ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 47(2): 241-255, June 2022

ECONOMIC FEASIBILITY OF SOLAR IRRIGATION PUMPS IN SOUTHERN REGION OF BANGLADESH

M. A. HOSSAIN[1], M. A. HOQUE[2], S. S. A. KAMAR[3]
M. A. RAHMAN[4] AND M. A. MOTTALIB[5]

Abstract

This study presents the economic suitability of solar pump in the southern region of Bangladesh. Field survey was conducted during 2018-19 at Kalapara and Galachipa Upazila of Patuakhali district, Borguna Sadar and Amtoli Upazila of Borguna district, Charfassion and Lalmohon Upazila of Bhola district. BARI developed large and mini solar pumps and were tested in those areas for irrigation in vegetables. Two water saving irrigation techniques (Drip and alternate furrow) and one conventional irrigation practice were used for cultivating tomato, brinjal, watermelon and chili. The internal rate of return of all irrigation systems were greater than the bank interest rate. Solar powered drip and alternate furrow irrigation system was found more profitable than low lift pump for cultivation of vegetables. The benefit-cost ratio of mini and large solar systems were found 1.50 and 1.42, respectively. So, solar pump may be recommended for irrigation vegetables in the southern region of Bangladesh.

Keywords: Benefit cost ratio, low lift pump, net present value, payback period, solar pump. vegetables.

Introduction

In Bangladesh, 187188 LLP (Low lift pump), 1357532 STW (Shallow tube well), 37634 DTW (Deep tube well) and 5500 solar pumps are in operation of 1.58 million irrigation pumps. There is about 65.08% irrigation coverage of which 78.45% operate on a diesel engine and 21.55% on electric motor and solar energy operated pumps (BADC, 2020). Bangladesh government has already decided to generate 1.5 GW electricity from solar within 2021 (SREDA, 2021). Solar based irrigation systems are innovative and environment friendly solution for the agro-based economy of Bangladesh. Farmers normally use pumps for 115-120 days of a year for irrigation, while the rest of the year the pumps remain off when solar electricity has no use. Bangladesh Rural Electrification Board (BREB) plans to install 2000 solar irrigation pumps allowing farmers to sell their unconsumed electricity to the national grid when irrigation is no longer required. Hossain *et al.* (2015) conducted a base-line survey in 2010 at different locations of Bangladesh to know the status of solar pumps. There were about 150 solar pumps in Bangladesh among them 65% were used for supplying drinking water to the poor people of the locality and about 35% solar pumps were used for irrigation

[1,2,4&5]Farm Machinery and Postharvest Process Engineering Division, [3]Irrigation and Water Management Division, BARI, Gazipur-1701, Bangladesh.

purposes. Statistics from a draft report of SREDA (Sustainable and Renewable Energy Development Authority) on National Solar Energy Roadmap 2021-41 shows that so far 1872 solar irrigation pumps were installed across the country by different organizations. Of these, BREB installed 40, IDCOL (Infrastructure Development Company Limited) 1523, BADC (Bangladesh Agricultural Development Corporation) 137, Barind Multipurpose Development Authority (BMDA) 106, RDA (Rural Development Academy) 15, and other authorities 51, which have installed power generation capacity is 43.178 MW. Islam and Hossain (2022) reported that small solar pump in Bangladesh is more profitable than large solar pump. Large solar pump is run by 'fees for service model' and small solar pump is run by ‘fees for ownership model' and it is more profitable due better management.

To achieve the government dictum Bangladesh Agricultural Research Institute (BARI) has started working on solar irrigation cum solar home system from the late 90s. Therefore, this study was executed to assess the technical and economic feasibility of BARI developed different solar irrigation system for vegetable cultivation over low lift pump in southern areas of Bangladesh.

