__Original Research Article__

Climate Resilient Solar Pump for Irrigation and Household Applications in the coastal Region of Bangladesh

ABSTRACT

Bangladesh is a climate vulnerable and agricultural country. Coastal region of Bangladesh is severely affected by climate change. To mitigate climate, change a solar pump of flow rate 180 L/minute was designed and tested in farmers' fields of Kalapara and Galachipa*Upazila* (sub-district) of Patuakhali district, Barguna Sadar and Amtali*Upazila* of Barguna district and Char Fasson and Lalmohon*Upazila* of Bhola district in the coastal region of Bangladesh for irrigating in high value crops like tomato and brinjal using pond/canal water. One solar pump was installed in each *Upazila* of off-grid area in 2018 and experiments were conducted during 2018-2021. Each solar pump was operated with 1200 W_p photovoltaic panels and the panels were also used for supplying electricity to home appliances and home water supply when the irrigation time was over. In farmers' fields, water saving irrigation methods such as drip irrigation and alternate furrow irrigation were conducted. The water savings from drip and alternate furrow irrigation methods over famers' practice (every furrow irrigation) for tomato were 48.79% and 30.39% and those for brinjal were 47% and 35%, respectively. The benefit cost ratio of the demonstrated solar PV system was found to be 1.62 which was higher than low lift diesel pump (1.30). A small solar pump of 0.8 kW reduced 1.76 ton of carbon emission per year than a similar diesel engine operated pump. The farmers in the project areas are using the solar panels for irrigation, lightings, operating fans, supplying drinking water, sanitation and other purposes. Therefore, solar pump is an environment friendly and climate resilient technology for small holder farmers in the coastal region of Bangladesh.

Keywords: Climate resilient;solar energy; PV panel; irrigation; low lift pump; coastal region; BCR

1. INTRODUCTION

Bangladesh is a climate vulnerable agricultural country. The effects of global warming are ever-growing and include rising sea levels, irregular precipitation, increased drought, salinity intrusion, shorter winter, flash floods, typhoons, and cyclones. Agriculture is negatively impacted, which lowers the yields of crops. Use of renewable energy especially solar energy may be one of the solutions to reduce carbon emission as well as global warming. Last year (2023) the main theme of World Food Day (16 October) was 'Water is Life, Water is Food, Leave No One Behind'. Irrigation is an important input for modern agriculture [1]. Irrigation started for cultivation of high yielding crops since the evolution of green revolution in Bangladesh. Net irrigation area in Bangladesh is 66.51% in which the contribution of surface water is 15,46,535 ha (27.35%) and groundwater is 41,08,254 ha (72.65%). There are 16,55,558 irrigation pumps are used for irrigating 5.65 million hectares of land. The irrigation area coverage of shallow tubewell (STW), low lift pump (LLP), deep tubewell (DTW) solar irrigation pump (SIP) and other methods are 53.16%, 22.76%, 19.19%, 0.31% and 4.59%, respectively [2]. About 56% area is irrigated by diesel engine operated pump which consumed 1.15 million tons of imported diesel producing about 3.0 million tons of carbon emission. For electricity generation renewable energy only contributes 5% that requires to be increase around 10% by 2025 and 20% by 2030 [3]. So, there is huge scope to use SIP for irrigation instead of diesel fuel operated irrigation pumps to mitigate carbon emission as well as saving foreign currency for importing diesel fuel and lubricating oil.

According to the Global Climate Risk Index, Bangladesh is the most climate change vulnerable country in the world [4]. Total greenhouse gas (GHG) emission in Bangladesh was 224.35 Mt CO_2e in 2020 which was 0.47% of global emission. In 2020, the agriculture sector contributed 86.2 MtCO_2e GHG emissions, which represented 41.72% of its total emissions [5]. Today, and in to the coming decades, the country is likely to be negatively affected by sea level rise and saltwater intrusion, mean temperature increases (1.7^{o}C by 2050), rainfall variability, and an increase in the frequency and intensity of extreme weather events [6]. Climate-resilient agriculture is the method of increasing agricultural production to cope with the harmful effects of this climate change. SIP is prioritised as climate-resilient as well as climate smart agricultural technology in Bangladesh [6].

