969 | 42.08 MW |
| BMDA | 792 | 4.37 MW |
| BADC | 233 | 3.06 MW |
| BREB | 249 | 2.32 MW |
| RDA | 25 | 292.08 kW |
| BARD | 9 | 99 kW |
| BARI | 37 | 51 kW |
| BRRI | 9 | 25.68 kW |
| **Total** | **3323** | **52.31 MW** |

(Source: SREDA, 2023)

The implementation of SPI has also been aided by other organizations including Barind Multipurpose Development Authority (BMDA), Bangladesh Agricultural Development Corporation (BADC), Rural Development Authority (RDA), and Bangladesh Rural Electricity Board (BREB), further broadening the landscape. Together, these groups have put more than thousands of SPI in place, spanning more than thousands of hectares and helping countless farmers. Currently, 3323 solar irrigation pumps are installed with a cumulative capacity of 52.31 MW by the above-mentioned organizations effort. The location of these SPI sites has been chosen based on regions with less flooding, less arsenic, high demand for Boro rice cultivation and high density of diesel pumps (Figure 1).

The solar irrigation pump plays a crucial role in harnessing renewable energy from solar sources, contributing to Bangladesh's growing solar energy capacity of 966.92 MW out of the total renewable energy installed capacity of 1200.91 MW (SREDA, 2023). With an allocation of 66.48 MW, these pumps efficiently convert sunlight into electricity, exemplifying a sustainable approach to agricultural irrigation while reducing dependency on conventional energy sources.

In Bangladesh, there are 8 divisions, 64 districts, 5556614 ha irrigated agricultural land, and 16.5 million farmers. At present, SPI is operating in 5 divisions and more than 25 districts, covering about 1% of total irrigated agricultural land and reaching approximately 125,000 farmers. Though the current coverage of SPI is low against the demand, the approach has a positive trend to expand.



## **Figure 1.** Solar Irrigated Pump (SIPs) location in different places in Bangladesh (Mitra et al., 2021 and Buisson et al., 2023)

## **3.2 Future prospects of using solar pump irrigation in Bangladesh**

Solar pump irrigation (SPI) in Bangladesh has the potential to revolutionize irrigation practices, offering significant benefits to the agricultural sector and the environment. SPI can reduce dependence on diesel and grid electricity for irrigation, lower irrigation costs, increase crop productivity, and decrease greenhouse gas emissions. These advantages make SPI prospects better in Bangladesh. A short description of these advantages, along with others, are mentioned below.

**3.2.1. Enhanced Water Accessibility**

SPI provides reliable access to water for irrigation, reducing dependence on erratic rainfall and increasing the availability of water for crops. They can also enhance water use efficiency, leverage surface water sources, minimize the risks of over-withdrawal of groundwater, and promote sustainable water use through capacity-building initiatives for farmers, especially in areas with limited access to traditional energy sources. These measures collectively contribute to enhanced water accessibility for agricultural purposes, supporting sustainable farming practices and improving overall water management (Salehin et al., 2023).

**3.2.2 Reduced Dependency on Traditional Energy Sources**

It is observed from Figure 2 that within the SPI command area, the use of diesel for irrigation is only 8% during the kharif 1 (1st part of summer crop season), 3% during kharif 2 (2nd part of summer crop season), and 22% during the Rabi season (winter crop season). This showcases a substantial decrease in reliance on diesel for irrigation within the areas covered by SPI. The SPI survey data reveals that farmers who previously relied entirely on diesel (from their own pump or buying) have shifted to solar pumps. This transition demonstrates the successful replacement of traditional diesel-based irrigation with solar pumps, reflecting a positive impact on reducing dependency on conventional energy sources (Buisson et al., 2023).

In summary, the data suggests that Solar Irrigation Pumps in Bangladesh have successfully reduced the dependence on traditional energy sources, especially diesel, in the irrigation process. Farmers have transitioned to solar-powered solutions, contributing to environmental sustainability and economic efficiency in the agriculture sector. Adopting solar-powered irrigation aligns with sustainable development goals, mitigating environmental impact and ensuring a consistent energy supply. SIP have the potential to alleviate pressure on the electrical grid and offer surplus power for export.