Materials and Methods

Experimentation

Two types of solar pumps were fabricated at Farm Machinery and Pos-tharvest Process Engineering (FMPE) Division, Bangladesh Agricultural Research Institute (BARI), Gazipur for surface water lifting. The large and mini solar pumps were selected and installed at Patuakhali, Borguna and Bhola districts of southern Bangladesh for irrigating vegetables in *Rabi* season. The large solar pump (910W dc motor, 180 L/min discharge) was designed and fabricated for large and medium farmers. The mini solar pump (280W dc motor, 40 L/min discharge) was designed and fabricated considering affordability of small farmers. The large solar pump had inlet and outlet diameters of 51 mm and the mini solar pump had inlet and outlet diameter of 25 mm. Field experiments were conducted at Galachipa and Kalapara Upazilla of Patuakhali district, Amtali, Borguna Sadar Upazilla of Barguna district, Lalmohon and Charfasson Upazila of Bhola district during *Rabi* season of 2019-2020 and 2020-2021 with the solar pumps for irrigating tomato, brinjal, chili and watermelon. Drip irrigation, alternate furrow irrigation and conventional method (Every furrow/ring basin) irrigation treatments were applied through randomized complete block design.Drip irrigation, alternate furrow/ring basin irrigation treatments were applied through randomized complete block design for executing watermelon experiments. The experiment information is given in Table 1.

Table 1. Description of field experiments during Rabi season of 2019-20 and 2020-21

District	Upazila	Year	Vegetables	Area (m^2)
Patuakhali	Kalapara	2019-20	Brinjal	264
		2020-21	Brinjal	216
	Galachipa	2019-20	Tomato	521
			Brinjal	264
		2020-21	Tomato	216
			Brinjal	240
			Chili	300
			Watermelon	924
Borguna	Sadar	2019-20	Tomato	472
			Brinjal	472
		2020-21	Tomato	250
			Brinjal	216
			Watermelon	360
	Amtali	2019-20	Tomato	336
			Brinjal	524
		2020-21	Watermelon	534
			Brinjal	400
Bhola	Lalmohon	2019-20	Tomato	360
			Brinjal	236
		2020-21	Tomato	584
	Charfassion	2019-20	Brinjal	326
		2020-21	Brinjal	400
			Tomato	120

Plant height (cm), fruit diameter (cm), fruit length (cm), number of fruits per plant, unit fruit weight (g) and yield (t/ha) data were collected. . Two types of solar pump were tested and recorded different cost parameters for installation and operations of all pumps. The relevant costs of LLP (3.0 kW diesel engine, 660 L/min discharge and 76.20 mm outlet diameter) were also collected from direct interviewing from the local service providers.

Financial analysis

Total operating cost of two types of solar pumps and diesel engine operated LLP for crop production is the sum of total fixed cost and total variable cost. Fixed cost is the sum of capital consumption, shelter/taxes/insurance and interest of investment. The life cycle cost (LCC) of any piece of equipment is the total "lifetime" cost to purchase, install, operate, maintain, replacement and dispose of that equipment. LCC analysis is a management tool that can help the owner to minimize waste and maximize energy efficiency for pumping system. LCC is calculated using the following formulae (Anonymous, 2001).

LCC = Total investment cost + Fixed cost + variable cost + replacement and disposal cost.

Total Investment cost = Purchase price of pump/panel + Installation cost + Cables and accessories cost

Fixed cost = Capital consumption + interest of investment + shelter

Variable cost = Repair & maintenance + labor cost + fuel cost + oil/lubrication cost

Operating cost =Fixed cost + variable cost

Repair and maintenance = 3% of purchase price of pump/engine

Salvage value = 10% of purchase price of pump/solar panel (Sv)

Shelter =2% of purchase price of pump/engine

$$\text{Capital Consumption} = \{(\text{TIc} - \text{Sv}) * \text{CRF}\} + (\text{Sv} * \text{i})$$

Where,	TIc	=	Total investment cost
	Sv	=	Salvage value
	CRF	=	Capital recovery factor
	i	=	interest (10%)

Where, TIc is the sum of purchase price of pump/solar panel, installation cost, cables, accessories and pipes and fitting cost.