Recently price of diesel fuel has increased about 60% and small farmers are facing difficulties to pay the diesel price for operation of irrigation pumps. On the other hand, price of grid power has also increased and farmers are facing load shedding to operate electric pump. Solar pump may be an alternative solution of the fuel and energy crisis for irrigation. Large solar pump is very costly and beyond the purchasing capacity of smallholder farmers. In winter season, most of the lands remain fellow in coastal region due to water salinity, lack of fresh water and very low rainfall. The surface water sources of this areas are mainly river, canal, fish pond, homestead pond, etc. The salinity level is more in river, canal and *Gher* (Saline water fish ditch) water rather than homestead pond. Around 20% of rural people have homestead pond [7].

In Bangladesh, the available ranges of solar radiation are between 4.0 and 6.5 kWh $m^{-2}day^{-1}$ and the bright sunshine hours vary from 6 to 9 hours/day (Biswas and Hossain, 2013). So, solar radiation in Bangladesh is suitable for operation of solar appliances. Though the initial cost of solar pump is higher than the conventional diesel engine operated pump, solar pump has lower maintenance cost which makes it cost effective over the years [8]. Therefore, this study was undertaken to find out the technical and economic suitability of solar photovoltaic (PV) systems for irrigation and household applications in the coastal region of Bangladesh.

2. MATERIAL AND METHODS

A series of activities were performed in the design and demonstrations of the solar PV system. These are presented sequentially in the following subsections. The design works were mostly done in Bangladesh Agricultural Research Institute, Gazipur.

2.1 Base Line Survey

The base line survey was conducted in 2018 in the project locations to get information on availability of literacy of the respondents, land use, land type, cropping pattern, existing irrigation systems, socio-economic conditions of the farmers, and fresh and surface water availability in the area. From each site 30 farmers were interviewed. Secondary data were collected from books, journal articles, researched reports, internet, etc.

2.2 Solar Pump and Solar Home System

The solar pump was designed, fabricated and installed in the selected sites for irrigation and solar home system (SHS). The command area of solar pump was calculated based on water requirement of crop (vegetables) and minimum discharge of solar pump. For household uses of solar power, maximum load was calculated using information generated from base line survey.The maximum desired load for SHS was calculated on the basis of the number of equipment used in a family. Four solar panels each of 325 W_p and 24 V were used for water pumping and one was used for operation of home appliances. The main features of solar pump and SHS are given in Table 1 and Table 2, respectively.

Table 1. Main features of solar pump

Main Features	
Suitability	Surface water lifting
Maximum suction head	6.50 m
Power of solar panel	1300 W_p
Type of motor	DC, 48 V
Power of motor	910 W
Motor speed	3500 rpm
Diameter of pipe (Suction and	51 mm

delivery)	
Average discharge	180 L/min

Table 2. The maximum desired load for solar home system in the study locations

Item	Number	Unit load (W)	Total load (W)	Operating time (hrs/day)	Total load (WH)
DC light	04	09	36	06	216
DC fan	02	25	50	05	250
LCD television	01	50	50	02	100
Mobile charger	01	10	10	01	10
Total			146		576

2.3 Land and Soil Types

The land types in the study areas were high land (7.65%), medium high land (80.40%), medium low land (11.48%) and low land (0.47%). Medium high lands were above 55% in all the sites. High land and medium high land are suitable for vegetable production. In the selected sites, most of the soil were found clay loam. Only in Galachipa and Lalmohon Upazila, the soils were clay and sandy loam, respectively.

2.4 Irrigation Scheduling

Irrigation to crop field was done by drip and alternate furrow irrigation (AFI) methods. Irrigation scheduling was followed by measuring daily crop evapotranspiration. The following equation was used to measure crop evapotranspiration [9].

$$ET_{crop} = ET_o \times K_c \qquad (1)$$

Where, ET_{crop}= crop evapotranspiration, ET_o=reference crop evapotranspiration andK_c=crop coefficient. ET_o was calculated by Penman-Monteith equation using the software, CROPWAT on a daily basis from daily meteorological and geographical data [10]. In drip method, the average discharge of a dripper was 3.3 Lh^{-1} at 2.0 m head of water. In case of furrow method, the required depth of irrigation water was measured by soil moisture monitoring and it was calculated by water balance method using the following equation [11].

$$P + L_m = ET + SR + I_f \qquad (2)$$

Where, P= precipitation (mm) for the cropping period, L_m = moisture loss from the soil in the form of capillary rise, ET=evapotranspiration, SR= storage in rootzone and I_f= infiltration to the vadose zone (soil water). As the moisture loss from the soil was replenished by irrigation water and water was applied to root zone depth, L_m was replaced by I_d (depth of irrigation). So, the equation can be written as

$$P + I_d = SR + I_f + ET \pm \Delta S \qquad (3)$$

So, $$\pm \Delta S = P + I_d - SR - I_f - ET \qquad (4)$$

Where, ΔS = changes in subsurface storage of water.