 Source: Buisson et al., 2023)

 **Figure 2.** Percentage of the SPI command area irrigated by different sources

**3.2.3. Save time in farming**

The data indicates in Figure 3 that farmers using fee-for-service IDCOL solar pumps spend significantly less time on irrigation activities compared to those using diesel pumps (owned or hired). Specifically, SPI users spend 1.25 hours per day on irrigation during the Boro season, while those using their own diesel pumps spend 2.7 hours/day, and hired diesel machine users spend 1.8 hours/day. This reduction in the time spent on irrigation is attributed to the operational model of fee-for-service solar irrigation, where much of the work is handled by the operator (Buisson et al., 2023).

Source: (Buisson et al., 2023)

Figure 3. Average hours spent on irrigation on a typical day during the Boro crop season

**3.2.4.** **Cost-Effectiveness and Financial Viability**

The use of SPI is more cost-effective and financially viable (Akter and Bari, 2020). According to Hossain et al. (2022) solar-powered drip and alternate furrow irrigation systems were found to be more profitable than low-lift pumps for the cultivation of vegetables. The benefit-cost ratio of mini and large solar systems was found to be 1.50 and 1.42, respectively. So, solar pump irrigation for vegetable production would be more profitable for the farmers. Another study conducted by Sunny et al. (2022) found that the use of SPI reduces the cost of the farmers for irrigation. The findings are presented in Table 2 where the study used three different treatment effect models: inverse probability weighting (IPW), regression adjustment (RA), and inverse probability weighted regression adjustment (IPWRA). The adoption impact results in Table 2 show that the adoption of solar irrigation has a significant impact on irrigation cost, Return on Investment (ROI), and production cost. Specifically, farmers who adopted solar irrigation facilities could minimize irrigation costs by an average of 1.88 to 2.22%, obtain 4.48 to 8.16% higher ROI, and reduce production costs by 0.06 to 0.98% compared to non-adopters (Table 2).

Table 2. Average treatment effects of solar irrigation adoption on outcome variables

|  |  |  |  |
| --- | --- | --- | --- |
| Outcome variables | IPW | RA | IPWRA |
| ATT | RobustSE | % ↓/↑ than POM | ATT | RobustSE | % ↓/↑ than POM | ATT | RobustSE | % ↓/↑ than POM |
| Irrigation cost | -0.17 \*\*\*  | 0.042  | 1.90 ↓ | -0.16\*\*\* | 0.029 | 1.88↓ | -0.20\*\*\* | 0.037 | 2.22↓ |
| ROI | 0.08 \*  | 0.044  | 5.49 ↑ | 0.12\*\*\* | 0.042 | 8.16↑ | 0.08\* | 0.042 | 4.48↑ |
| Production cost | −0.06  | 0.043  | 0.57↓ | -0.06\*\* | 0.028 | 0.06↓ | -0.10\*\*\* | 0.037 | 0.98↓ |

(Source: Sunny et al., 2022)

**3.2.5. Climate Resilience**

SPI is considered a climate-smart strategy, and it reduces emissions of 3 million tons of carbon dioxide equivalent per year (ADB, 2023). At present, the average mitigation of 2.8 metric tons of CO2 per SPI translates into a social benefit of 518 USD per year (Mitra et al., 2023). Diesel pump water irrigation has several environmental impacts, such as greenhouse gas emissions, air pollution, noise pollution, and groundwater depletion. One of the main impacts is the emission of carbon dioxide (CO2) from burning diesel fuel, which contributes to global warming and climate change. According to Buisson et al., (2023), diesel-based irrigation pumps in Bangladesh emit about 6.6 million tons of CO2 per year, which is equivalent to the annual emissions of 1.4 million cars. Another study (Anonymous, 2021) estimates that replacing diesel pumps with solar irrigation pumps (SIPs) could reduce CO2 emissions by 2.6 million tons per year, which is equivalent to the annual emissions of 0.6 million cars. Bangladesh is vulnerable to the impacts of climate change, including erratic rainfall patterns and increased temperature variability. Solar pump irrigation enhances climate resilience by providing farmers with a reliable water source, even during periods of water scarcity or changing climate conditions. This adaptability is crucial for ensuring agricultural sustainability and safeguarding the livelihoods of farming communities.