$$CRF = \frac{i(1+i)^L}{(1+i)^L - 1}$$

Where,	i	=	Interest (10%)
	L	=	Economic life of system

Marginal benefit cost ration for pump was calculated by the following equation

$$\text{MBCR} = \frac{\text{Gross Return}}{\text{Annual Operating Cost}}$$

Where,	Gross return ($/year)	=	Area under irrigation × irrigation charge per year/ season
	Operating cost ($/year)	=	Fixed cost + variable cost

Benefit cost ration for crop was calculated by the following equation

$$\text{BCR} = \frac{\text{Gross Return}}{\text{Total Cultivation Cost}}$$

Where, Net return ($/year) = Gross return – cultivation cost

Cultivation cost ($/year) = Fixed cost + Variable cost

Payback period for was calculated by the following equation

$$\text{PBP} = \frac{\text{Total Investment Cost}}{\text{Gross Return}}$$

Depreciation is often defined as the annual loss in value due to use, wear, tear, age, and technical obsolescence. Several methods or equations can be used to compute annual depreciation. Straight line method was used in this study to calculate depreciation. The straight line method of calculating depreciation is widely used. The useful life of solar pump and diesel engine-operated pump was assumed to be 20 years and 10 years, respectively. Annual interest rate was considered 10 % of the capital price of the pump.

Net present value (NPV) was calculated by using the following equation

NPV= PW of benefit at 10% DF – PW of cost at 10% DF

Where, PW = Present worth

DF = Discounted factor

To investigate investment prospects of PV water pumping applications, internal rate of return (IRR) is used as an indicator of project profitability. Internal rate of return is defined as the interest rate at which present worth of the cash flows of a project are zero. Internal rate of return higher than the market interest rate means profitable investment.

Present worth income = present worth (disbursements) then IRR = i

Results and Discussion

Base line information

Irrigation status of the selected Upazila of Patuakhali, Borguna and Bhola districts were given in Table 3. In all locations farmers used diesel operated LLP. Only 11.54 to 34.48% farmers used their own irrigation system. Rest of the farmers (65.52 to 88.46%) used the irrigation system as hiring basis. The engine horse power varied from 4.5 to 10.50 hp depending on the head of water source.

Table 3. Irrigation status in the selected areas in Patuakhali, Borguna and Bhola districts

Items		Patuakhali		Borguna		Bhola	
		Kolapara	Galachipa	Sadar	Amtoli	Charfassion	Lalmohon
Pump	LLP (%)	100	100	100	100	100	100
	Diesel (%)	100	100	100	100	100	100
	Engine (hp)	6.5	7.3	5.33	4.5	8.32	10.50
	Owner (%)	19.23	34.48	11.54	17.39	17.25	10.35
	Hire (%)	80.77	65.52	88.46	82.61	82.75	89.65
	Fuel consumption (Lh^{-1})	1.03	1.21	0.872	0.792	1.22	1.5
	Operating time (h)	8.5	9.5	10	9	9.85	10.35
Source of irrigation water	Canal (%)	85	73	90	65	87	74
	Pond (%)	15	27	10	35	13	26
Water available in dry season (m)		3.04	2.90	1.59	1.15	1.48	1.27

Fuel consumptions of the used engines were 0.79 to 1.5 L/h depending on the engine power. The operating time of those engines were varied from 8.5 to 10.35 h depending on the cultivated crop. Most of the southern farmers (65-90%) used canal water for irrigation and the head of available water sources varied from 1.15 to 3.04 m.

Financial analysis

Different cost components for two solar pumps and LLP are given in Table 4 . A large solar pump comprised of 1.3 kW photovoltaic panel and 1.2 hp centrifugal pump with 180 L/min discharge capacity and a mini solar pump comprised of 0.50 kW photovoltaic panel and 0.40 hp centrifugal pump with 40 L/min discharge capacity were selected for economic analysis. A 4.5 hp diesel engine operated centrifugal pump with 250 L/min discharge capacity LLP was also selected for economic analysis. Life of solar panel was assumed 20 years and life of DC motor was assumed five years. The command area of two selected solar pumps were 1.6 ha and 0.8 ha, respectively and was used in whole season. The command area of selected LLP was 2.94 ha. From Table 4 it is observed that the total cost (Cost of panel, cost of pump, cost of motor, installation and fitting cost) of large solar pump, mini solar pump and LLP were USD 940.80, 303.30 and 314.40 respectively. From Table 3, it is also observed that there was no installation cost for LLP. There was no fixed structure for LLP at the southern region of Bangladesh. Farmers usually keep LLP at home and transfer it in the field during the time of irrigation. The fitting cost of solar pump was higher than LLP. Solar pump need wiring and accessories for fitting with the solar panel but LLP does not require such type of wiring cost.

