SUSTAINABLE SOLAR WATER PUMPING FOR IRRIGATION IN BANGLADESH

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ABSTRACT

Solar water pumps (SWPs) are a mature, reliable, and economically attractive climate smart sustainable agricultural technology solution for responsible crop irrigation. The Government of Bangladesh (GoB) is implementing a large SWP project through Bangladesh Rural Electrification Board (BREB) named "*Photovoltaic Pumping for Agricultural Irrigation* (SPPAI)" project which is a subproject of Power System Efficiency Improvement Project of Asian Development Bank (ADB). The project aims to install 2,000 solar pumping systems in Bangladesh for irrigation with the objective to reduce the pollutants emitted by diesel driven pumps, reduction of grid power surges during irrigation season and diffusion of solar pumping systems throughout the country. Key challenges for SWP dissemination include market access, financing, and irrigation subsidies. This paper describes SWP technologies, lessons learned in Bangladesh, implementation challenges, project design, and economics, as well as key takeaways in providing reliable SWP solutions for a more sustainable agricultural sector in the age of climate change.

Keywords: Photovoltaics, solar water pumping, irrigation, sustainable agriculture, Bangladesh.

1. INTRODUCTION

Bangladesh is based on an agricultural economy which contributes about 20 percent of the national GDP. Approximately 3/4 of Bangladesh's population and its workforce lives in rural areas and directly or indirectly relies on agriculture. At present, Net Cultivable area in Bangladesh is more than 8.5 million hectors whereas about 65% of the net cultivable area is irrigated (BADC, 2019). Currently there are more than 1.58 million pumps used in irrigation system of which 78.5% are operated by diesel engines; approximately 21.4% are operated by electricity; and approximately 0.2% are operated by solar (BADC, 2019). Diesel operated pumps yearly consumes 1 million ton of diesel (worth $900 million) at a subsidized rate (World Bank, 2016) while emitting 3.22 million tons of CO_2. In addition, during the peak irrigation season 2,000 MW of power demand is solely required for running the electricity operated pumps (Al-Amin, 2017) which is provided at a subsidized rate for irrigation. A significant amount of subsidy could be reduced if a portion of diesel and electricity driven pumps could be replaced by SWPs.

Irrigation is an important component of the Bangladesh agriculture sector and allows smallholder farmers to increase yields and grow an additional crop a year, receiving higher off-season prices. Diesel water pumps are commonly used, but fuel and transport costs are high; as a result, without a government fuel subsidy, diesel irrigation would not be cost effective for farmers. Farmers using electricity operated water pumps for irrigation receives also a special subsidized tariff of about US$0.04 per kWh but pumping restricted to off-peak utility load hours.

Bangladesh a low-lying delta river country, is vulnerable to climate change and already suffering saltwater intrusion along the coast. Despite that, Bangladesh is showing its leadership in climate change mitigation measures and stands as global champion to tackle adverse impacts of climate changes. The use of solar water pumps (SWPs) to displace contaminating diesel water pumps is a positive step in adopting a clean energy future. These diesel units are typically not very efficient (less than seven percent) and emit carbon emissions that further contribute to climate change. Diesel particulate emissions are highly damaging and proven carcinogens. SWPs are a logical solution to improve this situation. There are new opportunities emerging in the transition from diesel to solar power for Bangladeshi farmers.

The Bangladesh Agricultural Development Corporation (BADC) estimates that there are 1.24 million diesel-run pumps used for agricultural irrigation in Bangladesh (BADC, 2019). Operating costs for these pumps is about ~US$900 million every year for the one million tons of imported diesel fuel needed to run Bangladesh diesel irrigation systems (World Bank, 2016). Diesel fuel is subsidized by about 30 percent by the Government of Bangladesh (GoB), totaling over US$400 million per year in government subsidies (BADC, 2019). So for every liter of diesel fuel sold in Bangladesh, it costs GoB subsidy funding. Depending on the volatility of fuel

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prices, diesel pumps cost about US$0.40 per kWh to run, or nearly four times the cost of a SWP amortized over 20 years.

In Bangladesh there are also 338,870 electricity operated irrigation pumps (BADC, 2019). The subsidized electricity tariff for irrigation is BDT 4.0/kWh (US$0.047/kWh) and a 20 percent rebate is provided from GoB at the end of he year. Considering the rebate, tariff rate become BDT 3.20/kWh (US$0.037/kWh) The seasonal irrigation period is about 5 months (Nov-Mar) and total cost of irrigation is BDT 3,600 to 13,500 per year (US$70/season).