**3.2.6 Empowering Smallholder Farmers**

According to Buisson et al. (2023), SPI promotes equity in access to irrigation, serving marginal and tenant farmers through the fee-for-service model. SPI provides more affordable access to irrigation services compared to traditional diesel pumps, with a lower cost for irrigation. SPI also reduces the time farmers spend on irrigation. Therefore, smallholder farmers can utilize the extra time to engage in other income-generating activities. Alternatively, it can be said that this time-saving can empower smallholder farmers by allowing them to allocate their time and resources to other productive activities, contributing to their overall economic empowerment.

## 3.3 Problems of using Solar Pump Irrigation in Bangladesh

Though there are multidimensional advantages of SPI in Bangladesh the way to make available and expand the approach to farmers has some problems also. A short description of those challenges or problems are mentioned below.

**3.3.1 High Initial Investment**

The high initial investment cost of SPI poses a significant barrier for farmers, especially small-scale and marginal farmers with limited resources. Despite government subsidies and financing, the remaining contribution required from the farmer or entrepreneur who owns the pump can be financially challenging. Additionally, the operational cost of SPI, mainly for maintenance and repair, adds to the overall cost of using solar pumps for irrigation. In contrast, traditional diesel pumps may not require the same level of upfront investment as SPI, although they incur ongoing fuel expenses (Salehin et al., 2023). Farmers need to carefully consider the financial implications when choosing an irrigation technology. While the initial cost of installing a solar irrigation system is higher than that of a diesel-based system, solar irrigation systems become more profitable over a period of 5 or more years and present a lower investment risk compared to diesel engine-operated pumps. The government of Bangladesh has taken steps to address this challenge by providing financing for SPI investments through IDCOL on an equity-grant-ownership basis (IDCOL, 2023).

**3.3.2 Weather Dependency**

SPI is affected by weather dependency, as its effectiveness is influenced by sunlight availability. This can lead to fluctuations in the pump's productivity, particularly during periods of reduced sunlight, which may affect the reliability of irrigation operations (Hussain et. al., 2023). SPI are also unable to operate at night, posing a limitation for farmers who require nighttime irrigation. To address this challenge, some SPI is equipped with battery storage systems that can store excess energy generated during periods of high sunlight for use during periods of low sunlight or at night. Again, due to fog during the early Boro rice cultivation season, the water supply from solar pumps gets affected, which is not the case for electric pump sellers who can sell throughout the day and night. The limited operation hours of SIP due to sunlight variation pose challenges for continuous irrigation and crop yield, particularly in areas with inconsistent sunlight.

**3.3.3 Technical Limitations**

Historically, solar irrigation pumps (SIPs) have faced technical limitations, including high panel costs and susceptibility to adverse weather conditions, which can impact their effectiveness (Salehin et al., 2023; Hussain et al., 2023). The instruments required for solar pump installation are not readily available in our country. So, we have to depend on imported materials.

**3.3.4 Limited Operation Hours**

 As SPI depends on the weather and also on the pump operator, the operation hours are limited and not according to the always farmers’ needs (Hussain et al., 2023). Sometimes, crops become hampered because of the negligence of the solar pump operator. An ICT-based smart irrigation system may help to reduce the barrier. This is because smart irrigation systems may not require a highly involved pump operator to provide irrigation.

**3.3.5 Compatibility and Complexity of Large-Scale Systems**

In Bangladesh, SPI irrigation is mainly provided for rice crops. Rice is a major crop in Bangladesh and is intensively cultivated all over the country in a large area. The compatibility of SPI with large-scale, especially for water-intensive crops, is limited, presenting a barrier to their widespread application. Due to limited capacity or a lower number of solar panels, the SPI can’t support irrigation on a large scale. On the other hand, the complexity of large-scale SPI systems, including their electricity requirements and infrastructure limitations, further adds to the challenges of adoption (Hussain et. al., 2023).