Table 4. Cost Components of two solar pumps and low lift pump

Item	Power	Cost of panel (USD)	Cost of pump associated with prime mover (USD)	Installation cost (USD)	Fittings cost (USD)	Total cost (USD)
Large solar pump	Panel:1300 W_p motor: 910 W	514.80	270.00 (dc motor with pump)	36.00	120.00	940.80
Mini solar pump	Panel: 365 W_p motor: 280 W	153.30	12.00 (dc motor with pump)	36.00	102.00	303.30
LLP	2984 W	-	240.00 (Engine with pump)	-	74.40	314.40

It can be illustrated from Table 5 that the investment cost and fixed cost were much higher in two types of solar pump than LLP. The purchase price (USD 0.40 per watt) of solar panel was much higher than LLP in Bangladesh. On the other side variable cost and operating cost were observed higher in LLP than the solar pumps. Variable cost included repair and maintenance, labor cost, fuel cost and oil cost. No fuel and oil cost were required for solar pump operation. The labor cost was not as much of in solar pump operation. In case of LLP, engine needs overhauling almost every year. Life of diesel engine and pump were considered five years. After five year new engine and pump would be required for LLP but for solar pump only pump would be required.

Table 5. Life cycle costs of two solar pumps and low lift pump

Cost Item	Large solar pump	Mini solar pump	LLP
Investment cost (USD)	940.80	411.30	314.40
Fixed cost (USD)	167.90	74.21	24.12
Variable cost (USD)	155.70	78.66	727.99
Operating cost (USD)	323.60	152.87	752.11
Life cycle cost (USD)	1588.00	717.03	1818.62

In case of solar pumps, only the motor and pump need to be changed after five years because the life of solar panel was assumed 20 years (Table 6). Hossain *et. al.* (2015) also found from a survey in Bangladesh that a 4.0 hp submergible solar pump was more cost effective than a 4.0 hp diesel engine operated shallow tube well.

Table 6. Capacity, operation and fuel used in LLP at six upazila in Patuakhali, Borguna and Bhola districts

Cost Item	Unit	Average value
Fuel consumption	Liter/hour	1.00
Fuel cost	USD/Liter	0.78
Daily use	Hour	8.00
Yearly use	Day	60.00
Annual use	Hour	480.00
Total energy cost	USD/year	374.40
Oil & lubrication (15% of total fuel cost)	USD	56.16
Area under irrigation	Hectare	2.94
Irrigation cost	USD/ha/season	287.42

Costs and benefit of solar pumps and LLP for vegetable cultivation

Table 7 gives different cost components regarding tomato, brinjal, watermelon and chili cultivation through drip, alternate furrow and every furrow irrigation using large solar pump. Among all three irrigation practices, drip irrigation required higher cost for all types of vegetables cultivation due to its high installation cost. Here input cost included land preparation cost, fertilizer cost, seed cost, insecticide and pesticide cost and labor cost. Irrigation cost included pipes, tank and other fitting costs. The variable cost is the sum of input cost and irrigation cost. The cultivation cost is the sum of variable cost and fixed cost. The input cost was varied due to the labor usage varied at different irrigation methods. In that case of, every furrow irrigation required higher labor cost than other irrigation practice. The cost of pump and fixed cost remained same at all irrigation method.