2.5 Installation and Field Trials of Solar Pump and SHS

Six solar pumps with SHSs were installed in farmers' fields of Kolapara and Galachipa Upazila (Sub-district) of Patuakhali district, Barguna Sadar and Amtali Upazila of Barguna district and Char Fasson and Lalmohon Upazila of Bhola district. A water supply system was installed in every house of the selected farmers having ponds near to their houses. A 500-liter overhead tank was used to store water for each house. The pond was used as the source of pumping water for household uses. The tank water was used for washing dishes, using in toilet, feeding cattle, bathing, washing hands and feet etc. The solar pump was also connected to a hand tube well if available in farmer's house for drinking and other water uses. The solar home system was installed in the houses of all the selected farmers. Most of the solar panels were installed on the rooftop of the house with a clear view of the sun. A battery (Brand: Hamko, model: HDP120T, 12 V, 120 AH) with a charge controller (Digital PWM, model: PVSC20A, 12V/24V, 20 A) and circuit breaker (30 A) was connected to the panel. During the Rabi (Dry winter) seasons of 2019-20 and 2020-21, tomato and brinjal were planted in the selected farmers' fields under solar pump irrigation systems. Row to row and plant to plant distances of tomato and brinjal were 100 cm and 80 cm, respectively. Experiments of tomato and brinjal were laid out in RCB design with three treatments and four replications as follows.

T_1= Drip irrigation system

T_2= Alternate furrow irrigation system
T_3= Farmers' practice i.e. every furrow irrigation (control)

2.6 EnvironmentalBenefit of the Solar Pump System

In this study solar DC pump of 1.0 kW used for surface water lifting for irrigation. One megawatt hour electricity is similar to 200 liter of diesel fuel [12]. Total amount of diesel used in LLP for lifting surface water can be expressed the following ways [13].

$$TDA = LLP_d + LLP_e \quad (5)$$

Where, TDA = Total amount of diesel fuel used in LLP, LLP_d = Amount of diesel used in diesel operated LLP and LLP_{de}=Amount of diesel used in electricity operated LLP. In this study environmental benefit was measured by calculating total amount of diesel used in each diesel operated low lift pump in 20 years. For calculation of CO_2 emission, the amount of diesel that combusted is multiply by amount of carbon content in diesel. Burning of one liter of diesel fuel contributes 2.640 kg CO_2 to the atmosphere [14]. One liter of diesel weights 835 g. Diesel consists for 86.20% of carbon, or 720 g of carbon per liter diesel. In order to combust this carbon to CO_2, 1920 g of oxygen is needed. The sum is then 720 + 1920 = 2640 g or 2.640 kg of CO_2L^{-1} diesel. Small amount of other gas such as CO and SO_2 emitted during burning of diesel and lubricating oil. Therefore, total Diesel use remains a great source of greenhouse gas (GHG) emitted from burning of one liter of diesel is equivalent 2.80 kg of CO_{2e}[15]. The environmental benefit of solar pump was determined by following equation [16].

$$\text{EB of solar irrigation pump} = TDA \times 2.8 \text{ kg } CO_{2e} \quad (6)$$

Where, EB = environmental benefit (Reduction of CO_{2e} emission), TDA = Total fuel (diesel) combusted in 20 years in liter (2.8 kg CO_{2e} emitted from one liter of diesel combustion [17].

The EB of solar pump can be said as monetary terms in the following way.

$$\text{EB of monetary terms} = \frac{\text{EB of solar pump}}{1000} \times \text{Cost reduction of } CO_{2e} \quad (7)$$

The cost required for removal one ton of carbon dioxide from atmosphere is around one hundred USD [18].

3. RESULTS AND DISCUSSION

3.1 Baseline Survey

Baseline surveys were conducted in Patuakhali, Barguna and Bhola districts. The selected Upazila were Kolapara and Galachipa of Patuakhali, Sadar and Amtali of Barguna and Char Fasson and Lalmohan of Bhola districts. Irrigation status in the study areas of Patuakhali, Barguna and Bhola districts is given in Table 3. In all study areas, 100% of irrigation was done by small diesel engine (3.5-9.0 kW) operated (82%) was done custom hired basis. Solar pump was not found to irrigate crops. Surface water was only source of irrigation water in the study areas. Krupnik [19] reported that in coastal region of Bangladesh almost 100% surface water is used for irrigation due to lower pumping cost of surface water.

Table 3. Irrigation status in the selected areas in Patuakhali, Barguna and Bhola district

Items		Patuakhali		Barguna		Bhola		Mean of all
		Kolapara	Galachipa	Sadar	Amtali	Char Fasson	Lalmohon	
Pump	LLP (%)	100	100	100	100	100	100	100
	Diesel (%)	100	100	100	100	100	100	100
	Owned (%)	19.23	34.48	11.54	17.39	17.25	10.35	18.37
	Hired (%)	80.77	65.52	88.46	82.61	82.75	89.65	81.63
	Maintenance cost (US$/season)	28.24	38.35	27.45	19.12	42.35	44.71	33.37

3.2 Testing of Solar PV System in Farmers' Field

The solar pumps were tested in all study areas individually. The suction heads were kept constant at 1.22 m, 1.25 m, 1.23 m, 1.21 m, 1.20 m and 1.15 m at Barguna Sadar, Amtali, Kolapara, Galachipa, Lalmohon and Char Fasson Upazila, respectively. A sample graph of Barguna Sadar is presented in Fig. 1. It is revealed from the graph that the tested parameters e.g. solar radiation, voltage, current, and pump discharge were found to vary from location to location and at different times of a day. In all locations, the average and the maximum voltage varied from 24.48 to 28.94V, the current from 11.76 to 14.01 A, the solar radiation from 557 to 907 W/m^2. The discharge of the solar pump varied with solar radiation and solar radiation was also varied with time of the day and it reached to 907 W/m^2 at 1.00 pm and then maximum discharge was found to be 191.9 L/min. In other locations identical results to Barguna Sadar were found out.

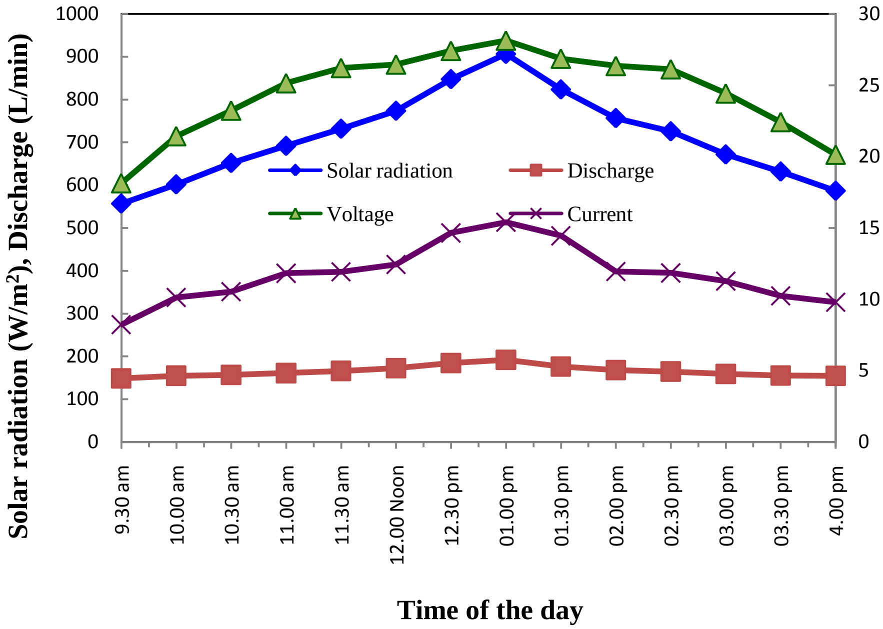

Fig. 1. Voltage, current, discharge and solar radiation at Barguna Sadar.

3.3 Irrigation of Tomato

Yield and yield contributing parameters of tomato at Barguna Sadar Upazila of Barguna district in 2019-20 are shown in Table 4. The plant population was 1.25 per m^2 in all locations. Significantly the highest yield (66.31 t/ha) of tomato was obtained from drip irrigation treatment followed by alternate furrow irrigation (AFI) (58.93 t/ha) and farmers practice i.e. every furrow irrigation (FI) (60.77 t/ha). There was significant difference between AFI and FI methods. In drip irrigation, plants get optimum water for nutrient uptake and produced higher plant height, number of fruits per plant, unit weight of fruit and fruit dimension than other treatments and hence produced highest yield of tomato. At Amtali Upazila of Boguna district, significantly the highest yield of tomato was obtained in 2020-21 from drip irrigation than AFI and FI. AFI and FI treatments were statistically alike (Table 5). The trend of results of tomato for other locations were found similar.

Table 4. Yield and yield contributing characters of tomato at Barguna Sadar, Barguna in 2019-20

Treatment	Plant height (cm)	No. of fruits plant^{-1}	Unit weight (g fruit^{-1})	Fruit length (cm)	Fruit diameter (cm)	Yield (t ha^{-1})
Drip	80.48	37.93a	84.97	6.52	6.41	76.31a
AFI	78.19	31.67b	82.16	6.02	6.17	58.93b
FI	74.14	31.16b	83.06	6.22	6.28	60.77b
LSD	NS	5.26	7.63	NS	NS	12.48
CV (%)	4.36	7.21	4.56	4.61	5.16	8.80

Note: AFI=alternate furrow irrigation, FI= Farmers practice (every furrow irrigation)

Table 5. Yield and yield contributing characters of tomato at Amtali, Barguna in 2020-21

Treatment	Plant height, (cm)	No. of fruits plant^{-1}	Unit weight (g fruit^{-1})	Fruit length (cm)	Fruit diameter (cm)	Yield (t ha^{-1})

Drip	113.43a	55.93a	49.32	4.63a	5.11	75.81a
AFI	104.64b	48.92b	47.51	4.35ab	4.98	63.93b
FI	105.59ab	50.41b	45.16	4.29b	4.98	65.27ab
LSD	8.60	5.22	NS	0.33	NS	11.37
CV (%)	3.67	4.65	6.35	3.46	2.34	7.66

3.4 Irrigation of Brinjal

Yield and yield contributing parameters of brinjal at Barguna Sadar Upazila of Barguna district in 2019-20 are given in Table 6. There were 40 plants per 32 m^2 land i.e. plant population was 1.25 per m^2 at all locations for brinjal. The highest yield of brinjal was obtained from drip irrigation than AFI and FP methods. But it was statistically similar with FP. There were no significant differences in yield contributing parameters among the treatments except fruit diameter. Significantly higher fruit diameter of drip irrigation enhanced the highest yield in drip treatment. Similar results of brinjal were found for Amtali, Kalapara, Galachipa, Char Fasson. In Lalmohon, significantly higher yield was found in 2020-21 from drip and FP than AFI as shown in Table 7. But drip irrigation method and FI were statistically insignificant. Hence number of fruits per plant contributed higher yield in drip irrigation treatment as well as FI method. Hossain [20] presented similar results for drip irrigation in brinjal in plain land.

Table 6. Yield and yield contributing characters of brinjal at Barguna Sadar, Barguna in 2020-21

Treatment	Plant height (cm)	No. of fruits $plant^{-1}$	Unit weight (g $fruit^{-1}$)	Fruit length (cm)	Fruit diameter (cm)	Yield (t ha^{-1})
Drip	101.32	45.75	74.23	12.99	7.86a	34.71a
AFI	98.96	40.50	66.47	12.24	7.23b	27.99b
FI	99.83	41.75	69.39	12.66	7.47ab	32.63ab
LSD	NS	NS	NS	NS	0.54	5.99
CV (%)	2.64	8.41	5.73	4.32	3.33	8.68

Table 7. Yield and yield contributing characters of brinjal at Char Fasson, Bhola in 2020-21

Treatment	Plant height (cm)	No. of fruits $plant^{-1}$	Unit weight (g $fruit^{-1}$)	Fruit length (cm)	Fruit diameter (cm)	Yield (t ha^{-1})
Drip	100.69	35.50	79.57 a	10.87	7.80	28.53a
AFI	97.71	32.00	67.48 b	10.48	7.00	21.81b
FI	98.71	33.25	72.95 ab	10.54	7.40	26.45ab
LSD	NS	NS	7.15	NS	NS	5.69
CV (%)	2.06	7.77	4.49	2.96	8.47	10.24

3.5 Water Applied to Tomato by Solar Pumps

Average amounts of water applied to tomato by solar pump for irrigation in different locations using different irrigation methods in 2019-20 is shown in Table 8. It is observed from the table that about double amount of water was required in FI than drip method. Irrigation water savings in tomato by drip method and AFI method over FI in the study locations of the coastal region were 46-47%, and 31-35%, respectively. So, drip irrigation was method found a water saving technology for irrigating in tomato followed by AFI method. Similar results were found in the year 2020-21. This result is agreed with the findings of Hossain [20].

Table 8. Amount of water applied and water savings in tomato during 2019-20 in different locations

Water application method	Barguna Sadar		Amtali		Golachipa		Lalmohon	
	Water applied (mm)	Water saving (%)	Water applied (mm)	Water saving (%)	Water applied (mm)	Water saving (%)	Water applied (mm)	Water saving (%)
Drip	213	50.23	217	47.84	205	46.75	235	47.31
AFI	268	37.38	275	33.89	264	31.43	292	34.53
FI	428		416		385		446	

3.6 Water Applied to Brinjal by Solar Pumps

The average water application in all locations by different irrigation methods using solar pump for irrigation in brinjal in 2019-20 is given in Table 9. Irrigation water savings in brinjal in AFI method and drip method over FI in different locations of the southern region were 34-36% and 47-49%, respectively. So, drip irrigation method was found the best water saving technology for irrigation in brinjal followed by AFI method. Similar results were obtained in the year 2020-21.

Table 9. Amount of applied water and water savings of brinjal during 2019-20 in different locations

Water application method	Barguna Sadar		Amtali		Golachipa		Kolapara		Char Fasson		Lalmohon	
	AW*	WS**	AW	WS	AW	WS	AW	WS	AW	WS	AW	WS
Drip	242	47.96	246	47.88	237	47.57	238	48.48	252	48.78	248	48.76
AFI	298	35.91	310	34.32	294	34.96	305	33.98	324	34.15	322	33.47
FI	465		472		452		462		492		484	

*AW = Applied water (mm); **WS = Water saving (%)

3.7 Water Productivity of Tomato and Brinjal

Water productivity of tomato in the year 2019-20 are given in Table 10. Water productivity of solar pump drip irrigation and AFI in comparison of FP in 2019-20 were 181% and 121% higher. Drip irrigation required 48% and 21% lesser water than AFI and FI respectively for tomato production. There was no rainfall during the tomato growing season. In case of FI, seasonal water use was higher than drip (52%) and AFI (26%) due to loss of soil moisture. Yield of drip irrigated tomato was also higher than AFI and FI. Therefore, the highest water productivity was found from drip irrigation followed by AFI. Similar results were found for the year 2020-21. Water productivity of brinjal in the year 2020-21 are shown Table 11. It is observed from the table that drip irrigation and AFI saved 49% and 27.5% water respectively than conventional FI. Seasonal water use was also 32.7% lower than drip irrigation and 7.7% lower than AFI. Hence, water productivity of brinjal was 162% and 110% higher than drip and AFI, respectively. Similar results were also observed in 2019-20. It is also observed from the tables (Table 10 and Table 11) that water productivity of tomato was higher than brinjal due to crop duration of brinjal (4 months) was higher than tomato (3 months) and required more water in brinjal than tomato.