**3.3.6 Energy Storage and Battery Maintenance**

Energy storage requirements, such as the need for batteries, not only add to the cost but also introduce complexity to the system. The maintenance and replacement of batteries in SPIs also incur additional costs and technical requirements, further contributing to the challenges associated with their use (Haque, 2022). The development of low-cost batteries for storage or backup may help to reduce the barrier.

# **CONCLUSION**

# The current status of solar pump irrigation in Bangladesh signals progress, with organizations like IDCOL, Grameen Shakti, and BRAC driving widespread acceptance. The installed capacity of 66.48 MW across 4,339 SPI covers 35,360 hectares, emphasizing the increasing recognition of solar irrigation pumps as a sustainable alternative. The prospects of solar pump irrigation in Bangladesh are bright, offering diverse benefits to agriculture, and the approach reaches 125,000 farmers, outlining the transformative potential of the solar pump environment. SPI exhibits a substantial reduction in reliance on traditional energy, particularly diesel, evidenced by low diesel usage within SPI command areas. This shift from diesel to solar pumps contributes to environmental sustainability and economic efficiency in agriculture. Solar pump irrigation enhances water accessibility, reduces dependence on traditional energy sources, improves crop yields, and proves cost-effective and financially viable for farmers. Despite these promising aspects, challenges persist, notably the high initial investment, weather dependency, technical limitations, and restricted pumping capacity. Addressing these challenges is crucial for the widespread application of SPI. However, the long-term economic benefits, financial viability, and positive environmental impact position solar pump irrigation as a worthwhile investment. In the future, solar pump irrigation in Bangladesh relies on continued collaboration among government agencies, NGOs, and private entities to overcome challenges and maximize the potential benefits. Addressing financial barriers, improving technical expertise, and enhancing the adaptability of SPI will contribute to the sustainable and equitable adoption of solar irrigation technology. Collaborative efforts among policymakers, researchers, and stakeholders are essential to create an enabling environment for the widespread adoption of solar pump technology, contributing to the advancement of Bangladesh's agricultural landscape.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

# **REFERENCE**

Asian Development Bank (ADB), 2023. Road Map to Scale Up Solar Irrigation Pumps in Bangladesh (2023–2031), December, 2023.

Akter, T., & Bari, K. E. (2022). Understanding the Economics of Solar Powered Irrigation System in Bangladesh. International Journal of Multidisciplinary: Applied Business and Education Research, 3(10), 2013–2027. https://doi.org/10.11594/ijmaber.03.10.15

Anonymous, (2021). *Solar Irrigation for Agricultural Resilience ( SoLAR ) Solar Irrigation in Bangladesh : Current Situation and Future Prospects Summary Report of Webinar 3*, International Water Management Institute (IWMI).

Biswas, H., & Hossain, F. (2013). Solar Pump: A Possible Solution of Irrigation and Electric Power Crisis of Bangladesh. International Journal of Computer Applications, 62(16), 1–5. https://doi.org/10.5120/10161-4780

Buisson, M.-C.; Mitra, A.; Osmani, Z.; Habib, A.; Mukherji, A. 2023. Impact assessment of Solar Irrigation Pumps (SIPs) in Bangladesh: a baseline technical report. New Delhi, India: International Water Management Institute (IWMI). 75p. doi: https://doi.org/10.5337/2022.230

Haque, A. 2022. A report on Solar irrigation systems are gaining popularity but challenges remain published on the daily newspaper The Business Standard, dated 9 September 2022.

Hossain, M. A., Hoque, M. A., Kamar, S. S. A., Rahman, M. A., & Mottalib, M. A. (2022). Economic Feasibility of Solar Irrigation Pumps in Southern Region of Bangladesh. *BANGLADESH JOURNAL*, 241.

Hossain, M. A., Hassan, M. S., Mottalib, M. A., & Ahmmed, S. (2015a). Technical and economic feasibility of solar pump irrigations for eco-friendly environment. *Procedia Engineering*, *105*. https://doi.org/10.1016/j.proeng.2015.05.047

Hossain, M. A., Hassan, M. S., Mottalib, M. A., & Hossain, M. (2015b). Feasibility of solar pump for sustainable irrigation in Bangladesh. International Journal of Energy and Environmental Engineering, 6(2), 147–155. https://doi.org/10.1007/s40095-015-0162-4

Hussain, F.; Maeng, S.-J.;Cheema, M.J.M.; Anjum, M.N.; Afzal,A.; Azam, M.; Wu, R.-S.; Noor, R.S.;Umair, M.; Iqbal, T. Solar IrrigationPotential, Key Issues and Challenges in Pakistan. Water 2023, 15, 1727.

 IDCOL, 2023. Infrastructure Development Company Limited. Renewable Energy, https://www.idcol.org/old/bd

Islam, M. T., & Hossain, M. E. (2022a). Economic feasibility of solar irrigation pumps: A study of northern Bangladesh. International Journal of Renewable Energy Development, 11(1). https://doi.org/10.14710/IJRED.2022.38469

Islam, M. T., Hossain, M. E., & Abdullah-Albaki, C. (2022b). Life Cycle Costs Comparison Between Solar, Diesel, and Grid electricity Powered Small Irrigation Pumps: Evidence From Northern Bangladesh. Journal of Sustainability Science and Management, 17(10), 88–97. https://doi.org/10.46754/jssm.2022.10.007

Joy, S. S., Khan, I., & Swaraz, A. M. (2023). A non-traditional Agrophotovoltaic installation and its impact on cereal crops: A case of the BRRI-33 rice variety in Bangladesh. Heliyon, 9(7). https://doi.org/10.1016/j.heliyon.2023.e17824

Kabir, M.H. and Rainis, R. (2013). Integrated pest management farming in Bangladesh: present scenario and future prospect. Journal of agricultural technology, 9(3):515-527.

Khan, S. A. (2021). Disseminating an Automated Irrigation System. 4(1), 14–25.

Mitra, A.; Alam, M. F.; Yashodha, Y. 2021. Solar irrigation in Bangladesh: a situation analysis report. Colombo, Sri Lanka: International Water Management Institute (IWMI). 39p.

Mitra, A., Buisson, M., Osmani, A. Z., & Mukherji, A. (2024). Unleashing the potential of solar irrigation in Bangladesh : key lessons from different implementation models. Environ. Res. Lett. 19: 014024

Mitra, A., Buisson, M., Osmani, A. Z., & Mukherji, A. (2023). Mitigation and beyond: Multiple co-benefits of solar irrigation in Bangladesh. International water Management Institute, Solar Issue Brief Series No. 2

Prutzer, E., Patrick, A., Ishtiaque, A., Vij, S., Stock, R., & Gardezi, M. (2023). Climate-smart irrigation and responsible innovation in South Asia: A systematic mapping. In *Ambio*. https://doi.org/10.1007/s13280-023-01895-4

Salehin, M. , Joy, J. , Hasan, S. , Babui, M. and Khan, F. (2023) Utilization of Solar Energy in Irrigation Systems in Bangladesh. *Energy and Power Engineering*, 15, 468-481. doi: [10.4236/epe.2023.1512026](https://doi.org/10.4236/epe.2023.1512026).

Sunny, F. A., Fu, L., Rahman, M. S., & Huang, Z. (2022). Determinants and Impact of Solar Irrigation Facility (SIF) Adoption: A Case Study in Northern Bangladesh. Energies, 15(7), 1–17. https://doi.org/10.3390/en15072460

 SREDA. (2023). Sustainable and Renewable Energy Development Authority. Energy Efficiency and Conservation Master Plan up to 2030. March, 1–212. http://sreda.gov.bd/files/EEC\_Master\_Plan\_SREDA.pdf%0Ahttp://www.sreda.gov.bd/d3pbs\_uploads/files/policy\_2\_energy\_efficiency\_and\_conservation\_master\_plan\_up\_to\_2030.pdf

Top of Form