Table 7. Costs of Vegetable cultivation under different irrigation methods for large solar pump

Crop	Irrigation method	Fixed cost ($)/ha	Input cost ($)/ha	Irrigation cost ($)/ha	Total variable cost ($)/ha	Total cultivation cost ($)/ha
Tomato	Drip	73.99	1142.78	961.61	2104.39	2178.38
	AFI	73.99	1294.27	144.00	1438.27	1512.26
	EFI	73.99	1541.27	300.00	1841.27	1915.26
Brinjal	Drip	73.99	3890.24	1215.66	5105.90	5179.89
	AFI	73.99	4075.49	210.00	4285.49	4359.47
	EFI	73.99	4353.36	420.00	4773.36	4847.35
Watermelon	Drip	73.99	1184.98	711.36	1896.34	1970.32
	RBI	73.99	1302.30	80.03	1382.33	1456.32
	EFI	73.99	1671.97	80.03	1752.00	1825.99
Chilli	Drip	73.99	3942.52	1130.98	5073.49	5147.48
	AFI	73.99	4347.19	264.00	4611.19	4685.18
	EFI	73.99	4841.18	540.00	5381.18	5455.17

Table 8 describes different cost components regarding tomato, brinjal, watermelon and chili cultivation through drip, alternate furrow and every furrow irrigation using mini solar pump. Among all three irrigation practices, drip irrigation required higher cost for all types of vegetables cultivation due to its high installation cost. Here input cost included land preparation cost, fertilizer cost, seed cost, insecticide and pesticide cost and labor cost. Irrigation cost included pipes, tank and other fitting costs. The variable cost was the sum of input cost and irrigation cost. The cultivation cost was the sum of total variable cost and fixed cost. The input cost was varied due to the labor usage varied at different irrigation practices. In that case, every furrow irrigation required higher labor cost than other irrigation practice. The cost of pump and fixed cost remained same in all irrigation system.

Table 8. Costs of Vegetable cultivation under different irrigation methods for mini solar pump

Crop	Irrigation method	Fixed cost ($)/ha	Input cost ($)/ha	Irrigation cost ($)/ha	Total variable cost ($)/ha	Total cultivation cost ($)/ha
	Drip	42.01	1142.78	961.61	2104.39	2146.40
Tomato	AFI	42.01	1294.27	144.00	1438.27	1480.28
	EFI	42.01	1541.27	360.00	1901.27	1943.27
	Drip	42.01	3890.24	1215.66	5105.90	5147.91
Brinjal	AFI	42.01	4075.49	180.00	4255.49	4297.49
	EFI	42.01	4353.36	420.00	4773.36	4815.37
	Drip	42.01	1184.98	474.24	1659.22	1701.22
Watermelon	RBI	42.01	1302.30	80.03	1382.33	1424.33
	EFI	42.01	1431.97	160.06	1592.03	1634.03
	Drip	42.01	3342.52	1215.66	4558.18	4600.19
Chilli	AFI	42.01	4347.19	144.00	4491.19	4533.20
	EFI	42.01	4841.18	300.00	5141.18	5183.19

Table 9 shows different cost components regarding tomato, brinjal, watermelon and chili cultivation through drip, alternate furrow and every furrow irrigation using LLP. Among all three irrigation practices drip irrigation required higher irrigation cost, variable cost and cultivation cost at all types of vegetable cultivation due to its high installation cost. Here input cost included land preparation cost, fertilizer cost, seed cost, insecticide and pesticide cost and labor cost. Irrigation cost included pipes, tank and other fitting costs. The variable cost was the sum of input cost and irrigation cost. The cultivation cost was the sum of total variable cost and fixed cost. The input cost was varied due to the labor usage varied at different irrigation methods. In that case, every furrow irrigation required higher labor cost than other irrigation methods. The cost of pump and fixed cost remained same in all irrigation systems.