SWPs are a mature, reliable, and economically attractive solution for water supply including for large-scale crop flood irrigation (IRENA, 2016). With ever increasing reliance on water pumping for food security needs in the age of climate change, and somewhat limited access to reliable electricity for many farmers, market development for pumping systems needs to be accelerated to further adoption through development programs such as this ADB/BREB project. Market access, financing and educational challenges for SWPs still exist in Bangladesh, which SPPAI activities aim to help overcome. Cost-effective off-season production using SWPs can help increase the competitiveness and bottom line of Bangladeshi farmers. SWPs can foster resiliency that helps farmers and market systems diversify risk to prepare for and thrive during economic, political, climate, and natural disaster shocks (Sheladia, 2019).

Water access is a key constraint for Bangladeshi farmers in the dry season, with water pumping required from about 3 to 4 months each year depending on location. Irrigation is critical to addressing food security challenges in the country. Bangladesh has ensured access to electricity for 97 percent of its population and by 2021 plans are to reach near 100%. GoB has improved reliability of the grid and taking necessary steps to improve it further. Diesel fuel costs are prohibitive to meet irrigation needs and only made possible with government subsidies, but solar powered irrigation systems can be economically deployed as an affordable and clean energy solution for agriculture sector and save GoB money on subsidized irrigation tariffs and diesel fuel subsidies. Climate smart irrigation using SWPs allows Bangladeshi farmers to farm an additional harvest and produce off-season vegetables and crops that garner higher prices. Climate smart agriculture couples an array of technologies besides SWPs, like shallow tube wells, lift irrigation, canal maintenance and rehabilitation, drip irrigation, sprinklers, water harvest tanks, and multi-use water systems.

Examples of successful large-scale SWP projects initiatives include projects in India, Nepal, Kenya, Mexico, etc. They demonstrate how to successfully overcome market barriers and demonstrate that challenges can be surmounted through public-private partnerships that take advantage of relative cost savings, increased reliability of both solar power and improved irrigation systems, and improved technology access through innovative financing or leasing arrangements (Foster, 2013). The initial ADB feasibility study (FS) indicates that up to 11 kW (pump size) is feasible (ADB, 2017), however did not initially consider on-grid options which could be economically expanded well beyond this size (Sheladia, 2019) The SPPAI team found many examples of 20 to 40 kWp solar and diesel water pumps already used in the field with the largest off-grid existing SWP system being ~65 kWp. In other countries like USA, grid-tied SWPs can exceed 100 kWp array size and offer an extra cash bonus to farmers selling energy back to the grid when not pumping.

Solar water pumping improves people's lives, protects the environment, increases economic activity, and helps safeguard people's health. The key to any successful project is to have a framework for long-term success. Solar-electric systems are commercially available today to meet a wide range of both urban and rural applications, from small to large scale. Institutional and market frameworks exist to successfully operate and maintain them. For long-term success of solar pumping systems, relevant mechanical and hydraulic aspects must be considered, during the phases of initial design, installation, and future maintenance.

2. SPPAI PROJECT BACKGROUND

Bangladesh Rural Electrification Board (BREB) is a non-profit semi-government autonomous organization, specializes in rural electrification and a pioneer in the field of diffusion of solar energy in Bangladesh. Over the last three decades BREB is playing a vital role in promoting environment friendly clean energy especially the solar energy in rural Bangladesh with the belief that "Energy Saved is Energy Produced". BREB pioneered the installation of Solar Home Systems (SHSs) through the first ever solar energy project in Bangladesh in 1993. Since then BREB has installed 15,250 Solar Home Systems (SHSs); 50,518 Solar Plants through consumers; 37 rooftop/hybrid type rooftop solar power plants; 40 solar powered irrigation pumps; 14 Solar Electric Auto Rickshaw Charging Stations; 191 solar plants connected to the national grid through net metering; and 4,000 solar streetlights. About 150 Solar Mini/Micro-grids are now being installed and 6,000 SHSs will be installed very soon.

The total capacity of the installed plants is about 24.2 MW_p. The main objective of BREB Renewable Energy program is piloting new type of renewable energy projects in the context of grid power limitations and promoting the uses of alternatives energy source. Considering the financial concept of PBS i.e. "No profit, No Loss" and cost effectiveness of solar systems, grant financing from development partners on renewable energy projects are always preferable.

In 2011-12, to introduce irrigation through solar energy, BREB installed 40 Solar Powered Irrigation Pumps with the support from Korea International Cooperation Agency (KOICA) and Climate Change Trust Fund (CCTF) of GoB. In recent years, steady awareness is growing on environmentally friendly irrigation using solar PV operated pumps in Bangladesh. With the objective to reduce the pollutants emitted by diesel driven pumps, reduction of any sudden surge of grid power during irrigation season through Solar Pumping Systems in the country, BREB is implementing a SWP project named "Solar Photovoltaic Pumping for Agricultural Irrigation Project" funded by GoB, BREB and ADB [Loan 2769-BAN, Grant 0583-BAN (EF) & 0584-BAN (EF)] to install 2000 solar irrigation pumps at 10 PBS area. The SWP project was originally conceived as a new additional component of ADB Loan 2769-BAN in 2018.