Table 10. Water productivity of tomato in 2019-2020

Water application method	Average yield (t ha^{-1})	Aplied water (mm)	Soil moisture use (mm)	Seasonal water use (mm)	Water productivity (kg ha^{-1}mm^{-1})	Water productivity as a % of FP
Drip	68.86	218	47	265	259.85	181.43
AFI	55.75	275	46	321	173.68	121.27
FI	57.86	419	-15	404	143.22	-

Table 11. Water productivity of brinjal in 2020-2021

Water application method	Average yield (t ha^{-1})	Applied water (mm)	Soil water use (mm)	Effective Rainfall (mm)	Seasonal water use (mm)	Water productivity (kg ha^{-1}mm^{-1})	Water productivity as a % of FP
Drip	45.85	283	36	20	339	135.25	161.61
AFI	42.76	403	30	32	465	91.96	109.88
FP	42.18	556	-52	0	504	83.69	-

3.8 Solar Home System

Four panels each of 325 W_p (325 W_p×4 =1300 W_p) were required for operation of solar pump. Only one panel 325 W_p was used for SHS as shown in Table 12. The load for operating five LED dc bulb, two dc table fan and one mobile charger with total load was 75 W. Solar pump was used for irrigation as well as supplying of potable water for drinking and sanitation purposes. So, solar pump was used for multipurpose works in farm level such as irrigation, lightings, operating fans, supplying drinking water, sanitation and other purposes.

Table 12. Field performance of solar home system at Kolapara, Patuakhali

Item	PV (W)	Battery AH	Battery Volt	Name of appliances	Numbers/ quantity	Power per appliance (W)/services	Total Load (W)/ quantity	Remarks
SHS	325	100	12	Light	5	7	35	Working well
				Fan	2	12	24	
				Mobile phone	2	8	16	
Water supply	1300			Sanitation and drip irrigation	500 L tank	Basin tap	1	Improved sanitation and hand wash
						Toilet tap	1	
						Bath tap	2	

3.9 Environmental Benefits of Solar Pump

Amount of the carbon emitted from the diesel and electricity operated LLPs is given in Table 13. Considering 8 hours per day of irrigation operation in 80 days per season it is noticed from the table that total amount of diesel emitted from LLP was 108406272 L from which carbon emission was found 303538 ton per year. It was also found that using single solar pump of 0.8 kW instead of diesel pump of 2.98 kW about 1.76 ton of carbon emission can be reduced per year and during 20 years of economic life 35.28 ton of carbon can be reduced and the monetary benefit would be about USD 30353756. Solar energy is environment friendly and zero carbon emission renewable energy. Therefore, solar irrigation pump can be used for irrigation purpose that can make environment pollution free and clean.

Table 13. Carbon emission and environmental monetary benefit from solar pump in 20 years

Name of the pump	LLP	LLP
Mode of operation	Electricity	Diesel
Number of the pump	11822	164656
Operation per season, day	80	80
Operation hour/day	8	8
Capacity, kW	2	2.98
Power consumption, kWh/season	1280	-
Fuel used, L/season	-	640
Total diesel used for surface water lifting, MWh	15132	-
Amount of diesel, L	3026432	105379840
Total amount of diesel	108406272	-
CO_{2e}, ton	303538	-
Money, USD	30353756	-

3.10 The Opportunity and Benefit of Solar Systems

Solar panel can be used in versatility such as solar home system, use of small farm machinery, use pump for drinking purpose, drainage purposes which finally balance the capital cost of solar irrigation systems. In this study it was observed that using large solar pumps return per year from SHS, drinking purpose, drainage purpose and small agricultural machinery like winnower used for winnowing purpose were USD 30 (for single panel of 250 W_p), USD 85, USD 3.50 and USD 70 per year, respectively. In such way, solar system can reduce the cost of electricity and maintain a quality life of user. After fulfilling own requirement, solar pump owner also work as a service provider. As there was no complicated device to operate the solar pump and related system. Only on-off switch was used to start and stop the pump. So, woman can easily use this system without environmental and health hazard.

4. CONCLUSION

In the study areas, 100% of irrigation was done using surface water by small diesel engine operated LLP. The discharge of the solar pump varied with solar radiation and time of a day. Yields of tomato and brinjal in drip irrigation were higher than AFI and FI. Similar yields of tomato and brinjal were found in AFI and FI. Solar pump was found more economical than diesel operated pump for vegetable cultivation. Its maintenance cost, energy cost and operating cost were lower compared to those of diesel-powered pump. A small solar pump of 0.8 kW reduced 1.76 ton of carbon emission per year than a similar diesel engine operated pump. The solar panels were used for both irrigation and household uses thus making it more profitable than low lift pump. Farmers in the project areas are using the solar panels for irrigation, lightings, operating fans, supplying drinking water, sanitation and other purposes. Therefore, solar pump is a climate resilient technology for small holder farmers in the coastal region of Bangladesh.

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