Table 9. Costs of Vegetable cultivation under different irrigation methods for low lift pump

Crop	Irrigation method	Fixed cost ($)/ha	Input cost ($)/ha	Irrigation cost ($)/ha	Total variable cost ($)/ha	Total cultivation cost ($)/ha
	Drip	24.12	830.78	961.61	1792.39	1816.51
Tomato	AFI	24.12	1414.27	144.00	1558.27	1582.39
	EFI	24.12	1181.27	360.00	1541.27	1565.39
	Drip	24.12	3374.24	1215.66	4589.90	4614.02
Brinjal	AFI	24.12	4195.49	180.00	4375.49	4399.61
	EFI	24.12	4101.36	420.00	4521.36	4545.48
	Drip	24.12	1184.98	474.24	1659.22	1683.34
Watermelon	RBI	24.12	1302.30	80.03	1382.33	1406.45
	EFI	24.12	1431.97	80.03	1512.00	1536.12
	Drip	24.12	3342.52	1215.66	4558.18	4582.30
Chilli	AFI	24.12	4347.19	144.00	4491.19	4515.31
	EFI	24.12	4721.18	300.00	5021.18	5045.30

Table 10 demonstrates that the gross return was comparatively high at drip and alternate furrow irrigation over every furrow irrigation. High gross margin was found in alternate furrow irrigation which was followed by drip irrigation and every furrow irrigation for tomato, brinjal, watermelon and chili cultivation at the selected locations of the southern districts. Two improved irrigation technologies gave highest return than every furrow irrigation for all types of vegetable cultivation.

Table 10. Gross margin of two solar pump and LLP under different irrigation methods for vegetable cultivation

Crop	Irrigation method	Yield (t/ha)	Selling price ($/t)	Large solar pump ($)/ha	Mini solar pump ($)/ha	Low lift pump ($)/ha
	Drip	44.29	122.04	3226.77	3258.75	2860.65
Tomato	AFI	38.41	122.04	3175.30	3207.28	2377.17
	EFI	37.69	122.04	2684.43	2656.41	2306.31
	Drip	47.71	300.00	9133.11	9165.09	6108.39
Brinjal	AFI	44.62	300.00	9026.53	9088.51	5581.20
	EFI	44.04	300.00	8364.65	8396.63	5296.13
	Drip	44.69	148.44	4663.46	4932.56	4222.46
Watermelon	RBI	40.33	148.44	4530.27	4562.25	3852.15
	EFI	38.70	148.44	3918.64	4110.59	3480.52
	Drip	12.50	960.00	6852.52	7399.81	6689.71
Chilli	AFI	12.40	960.00	7218.82	7370.80	6660.70
	EFI	11.72	960.00	6266.43	6538.41	5948.30

It is shown in Table 11 that the marginal benefit cost ratio was higher in mini solar pump (1.51) and large solar pump (1.42) than LLP (1.12). Though it could be observed from Table 11 that the gross return was found high in LLP but the variable cost and operating costs were much higher in LLP operation than solar pumps (Table 5). So that the MBCR became lower in LLP. Biswas and Hossain (2013) also reported that a 10 hp solar operated pump became more economic than a 10 hp diesel engine operated pump after 10 years of operation. Abu-Aligah (2013) reported that for long-term irrigation project (more than five years) solar pump is more economic than same sized-diesel pump.

Table 11. Gross return, gross margin , BCR and payback period of two solar pumps and low lift pump

Benefit Item	Large solar pump	Mini solar pump	Low lift pump
Gross return (USD)	460.80	230.40	844.80
Gross margin (USD)	137.20	77.53	92.69
Marginal benefit cost ratio	1.42	1.51	1.12
Payback period	6.86	5.30	3.39

From the above discussion, it could be stated that the solar pump was more economical than diesel operated pump for vegetable cultivation. Though the investment cost was high in solar pump irrigation system but the variable cost and operating cost were much lower in comparison with diesel operated LLP. Generally, farmers of Bangladesh use LLP as hire basis for irrigation. In that case, farmers would have to bear the fuel cost and operation cost for the benefit of the pump owner. In the survey area, irrigation water was applied through 4.5 hp diesel engine operated LLP. Only 18% people were the owner of those pumps and the rest 82% people used the pumps for irrigation as hiring basis. The irrigation cost per hectare was calculated 287.42 USD per season in the selected survey area (Table 5). However, in case of solar pump there was no fuel cost. Therefore, the irrigation rent would be less in solar irrigation system than LLP. In case of benefit cost ratio, for each type of vegetable cultivation, alternate furrow irrigation and ring basin irrigation gave highest BCR than other two-irrigation practices. It could be stated from the Table 12 that the improved irrigation techniques were more suitable than conventional practice.