Initially the key objective of BREB is to disseminate 2,000 SWPs (~19.3 MW_p) under 10 Palli Biddyut Samitity (PBS), local electric cooperative, commanding area in 10 districts, develop a sustainable business model and strengthen the rural economy by decreasing cost of irrigation in long term as well as increasing income from agriculture. The project was originally focused on rural off-grid areas, but many of these areas have now been electrified. Thanks to BREBs tremendous effort, 97 percent of rural Bangladesh has access to grid electricity.

3. BANGLADESH SOLAR RESOURCE

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Among the different forms of RE potentials, at present solar energy seems to have the greatest potential in Bangladesh. It has a good solar resource which allows solar systems to generate significant energy over the year. SWPs tilted at latitude tilt maximize annual energy production, which for Bangladesh is about an 18-degree tilt. The latitude tilt annual solar resource shown below is about 4.5 to 5.0 $kWh/m^2/day$ as shown in Table 1. The solar resource is even up to 20 percent more during the irrigation season. The solar resource map below is estimated from satellite data and indicates that there is a good annual solar resource of about 1,300+ kWh/m2 in most of Bangladesh in the BREB project areas. Solar resource is most greatly affected by cloudiness and monsoonal rainfall patterns. Fortunately, for SWPs, the proportion of rainfall is inversely proportional to the amount of water that needs to be pumped, i.e., when it is raining, there is no need for irrigation. Thus the advantage of grid-tied SWPs that can be injecting energy into the energy grid when not being used for pumping, which greatly improves their economic performance rather than having an idle solar power system for 7 or so months a year when irrigation is not needed (Sheladia, 2019).

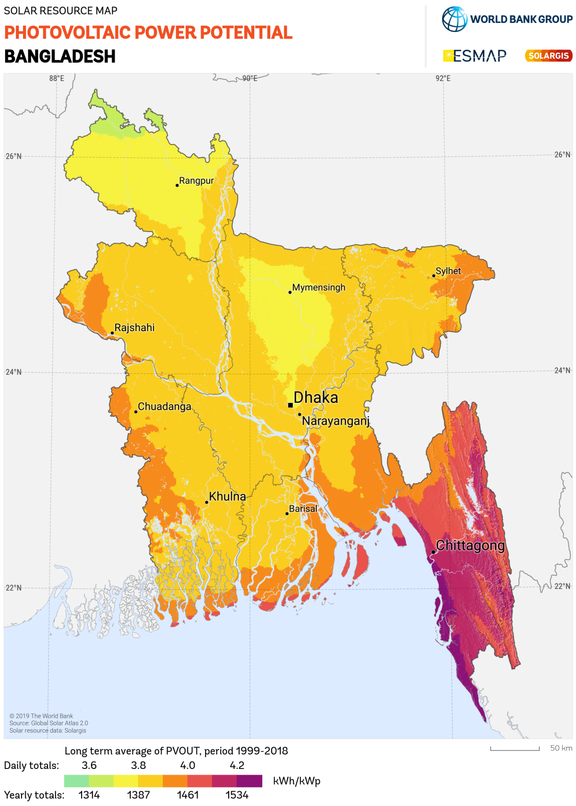

Fig. 4. Bangladesh satellite based solar resource data shows a good annual average solar resource The solar resource is even better than the annual average during the dry and sunny irrigation season. (Source: World Bank - ESMAP).

The solar resource data in the following table shows monthly GHI solar resource (Dhaka University, 1998). Note that there is not a great deal of solar resource variation in Bangladesh across the country as a whole (less than 10 percent nationally over the year) given its generally flat topography and tropical latitudes. There is about a 35 percent variation across the seasons over the year; however this is not as significant in the case of SWPs since there is no need to be pumping water during the cloudier monsoon rainy season, but in some cases may be supplying power to the grid through grid-connected SWPs.