Net present value (NPV), benefit cost ratio (BCR), and internal rate of return (IRR) at 10% discounted factor was calculated for project analysis. Discounted measures of project were used for financial analysis since undiscounted measures of project worth is quite unable to be taken into consideration the timing of benefits and costs. From Table 13, it is pointed that the solar pumps and LLP were profitable for the owners in using irrigation practice. A cash flow chart was prepared for project analysis in making comparison between large solar pump, mini solar pump and LLP. The project analysis was calculated for 20 years project period. The project cost was the sum of capital cost and operating cost of solar PV pumping system. The cash inflow of the project came from custom hire of irrigation service to the farmers. The hire rate was equal for both diesel pump and solar pump. In Table 13, the large solar pump cash out flow it was stated that the NPV, BCR, IRR and DPBP was 968.62 USD, 1.33, 14% and 14.28, respectively. Whereas for mini solar pump cash out flow stated that the NPV, BCR, IRR and DPBP was 560.65, 1.40, 25% and 16.48, respectively. Once more for LLP the cash out flow stated that the NPV, BCR, IRR and DPBP was 433.01, 1.06, 17% and 16.61, respectively. The NPV indicates that the solar irrigation system was considered financially sound and the project may be financially viable because the highest IRR (20%) of solar irrigation system was greater than the bank interest rate. Therefore, solar PV system for using irrigation purpose in vegetable cultivation is more risk free than other irrigation system.

Table 12. Benefit cost ratio of solar pumps and LLP under different irrigation system for vegetable cultivation

Crop	Irrigation method	Large solar pump	Mini solar pump	Low lift pump
Tomato	Drip	1.48	1.52	1.12
	AFI	2.10	2.17	1.03
	EFI	1.40	1.37	1.01
Brinjal	Drip	1.76	1.78	1.14
	AFI	2.07	2.11	1.09
	EFI	1.73	1.74	1.00
Watermelon	Drip	2.37	2.90	1.75
	RBI	3.11	3.20	1.80
	EFI	2.15	2.52	1.54
Chilli	Drip	1.33	1.61	1.26
	AFI	1.54	1.63	1.27
	EFI	1.15	1.26	1.03

Table 13. Comparison of NPV, BCR, IRR and DPBP for two solar pumps and low lift pump

Item	Large solar pump	Mini solar pump	Low lift pump	Remarks
NPV (USD)	968.62	560.65	433.01	If greater than zero, accepted
BCR	1.33	1.40	1.06	If greater than unity, accepted
IRR	14%	25%	17%	If greater than prevailing interest rate, Accepted
DPBP	14.28	16.48	16.61	If less than economic life, accepted

3.4 Cost and benefit of large and small solar irrigation system including solar home system

Life cycle cost in Table 14 and Table 15 described the gross and net returns, BCR and payback period of two solar irrigation system including solar home system. In case of large solar pump investment cost, fixed cost, variable cost, operating cost and life cycle cost increased about 358.80, 61.25, 180.00, 241.25 and 841.30 USD, respectively. On the other hand, for mini solar pump investment cost, fixed cost, variable cost, operating cost and life cycle cost increased about 358.80, 61.25, 90.00, 151.25 and 661.31 USD, respectively.

Table 14. Life cycle costs of two solar pumps including solar home system

Cost item	Large solar pump	Mini solar pump
Investment cost (USD)	1299.60	770.10
Fixed cost (USD)	229.15	135.46
Variable cost (USD)	335.70	168.66
Operating cost (USD)	564.85	304.12
Life cycle cost (USD)	2429.30	1378.34

Though the expenses were increased gradually at all cost items, the returns also increased thoroughly. The gross return was increase USD 367.20 for large and mini solar pumps. The gross margin was increased USD 493.15 and 215.95, respectively for large and mini solar pumps. It was observed that the solar irrigation system including solar home system provided higher marginal benefit cost ratio than solar irrigation system excluding solar home system. The pay back period was observed less in solar irrigation system including solar home system.