Table 1. Monthly Global Solar Insolation for Bangladesh Regions (kWh/m2/day)

Month	Dhaka	Rajshahi	Sylhet	Bogra	Barishal	Jessor
Jan	4.03	3.96	4.00	4.01	4.17	4.25
Feb	4.78	4.47	4.63	4.69	4.81	4.85
Mar	5.33	5.88	5.20	5.68	5.30	4.50
Apr	5.71	6.24	5.24	5.87	5.94	6.23
May	5.71	6.17	5.37	6.02	5.75	6.09
June	4.80	5.25	4.53	5.26	4.39	5.12
July	4.41	4.79	4.14	4.34	4.20	4.81
Aug	4.82	5.16	4.56	4.84	4.42	4.93
Sep	4.41	4.96	4.07	4.67	4.48	4.57
Oct	4.61	4.88	4.61	5.65	4.71	4.68
Nov	4.27	4.42	4.32	4.35	4.35	4.24
Dec	3.92	3.82	3.85	3.87	3.95	3.97
Average	4.73	5.00	4.54	4.85	4.71	4.85

Source: Dhaka University, Dr. Shahida Rafique, recorded from 1988-98

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4. BANGLADESH SOLAR WATER PUMPING LESSONS LEARNED

5.

Over the past decade, there have been some pilot efforts to introduce SWPs in Bangladesh with mixed results. A small survey was conducted by SPPAI onexisting SWPs and take lessons learned that can be applied to SPPAI.

KOICA and CCTF

BREB piloted twenty 5 HP SWPs (Installed PV Capacity is 6.72 – 7.2 kWp) in six districts during 2010-12 through the grant funding by KOICA and twenty more 5 HP SWPs (Installed PV Capacity is 5.16 kWp) in 8 districts during 2011-13 through the CCTF fund of GoB. Some of the KOICA and CCTF funded SWPs were not functional during the survey mostly due to inverter/ motor controller failures and a few cases of theft. The survey found that these pumps were designed to cover about 8 acres of land whereas farmers informed, they could only irrigate about 2 acres of land during Boro Rice season. It was insufficient water for the participating farmers using these installed SWPs. Due to the technology available that time, some issues were identified as follows:

- Industrial VFDs used as pump inverters housed in a plastic box, which could not protect the VFD from dust, etc;
- Pump water delivery rate is 300 l/min which could draw maximum of 100,000 liters of water/day. A minimum need is ~65,000 liter/day of water to irrigate 0.3 acres of rice.
- Water is distributed through open soil drain resulting in wastage of 40-50 percent of water.
- Adequate training on usage, operation and maintenance was not provided to the farmers.

The SWPs were provided to the farmers at no cost but the responsibility for operation and maintenance of pumps lies with the farmer and the ownership of the pumps belongs to the PBSs. Farmers are also liable to pay a yearly lump-sum BDT 6,000 (US$ 70.50) to the PBSs for using the SWPs. During the survey it was identified that the farmers do not own the SWPs and have no motivation to repair the SWPs since the revenue generated from the pumps was insufficient for repairs. Due to lack of budget for maintenance, it was not possible for the PBSs to take action to repair. Recently, BREB took initiatives to repair the pumps through PBS's own cost.

Fig. 5: KOICA financed Solar Pumping Project of BREB (5.16 kW$_p$ PV array in a rice field powering a 3.7 kW submersible pump providing 300 l/min in Singair, Manikganj.

Infrastructure Development Company Ltd. (IDCOL)

IDCOL was founded in 1997 by GoB and is licensed by the Bangladesh Bank as a non-bank financial institution which is financing SWPs in Bangladesh. IDCOL's bridges the financing gap for developing medium to large-scale infrastructure and renewable energy projects. The company is a market leader in private sector energy and infrastructure financing. IDCOL channels grant and credit support to partner organizations comprised of NGOs and private investors. IDCOL receives funds from development partners such as World Bank, KfW, USAID, etc. IDCOL has financed about 1500 SWPs. IDCOL plans to promote a new ownership model for smaller-sized SWPs. Instead of buying water from POs, farmers will be able to own SWPs with credit and grant support from the project. By 2019 IDCOL has financed more than 1,500 solar irrigation pumps in operation with a cumulative capacity of about than 26.59 MW$_p$. IDCOL has set a target of installing 50,000 irrigation SWPs by 2025.

Fig. 6: IDCOL financed Solar Pump. 14.4 kW$_p$ solar array powering a 10 HP submersible pump irrigating 72 bighas (~24 acres) of rice for 25 farmers in Biral, Dinajpur. The SWP installation cost was BDT 3,500,000 (~US$41.1k)

Barind Multipurpose Development Authority (BMDA)

Surface SWP systems were financed by GoB and installed by BMDA, with over a hundred SWPs installed over the past four years that are operated on a pre-paid meter. BMDA originally installed ten pilot 11 kW

(15HP) centrifugal surface SWPs in 2016 in Godagari, Rajshahi with support from GoB. BMDA owns the pumps and sells water to farmers via a prepaid meter. Farmers use prepaid cards and are charged BDT 180/hour (US$2.12/hr). All the BMDA SWP installations were found to be safe with proper overcurrent protection.

Based on good results, BMDA installed more surface centrifugal SWPs and owns 106 SWPs installed by 2019 around Rajshahi, Chapai Nawabganj and Naogaon. These SWPs are 11 kW (15 HP) surface centrifugal and vertical inline type pumps with a maximum discharge rate of 200 m^3/hr. PV Capacity is 20.4 kW_p. Water is pumped from surface sources like rivers, ponds and canals for rice irrigation.

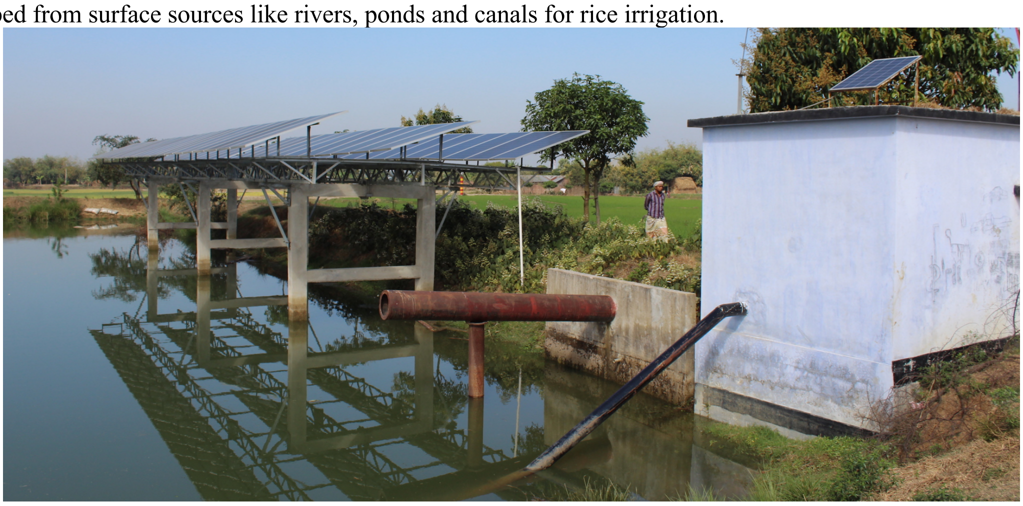

Fig. 7: BMDA 20.4 kW_p. SWP in Godagari, Rajshahi installed in 2016. System is operated with pre-paid cards. GoB funded installation R BDT 2,400,000 or about US$1.38 per W_p , including additional cost of 1,500 meters of 10" PVC pipe for BDT 700,000.

Fig. 8: BMDA 20.4 kW_p (300 W_p x 68) PV array used for rice irrigation in Rajshahi.

Fig. 9: BMDA Solar Surface Water Pumping System. MPPT Pump inverter with overcurrent protection for the DC strings. The pre-paid meter on the right uses AC circuit breakers. Note the green ground wire on the far left.

5. Common SWP Technical Issues and Lessons Learned in Bangladesh

Many existing Bangladesh SWPs have technical issues related to poor design and poor installation which can cause performance failures that lead to end-user dissatisfaction. A survey was conducted to identify these common problem areas as important to address for project implementation. Some common problem areas include the following:

Undersized SWP Systems

Some of the SWP systems were not designed properly omitting voltage crash due to hot temperatures, soil type needs, total dynamic head, and cropping patterns. A common result is undersized SWPs and insufficient water for the required irrigation area which makes farmers dissatisfied.

One solar pump operator Mr. Iqbal in Dinajpur stated that SWP operational and management costs are not affordable due to low revenue generation due to power disruption from the PV system and lack of timely technical support. The sponsor stopped to operate their SWPs and withdrew their staff from the field. In regard to the installation of SWPs, he mentioned that his organization had a plan to install more solar irrigation pumps but considering the experience observed from the existing pumps, the sponsor postponed their plans. The pump operator added that the BREB 100 percent electrification program funded by GoB, as well low irrigation costs from grid electricity due to subsidy caused the farmers to lose interest in SWPs and the sponsors were unable to repay on their installments. The SPPAI survey team found in general that the SWP projects were often not properly designed to fit the farmer water requirements as well as poor and unsafe installation quality.

Array shading: Vegetation sometimes grows up over the PV array, which causes poor system performance and can lead to module failures due to shaded cell hot spots. Also, we sometimes saw clods of dirt and plants from inattentive farmer weeding with hoes or dropped from birds can shade entire cells and create module hot spots and potential failures. Systems should be installed in anticipation of future vegetation growth and farmers trained to cut back on any offending plants that are shading the PV array.

Fig. 10: Banana tress have grown taller than this array on the north side and partially shaded a PV string on this Biral SWP system causing module shading and related current drop and module hotspots that can lead to premature failure.

No bonding and grounding: Most of the evaluated SWPs were not bonded to ground, which present a shock hazard to people. This also increases the likelihood of early failures from lightning strikes. This can present a high electrocution hazard especially in muddy rice paddy fields. It can be suspected some of the KOICA financed systems that failed had been from lightning strikes on systems that had loss of grounding due to lack of maintenance.

Poor or Improper wiring: Many SWP systems have undersized wires that cause high voltage drops. Also, many of the wires used outdoors are actually only rated for indoor use, so they will gradually deteriorate over time due to UV damage. Often systems showed poor workmanship, sometimes with wires carelessly strewn across the ground, and no use of conduit. This is usually the first indication that the installation is lacking.

Fig. 11: Example of poorly installed wiring. Wires dangerously and carelessly scattered across the ground; the farmers came back and installed loose wires on the wooden posts. There is no ground and no array string fuse, presenting a significant electric shock hazard. This 30 kW_p solar array powering a 20 HP submersible pump irrigating 48 bighas (~16 acres) of mostly boro and aman rice in Biral, Dinajpur. Water is sold to farmers at BDT 2,000 (US$ 23.50) per bigha.

Improper or No Overcurrent Protection: Some SWP arrays were found have no string fuses on the DC source circuits. There are typically no surge protection devices (SPDs) to protect inverter circuits and pumps from lightning or other surges. Both string fuses and SPD ensure safety and a longer life. The SPPAI evaluation team also found a number of SWPs that improperly use AC circuit breakers in DC source circuits. The AC circuit breakers are not rated for DC circuits and can easily fail and result in frequent malfunctions or system failure. They are also not safe in DC circuits and can cause a fire and are an electrocution hazard. Good SWP design requires the use of listed DC components in DC circuits.

Fig. 12: Pump inverter used to power solar pump project in Setabjanj, Dinajpur. The system ran for 3 years and then a AC circuit breaker failed because it was inappropriately used in a DC circuit. It was replaced again with an AC circuit breaker in 2019 which can be expected to fail again.

Fig. 13: A SWP project in Biral, Dinajpur with a inverter with no string fuses or SPD to help protect from power surges.

Variable Frequency Drive (VFD) Inverters with No MPPT

Many SWP inverters installed use simple VFDs designed for 3 phase industrial induction motor applications and not for variable solar power generation. Good system reliability requires proportional integral-derivative (PID) controller synchronisation which varies the frequency and supply voltage for the motor. If VFD operates in a variable set-point mode, it must have array maximum power point tracking (MPPT). A VFD with no MPPT can cause the pump to start late in the morning and stop early in the afternoon. The SWP frequently turns on and off with passing clouds, The PV array is often way oversized PV array double or more of what is required and causes inefficient operation and less water to be pumped. This also shortens the inverter and pump life span.

6. Economics of Solar Water Pumps in Bangladesh

Solar power is a natural and symbiotic choice for water pumping and is one of the most economically attractive ways to power a pump with direct drive PV systems that can provide decades of reliable service. There is a good match between seasonal solar resource and seasonal water needs. There have been dramatic reductions in PV modules over the past decade, by over 90 percent. SWP is most cost-effective for steady pumping needs year round such as community water supply (Foster, 2013). For part-time pumping like for rice farmers in Bangladesh which only irrigate for about 5 months out of the year, grid-tied SWPs are the most attractive since they can provide power to the grid year round after the irrigation season is over.

In Bangladesh, pumps are most feasible where soil water retention capacity is at least three days or above in the case of rice cultivation. For other type of crops, it may not be as feasible an investment. The water head for most SWPs in Bangladesh is usually within ~5 m. Locations with water head greater than 5 m are still feasible, but with a smaller return on investment. A reasonable estimate for pump capacity is about 0.25 l/h. A 3 HP pump in Bangladesh costs only for BDT 15,000. 5 HP Pump price is BDT 25,000. This following analysis is for a 20.4 kWp SWP in Dinajpur.

Energy Generation

Capacity factor is the ratio of the PV energy produced in a given time to the energy that could be produced in that time if the plant had been continuously generating its fully rated output. Because PV plants can only produce during daylight hours, a capacity factor of about 20% can be expected for Bangladesh latitudes. The figure below shows the expected energy production for a 20.4 kWp grid-tied SWP in Dinajpur. The energy, which is not used by the pump is back fed into the power grid (anticipated to be about 245 days of the energy generation back to the grid).

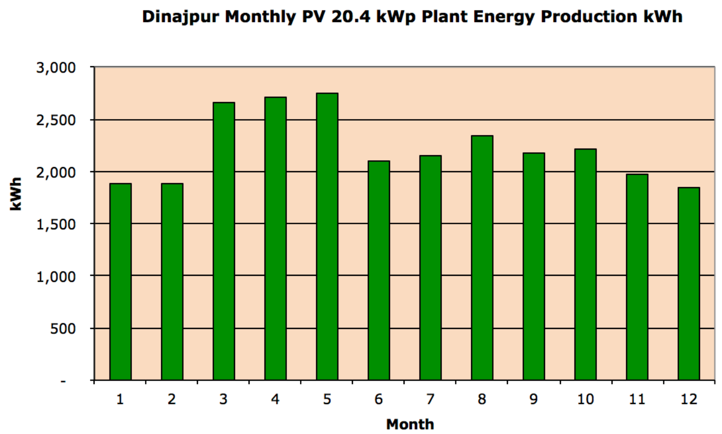

Fig. 14: Expected monthly energy generation from grid-tied SWP in Dinajpur (Year 1). Note that most of the energy Nov-March would be used for water pumping, while the rest of the year the system will be backfeeding the grid through net metering.

Array Degradation

Over time, the PV array will gradually degrade and performance and energy production will likewise drop. The SPPAI SWP array is assumed to degrade within PV module manufacturer specifications of providing 80 percent of rated power after 25 years, which implies an annual module degradation rate on average of 0.8 percent per year. Total first year expected energy production is about 26,682 kWh/year. Actual energy production will vary with solar insolation and overall PV plant availability and will gradually drop off slowly. The PV array will probably actually function at about 75% of nameplate rating even after 30 years.

Life Cycle Cost of Energy (LCOE)

For solar power systems, a life cycle cost of energy (LCOE) analysis is used to determine the economic value of a grid tied SWP. Using this methodology, including all future costs (O&M, replacements, and fuel), a comprehensive view of total system lifecycle costs is determined. LCOE analysis was made for a 20.4 kWp grid-tied SWP project looking at actual PV SWP system bid prices. We see a total solar system installed cost of about US$17,305 in this case, or about US$0.85 per W_P. These prices are for bulk purchases by BREB of hundreds of SWPs at a time. Taking the energy generation and amortizing the price over 25 years bringing everything to present value, we find that the life cycle cost of energy after 25 years is about 3.8 cents per kWh (US$). Even in a subsidized electric market for irrigation this LCOE is competitive. Since water is pumped for irrigation only for about 5 months a year and not every day, the excess energy when not pumped is worth more than the electrcity only used for irrigation. Simple system payback of the initial $17.3k investment cost is achieved at about 9.8 years at current Bangladesh net metered rates (US$0.0514/kWh), which were only adopted in August, 2020. This assumes one inverter replacement after 15 years; the AC pump and PV modules should last over a quarter century. There may be additional farmer costs for new irrigation piping and boreholes, but these will vary from farmer to farmer and are not part of the power system LCOE analysis.

Table 2. SWP System Cost Breakdown (15 HP pump and 20.4 kWp PV array)

15 HP PV System Cost Breakdown with Tax

US$/Wp		% Costs		TOTAL COST US$	
$	0.27	31.5%	PV Modules	$	5,448
$	0.09	10.5%	Pump Inverter	$	1,819
$	0.06	7.0%	Pump & Motor	$	1,212
$	0.14	16.7%	Mounting Structures	$	2,890
$	0.01	1.7%	OC Protection/Wire	$	293
$	0.00	0.3%	Design	$	57
$	0.17	20.3%	Installation	$	3,510
$	0.01	1.2%	Commissioning	$	212
$	0.02	2.7%	Tax PV installation	$	462
$	0.07	8.1%	Tax SWP Goods	$	1,402
$	0.85	100.0%	SubTotal PV System Costs	$	17,305
			$/Wp	$	0.85

Based on annual energy savings alone, the PVPS levelized life cycle cost per kWh generated the value of the electricity generated amortized over 25 years would be approximately $0.038 per kWh, or about 3/4 of the grid net metered rates. The SWP grid-tied PV energy production would also help with peak shaving opportunities to displace BREB daytime loads, as well as improving grid power quality at the end of the grid where these systems are typically located.

Table 3. Amortized Net Present Value of Grid-Tied 20.4 kWp SWP over 25 years

Item	Year	PV Array Degradation	PV Energy Production kWh/yr	Grid Price $/kWh	Electricity Value Saved $	PVIF	Net Present Energy Value $
1. Costs		0.80%					
	0	100%	26,682	0.05139	$ 1,371	1.00	$ 1,371
	1	99.2%	26,469	0.05293	$ 1,401	1.01	$ 1,415
	2	98.4%	26,256	0.05452	$ 1,431	1.02	$ 1,460
	3	97.6%	26,042	0.05615	$ 1,462	1.03	$ 1,506
	4	96.8%	25,829	0.05784	$ 1,494	1.04	$ 1,555
	5	96.0%	25,615	0.05957	$ 1,526	1.05	$ 1,604
	6	95.2%	25,402	0.06136	$ 1,559	1.06	$ 1,655
	7	94.4%	25,188	0.06320	$ 1,592	1.07	$ 1,707
	8	93.6%	24,975	0.06510	$ 1,626	1.08	$ 1,761
	9	92.8%	24,761	0.06705	$ 1,660	1.09	$ 1,816
	10	92.0%	24,548	0.06906	$ 1,695	1.11	$ 1,873
	11	91.2%	24,334	0.07113	$ 1,731	1.12	$ 1,932
	12	90.4%	24,121	0.07327	$ 1,767	1.13	$ 1,992
	13	89.6%	23,908	0.07546	$ 1,804	1.14	$ 2,053
	14	88.8%	23,694	0.07773	$ 1,842	1.15	$ 2,116
	15	88.0%	23,481	0.08006	$ 1,880	1.16	$ 2,182
	16	87.2%	23,267	0.08246	$ 1,919	1.17	$ 2,251
	17	86.4%	23,054	0.08493	$ 1,958	1.18	$ 2,318
	18	85.6%	22,840	0.08748	$ 1,998	1.20	$ 2,390
	19	84.8%	22,627	0.09011	$ 2,039	1.21	$ 2,463
	20	84.0%	22,413	0.09281	$ 2,080	1.22	$ 2,538
	21	83.2%	22,200	0.09560	$ 2,122	1.23	$ 2,615
	22	82.4%	21,986	0.09846	$ 2,165	1.25	$ 2,695
	23	81.6%	21,773	0.10142	$ 2,208	1.26	$ 2,776
	24	80.8%	21,559	0.10446	$ 2,252	1.27	$ 2,860
	25	80.0%	21,346	0.10759	$ 2,297	1.28	$ 2,944
Total 25 Year			624,370		$ 46,879		**$ 53,848**
				SWP LCOE Generation Value	$ 0.038	/kWh	

7. CONCLUSIONS

In summary, solar water pumping (SWP) technology ensures sustainable and effective access to water for irrigation, livestock watering and drinking water supply for smallholder farmers in Bangladesh. The key barriers for generating large scale commercial sales of SWP systems are subsidized electric tariffs, subsidized diesel fuel, and financial access to credit. The technology with properly designed and sized systems is reliable and mature. SWP systems costs have dropped by 50 percent over the past decade, but still require a somewhat higher initial capital investment than conventional diesel pumps. The life cycle cost analysis showed that the cost of energy from a grid-tiedgrid tied SWP system is about half of current electric tariffs amortized over a 25 year period at a cost of about US$0.026 per kWh. Efforts to commercialize SWP technology for irrigation are still developing in Bangladesh, butBangladesh but have a higher value by embedding SWP technologies into value chain projects, which support farmers to increase income through improved yields and growing high value crops off season. Challenges include lack of awareness about the technology, upfront capital costs, and absence of technical repair services that are being addressed through the BREB SPPAI demonstration project and partnerships with farmers and technology providers.

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9. REFERENCES

(ADB, 2017) Feasibility Study, Proposed Bangladesh: Power System Efficiency Improvement Project (Off-grid Solar Pumping Component, September.

(Al-Amin, 2017) Al-Amin, & Tanni, Tasmiah & Rahman, Dr.Md & Asaduzzaman, Miah & Al Matin, Md Abdullah. A Study on the Present Scenario of Solar Irrigation in Bangladesh. International Journal of Scientific and Engineering Research. 8.

(BADC, 2019) Bangladesh Agricultural Development Corporation, Minor Irrigation Survey Report 2018-19, Dhaka, Bangladesh

(IRENA, 2016), Solar pumping for irrigation: Improving livelihoods and sustainability, June

(Foster, 2013) R. and A. Cota, "Solar Water Pumping Advances and Comparative Economics,"Solar World Congress, International Solar Energy Society (ISES), Quintana Roo, Mexico, November 3-7, 7 pp.

(Sheladia, 2019) "Feasibility Study Review: Proposed Bangladesh: Power System Efficiency Imporvement Project (Off-grid Solar Pumping Component), Dhaka, Bangladesh, May 27, 2019.

(World Bank, 2016) http://www.worldbank.org/en/results/2016/10/07/bangladesh-growing-economy-through-advances-in-agriculture

(World Bank, 2016) Solar pumping Pumps: A New Way of Agriculture in Bangladesh, Dhaka, Bangladesh.