Table 15. Gross return, net return, BCR and payback period of two solar pumps

Benefit Item	Large solar pump	Mini solar pump
Gross return (USD)	828.00	597.60
Gross margin (USD)	630.35	293.48
Marginal benefit cost ratio (MBCR)	2.12	1.97
Pay back period (PBP)	2.06	2.62

Social benefits of solar pump

Solar irrigation is potential for increasing agricultural productivity and income due to improved access to water (additional cropping season, diversification of cropping pattern, higher value crops). From Table 6, it is observed that the farmers could save 374.40 USD per year as fuel cost by using solar irrigation system, which will save carbon dioxide emission. A single unit solar irrigation system could save 1.29 tons carbon dioxide emission per year over diesel engine operated low lift pump.

Farmers could save on an average USD 28.8 per year in domestic use (electricity) andabout USD 14 per year in homestead watering (bathing, clothing, cleaning and livestock watering etc.). Solar irrigation is time saving technology due to replacement of labor-intensive manual irrigation, which can lead to other income-generating activities. Women and/or children might profit from time not spent on watering anymore and potential for job creation in the renewable energy sector, which reduced dependence on energy exports. Energy subsidies for fossil fuels can be reduced while offering an alternative to farmers and rural communities whose livelihoods would otherwise be negatively affected.

Conclusion

In all selected locations, 1.91 m depth of water was always available in dry season at all water sources. With this available water, about 4.5 hp power diesel operated low lift pump is used. Solar pumps (Large and mini) were found suitable in terms of technical and financial performance over LLP. The solar irrigation system for vegetable cultivation was found profitable. The installation cost of solar irrigation system was high but the economic life, labor cost, fuel cost, oil cost and repair maintenance cost of solar irrigation system were lower than the LLP. Entrepreneurs can save fuel cost, oil cost and repair maintenance cost in operation of solar pump. The BCR was found 1.50 and 1.42 for mini and large solar pumps respectively. The solar irrigation system was not familiar to the farmers and the service providers of the study areas. A solar irrigation system owner or local service provider (LSPs) can start this business, which would be a profitable scheme for an entrepreneur. To extend the benefits of solar irrigation system among the farmers and custom hire service providers, appropriate adoption and dissemination programs must be launched all over Bangladesh. After fulfilling own demand, service providers can trade excess electricity to others through grid line, charging batteries, charging mobile phones and charging battery operated vehicles.

Acknowledgments

The authors would like to thank Project Implementation Unit, Bangladesh Agricultural Research Council for funding the project (PBRG, ID 001) through National Agriculture Technology Project and also thank to project partners for cooperation of this project.

Reference

Anonymous. 2001. Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems. Collaboratively published by the Hydraulic Institute, Europump, and the US Department of Energy's Office of Industrial Technologies (OIT). DOE/GO-102001-1190.

BADC. 2020. Minor Irrigation Survey Report 2018-19 (Rabi Season). Digitalization of Survey & Monitoring for Development of Minor Irrigation Project, Bangladesh Agricultural Development Corporation. 22, Manikmia Avenue, Shere-e-Bangla Nagar, Dhaka-1207.

Biswas, H. and H. Hossain. 2013. Solar Pump: a possible solution of irrigation and electric power crisis of Bangladesh. *Int J. Comput Appl*. **62(16):** 1-5.

Hossain, M. A., M. S. Hassan, M. A. Mottalib, and M. Hossain. 2015. Feasibility of Solar Pump for Sustainable Irrigation in Bangladesh. *International Journal of Energy & Environmental Engineering* **6(2):** 147-155.

SREDA. 2021. Energy Efficiency and Conservation Master Plan up to 2030. Power Division, Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh.