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ORIGINAL RESEARCH

Feasibility of solar pump for sustainable irrigation in Bangladesh

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Abstract A base-line survey was conducted in 2010 at different locations of Bangladesh to know the present status of solar pumps. The respondents were solar pump users, suppliers and service providers. 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 purposes. The size of solar pumps varied from 300 to 1,190 W_p and discharge capacity varied from 2,000 to 800,000 L/day. Panel cost was the major cost (45 %) in solar pump followed by the costs of installation (18 %), motor (16 %), pump (10 %), and pipes and fittings (4 %). Life cycle cost of diesel engine-operated pump was lower up to 5 years. After 5 years, the life cycle cost of solar pump became lower than that of diesel engine-operated pump. Benefit cost ratio, net present value and internal rate of return of solar pump were found higher than diesel-operated pump. Therefore, solar pump is profitable and investment on solar pump is more risk free than diesel engine-operated pump. Diesel engine-operated irrigation pump emits carbon dioxide and pollutes environment, but solar pump is an environment-friendly irrigation technology.

Keywords Solar pump · Irrigation · Benefit cost ratio · Net present value · Life cycle cost

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Introduction

There are about 1.71 million irrigation pumps in Bangladesh among them 83 % are diesel engine-operated and 17 % are electricity operated [1]. Solar pump may be an alternative for small-scale irrigation for crop production in the off-grid areas of Bangladesh. Solar pump is a pollution-free and environment-friendly water pumping system in agriculture. Being a tropical country, Bangladesh is endowed with abundant supply of solar energy. The ranges of solar radiation are between 4.0 and 6.5 kWh/m^2/day and the bright sunshine hours vary from 6 to 9 h/day [2, 3]. In Bangladesh about 60 % land is under irrigation. There is a vast area to be irrigated where most of the areas (Charland, coastal area, hilly area, etc.,) have no grid connection. Solar PV pump may be used for irrigating these lands to enhance crop production and to increase cropping intensity.

Abu-Aligah [4] reported that in locations where electricity is not available photovoltaic pumping system is a good option for irrigating crops and supplying drinking water. Advantages of PV pumping systems include low operating cost, unattended operation, low maintenance, easy installation, and long life. These are all important in remote locations where electricity is unavailable. Namibia renewable energy programme (NAMREP) conducted a study on feasibility of solar pump in Namibia [5]. The report furnished that for small- to medium-sized wells, solar photovoltaic pump was much cheaper on a life cycle cost basis than diesel-powered pumps. When looking beyond the original purchase price, solar pumping systems costed from 22–56 % of diesel pumps' cost and can achieve a payback over diesel engine-operated pump little as 2 years. It is also reported that maintenance and high fuel costs have been long-standing problems with diesel engine. The systems were often in remote locations, and the difficulties of purchasing imported spare parts and fuel have often made them unreliable. Hahn [6] reported that in regions with high insolation levels, photovoltaic pumping systems were technically suitable for use, beneficial for the environment and were able to yield cost advantages over diesel engine driven pumps. However, the high initial investment costs were still the main obstacle for acceptance of solar pump. He added that fuel and lubricants for diesel pumps often pollute wells, soil and groundwater. By contrast, photovoltaic pumps are an environmentally sound and resource conserving technology. Contamination of soil and groundwater resources could be completely avoided when using solar pump.

Burney et al. [7] conducted a study in the rural Sudano–Sahel region of West Africa. Using a matched-pair comparison of villages in northern Benin, and household survey and field-level data they reported that solar-powered drip irrigation significantly augmented both household income and nutritional intake, particularly during the dry season. Group for rural infrastructure development Nepal (GRID Nepal) initiated PV water pumping project at Bhujikot provided by Nepal development marketplace for supplying drinking and agriculture water to the rural people. The feedback from the community people was very encouraging and they were very happy with the successful work. Solar pump provided their fresh drinking water and increased agricultural production thus improving and upgrading the life style of the community people [8]. Zieroth [9] conducted a feasibility study on water supply by solar pump in Mauke, Cook Island. The solar project showed a good performance in comparison with diesel-powered pump. Cost of solar pump use was US$ 0.16 per m^3 as compared to US$ 0.22 per m^3 for the diesel-powered pump. At the discount rate of 10 % the net benefits of solar savings were equal to an economic rate of return of 31.5 %, i.e., the solar project was quite economic. In 1999 and 2000, cabbage and peppers, respectively, were grown comparing solar and conventionally powered drip irrigation systems at the Rutgers University Research and Extension Farm, Pittstown. The solar system was operated by a 1.5 horse power (hp) motor powered by 18 solar modules. Utilizing the sun's energy, captured by photovoltaic panels, to power irrigation systems offered a cost-effective, pollution-free and virtually maintenance-free alternative to diesel pumps in remote areas. Solar-powered pumping systems were capable of delivering water from rivers and wells in volumes up to 2,000 gallons/min [10].

Odeh et al. [11] made a comparison of the economic analysis of photovoltaic and diesel water pumping systems of sizes in the range 2.8–15 kWp. Net present value, annuity and cost annuity per equivalent hydraulic energy unit were calculated. It is found that PV water pumping systems are more economical than diesel pumping systems for equivalent hydraulic energy below 2,100,000 m^4/year, where diesel pumping systems become more economical than PV water pumping systems for larger applications. Curtis [12] conducted an economic feasibility study of solar photovoltaic irrigation for forage production in the Great Basin Nevada, western Utah. He reported that solar PV irrigation system was a cost-effective alternative for forage production the area. Production cost of the alfalfa stand, decreased annual operating costs, but increased annual ownership costs. Annual farm net returns to production also increased from $1,395.17 to $5,449.10, or $10.90 per acre.

A PV solar pump was also tested for irrigation in Bangladesh Agricultural Research Institute, Gazipur during eighties. Solar pumps were found technically suitable for low lift small-scale irrigation. Solar pumps were not then found economically viable due to high PV cost. Moreover, these photovoltaic solar panels could not function during cloudy, foggy and rainy weathers [13]. Sometimes, in winter and rainy seasons, several days to week sun is not found in the sky (no effective solar radiation) in Bangladesh and solar pump cannot be operated. This problem may be effectively solved introducing high integrated hybrid system (HIHS) in continuous operation of solar pump. Leva and Zaninelli [14] studied the hybrid photovoltaic–wind–diesel generation systems supplying a remote power load considering the advantages of sustainable energy from the economic point of view. They also introduced a fuel cell generation device in a photovoltaic–wind existing plant for supplying telecommunication apparatus. HIHS (photovoltaic, wind diesel) is found technically, economically and environmentally suitable for operation of telecommunication devices [15, 16].

Some NGOs have installed solar pumps mainly for drinking and irrigation purposes. Some policy makers and users hesitate to use solar pump for irrigation because they are unaware of whether it is economically feasible or not. Therefore, this study was undertaken to evaluate the present status and economic performance of solar pumps at field conditions.

Methodology

Baseline survey

Field data were collected from solar pump suppliers, service providers and users. Solar pumps were in operation in different locations of the country. Therefore, field-level data were collected from the relevant traders, service providers and users associated with the selected pumps. Most of the solar pumps were in operation in field level, supplied and installed by Rahimafrooz Renewable Energy Limited and Electro Solar Power Limited. Therefore, trader's data were collected from Rahimafrooz Renewable Energy Limited and Electro Solar Power Limited. Information of service providers were collected from the solar pump locations. Twelve solar pump users from each solar pump were randomly selected and directly interviewed. The list of the solar pumps, service providers of the relevant solar pumps at different locations is given in Table 1. All primary data were collected from each of the respondents using pre-tested interview schedules. Three sets of interview schedule (solar pump suppliers, service providers and users) were prepared for primary data collection. Secondary data were gathered from books, journal articles, research reports, internet, etc.

Economic analysis

Total cost of solar pump and diesel engine-operated pump for crop production is the sum of fixed cost and variable cost. Fixed cost is the sum of depreciation, interest on capital cost, repair, maintenance and shelter cost and cost of land use. 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 14 % of the capital price of the pump.

The aim of this study is to compare the economic viability of PV water pumping systems and diesel water pumping systems. Interest rate is a function of supply and demand for money. For the base case, a value of 5 % is considered. A market interest rate includes components for nominal interest rate (i) and inflation rate (r) defined by Fisher equation [17, 18]:

$$i = (1 + i_{\mathrm{n}})(1 + r) - 1 \quad (1)$$

Therefore, the life cycle cost approach is used for economic appraisal and comparison where all future costs are discounted to their present worth by a discount rate of 5 %. The economic indicators selected are: net present value (P), annuity (A) and cost annuity per equivalent hydraulic energy unit (C). For a simple single payment, they are defined as follows [19]:

$$p = f\frac{1}{(1 + i)^{\mathrm{n}}} \quad (2)$$

where p is the present value of a single payment, f is a future single payment.

$$a = p\left[\frac{i(1 + i)^{\mathrm{n}}}{(1 + i)^{\mathrm{n}} - 1}\right] \quad (3)$$

where a is the annuity of a single payment.

$$C = \frac{A}{E} \quad (4)$$

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.

$$\text{Present worth (incomes)} = \text{present worth (disbursements) then IRR} = i$$

Table 1 Selected solar pumps at different locations of Bangladesh

Sl no.	Locations			Solar pump installer (suppliers)
	District	Upazilla	Village	
1	Barguna	Sadar	Kumrakhali	Rahimafrooz Renewable Energy Ltd.
2	Chapai Nawabgonj	Gomostatpur	Malopara	Rahimafrooz Renewable Energy Ltd.
3	Chapai Nawabgonj	Nachol	Nizampur	Rahimafrooz Renewable Energy Ltd.
4	Naogaon	Shapahar	Sheronti	Rahimafrooz Renewable Energy Ltd.
5	Naogaon	Porsha	Bondhupara	Rahimafrooz Renewable Energy Ltd.
6	Naogaon	Potnitola	Jugirghopa	Rahimafrooz Renewable Energy Ltd.
7	Dinajpur	Birol	Rudrapur	Rahimafrooz Renewable Energy Ltd.
8	Bagerhat	Morelgonj	Badnivanga	Rahimafrooz Renewable Energy Ltd.
9	Dhaka	Savar	Kaisharchar	Rahimafrooz Renewable Energy Ltd.
10	Madaripur	Shibchar	Chargozaria	Electro Solar Power Limited
11	Rangamati	Barkal	Barkal	Rahimafrooz Renewable Energy Ltd.
12	Dhaka	Dhaka	BUET	Rahimafrooz Renewable Energy Ltd.

Calculation of carbon dioxide emission

Carbon dioxide (CO_2) emission from irrigation pumps in Bangladesh was calculated from the total diesel consumed by the irrigations pumps in a year. Total numbers of irrigation pumps such as deep tube well (DTW), shallow tube well (STW) and low lift pump (LLP) used in Bangladesh from 1990 to 2012 were obtained from the reports of Bangladesh Agricultural Development Corporation (BADC). Total quantity of diesel and electricity used by the irrigation pumps was also obtained from the secondary source of BADC [1]. Quantity of diesel used by each type of diesel engine-operated irrigation pump was calculated using operation data given in Table 2. Diesel required for electric power-operated pump was converted to diesel power using the conversion factor that one MWh electricity is equivalent to 200 L of diesel [20]. Then the total quantity of diesel required for operation of all types of irrigation pumps was calculated using the following formula.

$$TDU_{ip} = DTW_{dd} + DTW_{de} + STW_{dd} + STW_{de} + LLP_{dd} + LLP_{de} \quad (5)$$

where TDU_{ip} = Total diesel used in irrigation pump (L). DTW_{dd} = Diesel used in diesel-operated DTW (L). DTW_{de} = Diesel used in electrically operated DTW (L). STW_{dd} = Diesel used in diesel-operated STW (L). STW_{de} = Diesel used in electrically operated STW (L). LLP_{dd} = Diesel used in diesel-operated LLP (L). LLP_{de} = Diesel used in electrically operated LLP (L).

Total quantity of carbon dioxide emission from all irrigation pumps was estimated by multiplying total quantity of diesel used in liter by 2.8 (one liter of diesel fuel produces 2.8 kg of CO_2) [21]. Then total quantities of carbon dioxide emissions from total numbers of irrigation pumps in different years were calculated.

Table 2 Average capacity, operation and fuel used for diesel-operated pumps

Name of the pump	Parameters	Average value
Deep tube well	Operation per season	80 days
	Operation time per day	15 h
	Capacity	55 hp
	Fuel used	4.50 L/h
Shallow tube well	Operation per season	80 days
	Operation time per day	12 h
	Capacity	12.50 hp
	Fuel used	1.25 L/h
Low lift pump	Operation per season	80 days
	Operation time per day	8 h
	Capacity	7.50 hp
	Fuel used	1.00 L/h

Results and discussion

Baseline survey

The selected solar pumps and their users are given in Table 3. Among 12 solar pumps, six were located in North Bengal, mainly in the Barind area. It is evident from Table 3 that solar pump users were small to medium categories of farmers. The service providers were one government organization, BMDA (Barind Multipurpose Development Authority), one company (Rahimafrooz) and four different NGOs. All the solar pumps were installed after 2004. All the pumps were used for supplying drinking water except four pumps located in Borguna, Savar, Chargozaria and Gomostapur. Eight pumps were used for lifting ground water and only one pump (Borguna) was used to pump surface water. All the pumps were submersible type and operated by dc motor. The capacity of solar panel was 300–1,190 W_p. The average discharges of these pumps varied from 2,000 to 800,000 L/day. The lowest discharge was in BUET (Bangladesh University of Engineering and Technology) pump used for ground water lifting whereas the highest discharge was from Lorentz pump for surface water irrigation. The variations were due to variations of panel capacity and delivery head of the pump.

LGED (Local Government Engineering Department) supplied drinking water to 5,000 people from each of the solar pumps located in Nizampur in Chapai Nawabgonj district and Sheronti, Bondhupara, Jugirghopa in Naogaon district at free of cost. Gozaria Agro Farm, Chargozaria, Shibchar, Madaripur installed a 360 W_p submersible solar for irrigating four hectare of boro rice. The discharge of the pump was 50,000 L/day. This pump was also used for supplying drinking water for livestock. An NGO, Dipshikha installed solar pump and used the water for drinking and domestic uses in their technical school and office campus. In Badnivanga, Morelgonj an NGO called CEO (Centro Orientamento Educativo) installed a solar pump cum water purification plant for supplying drinking water to the local 500 families. They would collect water charge from the water user but during the survey the charge was not fixed and people were getting water at free of cost. The solar pumps in Borguna, Savar, Shibchar and Gomostapur were used to irrigate 16, 8, 4 and 4 ha of rice with the discharge capacity 800,000, 500,000 and 40,000 L/day, respectively. Solar pump used for irrigation was chargeable in all locations except Gomostapur, Chapai Nowabgonj. This pump was installed by CARITAS, a charity

Table 3 Users and uses of solar pump at farm level in the selected locations in Bangladesh

Sl no.	Location	Service provider	Year of installation	Users	Size of panel (W_p)	Discharge capacity (L/day)	Uses of water	Cost of water (US$/ha)
1	Kumrakhali Borguna	RDF (NGO)	2010	Small and medium farmers	8,400	800,000	Irrigation of 16 ha (40 acre)	95
2	Kaisharchar Savar Dhaka	RRE (Company)	2009	Medium farmers	11,900	500,000	Irrigation of 8 ha (20 acres)	192
3	Gomostapur Chapai Nawabgonj	Caritus (NGO)	2008	Landless and small farmers	375	40,000	Irrigation 4 ha (10 acre)	Free
4	Nizampur Nachol Chapai Nawabgonj	BMDA (GO)	2005	Landless farmers	1,800	26,000	Drinking of 5,000 people	Free
5	Sheronti Shapahar Naogaon	LGED (GO)	2005	Landless farmers	1,800	26,000	Drinking of 5,000 people	Free
6	Bondhupara Porsha Naogaon	BMDA (GO)	2005	Landless farmers	1,800	26,000	Drinking of 5,000 people	Free
7	Jugirghopa Potnitola Naogaon	BMDA (GO)	2005	Landless farmers	1,800	26,000	Drinking of 5,000 people	Free
8	Rudrapur Birol Dinajpur	Dipshikha (NGO)	2010	Students and office staffs	600	35,000	Domestic uses of about 50 persons	Own
9	BadnivangaMorelgonj Bagerhat	COE (NGO)	2010	Small	600	16,000	Drinking of 500 families	Free
10	Chorgozaria Shibchar Madaripur	Gozaria Agro Farm	2010	Medium farmers	360	15,000	Irrigation 4 ha (10 acre)	Own
11	Barkal Rangamati	PDB (GO)	2005	Small tribal farmers	1,800	26,000	Drinking of 600 families	Free
12	BUET Dhaka	BUET (GO)	2010	Students	300	2,000	Demonstration	Free

BMDA Barind Multipurpose Development Authority, *BUET* Bangladesh University of Engineering and Technology, *COE* Centro Orientamento Educativo, *LGED* Local Government Engineering Department, *PDB* Power Development Board, *RDF* Resources Development Foundation, *RREL* Rahimafrooz Renewable Energy Limited

organization for livelihood improvement of indigenous people. Irrigation charge of solar pump in Savar was higher than that of Borguna. The irrigation costs in Savar (95 US$/ha) was almost double than that of Borguna (192 US$/ha). This variation was due to surface irrigation, lower installation cost, higher discharge and more subsidy provided by the NGO (Resource Development Foundation) for Borguna pump. Beside this, Borguna is a remote area in Bangladesh and Savar is situated near the capital city. Irrigation charge of diesel- and electricity-operated pumps in Bangladesh is 256–320 US$ per hectare in boro session (January–April) which is higher than that of solar pump irrigation. The reason might be that all solar pump services were provided by different NGOs and they provided services at subsidized rate. But diesel or electricity pumps are operated by individual farmers and they provided service to their neighboring farmers at custom hire basis.

The specifications of selected solar pumps available at different locations of Bangladesh are given in Table 4. Power of panel of different solar pumps varied from 300 to 1,190 W_p. Among 12 solar pumps, two solar pumps were 600 W_p, three were below 400 W_p and seven were above 1,000 W_p. The nominal voltage of each panel was either 17.1 or 35.0. This was due to the panel capacity and matching suitability of panel with the motor. It is observed from the table that 10 solar pumps were dc operated and two solar pumps were ac motor operated. For ac motor operation, an inverter is needed to convert dc power produced in solar panel to ac power for operation of motor. The motor speeds of all solar pumps were similar (2,900–3,200 rpm). All motors used in the solar pump were submersible, brushless and of variable speed. It can be operated at lower voltage available from solar radiation. All the selected pumps were China made. Rahimafrooz Renewable Energy Limited supplied solar pumps were Lorentz, China made. But Electro Solar Power Limited supplied pumps were Solartech, China made. Both of Lorentz and Solartech companies are reputed companies for manufacturing solar devices. All the selected solar pumps were submersible types, but two pumps were installed in ponds (Kumrakhali, Borguna and Gomostapur Chapai Nawabgonj) for surface water lifting. Other pumps were installed for groundwater lifting. This is why pump heads varied from location to location. During the interviewing period, all the solar pumps were found active in operation. The users of the solar pumps were happy with the solar pumps as these pumps were operated by natural solar energy rather than any fuel or grid electricity.

The average discharge of these pumps varied from 2,000 to 800,000 L/day. The command areas in Borguna, Savar, Shibchar and Gomostatpur were 16, 8 4, and 4 ha, respectively. The variations of command areas were due to the variations of discharges of pumps as well as panel

Table 4 Specification of selected solar pumps installed in different locations of Bangladesh

Sl no.	Location of pump	Panel power (W_p)	Nominal voltage of each panel	Motor type	Max. motor speed (rpm)	Make/model of solar pump	Head (m)	Water discharge (L/day)
1	Kumrakhali Borguna	8,400	17.2	ac	2,900	Lorentz China	7.60	800,000
2	Kaisharchar Savar, Dhaka	1,190	17.1	ac	2,900	Lorentz China	19.8	500,000
3	Gomostapur Chapai Nawabgonj	375	35	dc	3,300	Lorentz China	9.0	40,000
4	Nizampur Nachol Chapai Nawabgonj	1,800	17.1	dc	3,200	Lorentz China	30.0	26,000
5	Sheronti Shapahar Naogaon	1,800	35.0	dc	3,000	Lorentz China	30.0	26,000
6	Bondhupara Porsha Naogaon	1,800	35.0	dc	3,300	Lorentz China	30.0	26,000
7	Jugirghopa Potnitola Naogaon	1,800	35.0	dc	3,200	Lorentz China	32.0	26,000
8	Rudrapur Birol, Dinajpur	600	17.1	dc	3,200	Lorentz China	24.4	35,000
9	Badnivanga Morelgonj Bagerhat	600	17.1	dc	3,300	Lorentz China	9.6	16,000
10	Chorgozaria Shibchar Madaripur	360	17.2	dc	3,000	Solartech China	24.0	15,000
11	Barkal Rangamati	1,800	17.2	dc	3,200	Lorentz China	46.0	26,000
12	BUET Dhaka	300	17.1	dc	3,000	Lorentz China	30.0	2,000

capacities. In Borguana, Shibchar and Savar, rice was cultivated but in Gomostatpur vegetables were cultivated with the solar pumps. BMDA-supplied solar pumps were lifting drinking water for 5,000 people free of cost from each of the solar pump located in Nizampur in Chapai Nawabgonj district and Sheronti, Bondhupara, Jugirghopa in Naogaon district. The pumps were provided by BMDA with the financial assistance of a donor for supplying drinking water to the indigenous people of areas. The indigenous people are very poor and socially neglected. An NGO, Dipshikha installed solar pump and used the water for drinking and domestic uses in their campus. Dipshikha is providing vocational training to the rural poor especially to the indigenous and tribal people. In Badnivanga, Morelgonj an NGO called CEO (Centro Orientamento Educativo) installed a solar pump cum water purification plant for supplying drinking water to the local 500 families. They will collect water charge from the water user but during the survey period the charge was not fixed and people were getting water free of cost. There was no solar pump owned by individual person. The reason was the higher initial cost of solar pump in comparison to conventional electric motor or diesel engine-operated pumps.

The average costs of different components of solar pumps are given in Table 5. The total cost of 400 W_p panel power solar pump was US$ 3,285 whereas the 5,600 W_p capacity solar pump was US$ 40,733. This variation was due to the variations of panel, motor, installation, fittings and other costs. Total cost for purchasing and installation of solar pump varied from 6.0 to 8.8 US$ per W_p. The average cost of installation of solar pump in all location was US$ 7.2 per W_p. From this information a user can get an idea about the installation cost of solar pump with his available facilities.

Cost component for installation of solar pump is shown in Fig. 1. Panel cost was the individual highest cost (45 %) in solar pump followed by installation cost (18 %), motor cost (16 %) and pump cost (10 %). Pipes and fitting cost was the lowest (4 %) among the cost components. The other associated cost attributes 7 % of total cost. The pipes and fittings were almost PVC made and locally available. It is evident from the table that to reduce the cost of solar pump, the panel cost must be reduced. When the survey was conducted in 2010, the panels, motor and pump were imported from the foreign countries, because, at that time, no panel was manufactured in the country. In 2013, Rahimafrooz Renewable Energy Limited, Electro Solar Power Limited and other few companies are manufacturing (mainly assembling) solar panels in Bangladesh. These companies are also marketing solar panel in Bangladesh as well as exporting to foreign countries.

Economic analysis

Cost components of solar PV pump and diesel power-operated pump are shown in Table 6. A 5 kW PV-operated 4-hp submersible solar pump with 150,000 L/day discharge capacity is selected in economic analysis. A 4-hp diesel-operated shallow tube well with same discharge capacity is selected for cost comparison with solar pump. The life of solar panel is 20 years and life of dc motor is 10 years. The command area of both the pumps is 4 ha and irrigation is applied in three crops per year. The initial costs (price of engine, pump set, installation, fittings, etc.) of diesel and

Table 5 Costs of different components of solar pump (Lorentz, China)

Location of pump	Power (W_p)	Cost of panel	Cost of motor	Cost of pump	Installation cost	Fittings cost	Other cost	Total cost	Cost per W_p
Fultola-Kumrakhali Borguna	400	1,265	716	477	506	111	209	3,285	8
Kaisharchar Savar, Dhaka	600	1,898	1,278	852	759	167	313	5,267	9
Gomostapur Chapai Nawabgonj	1,050	3,333	1,278	852	1,333	293	550	7,639	7
Nizampur Nachol Chapai Nawabgonj	1,920	6,173	1,495	996	2,493	546	1,020	12,722	7
Sheronti Shapahar Naogaon	2,800	8,858	1,263	842	3,543	779	1,462	16,747	6
Bondhupara Porsha Naogaon	3,675	11,626	2,600	1,734	4,650	1,023	1,918	23,551	6
Jugirghopa Potnitola Naogaon	5,600	17,715	6,870	4,580	7,086	1,559	2,923	40,733	7
Average of all locations	2,292	7,267	2,214	1,476	2,910	640	1,199	15,706	7

Cost in US$

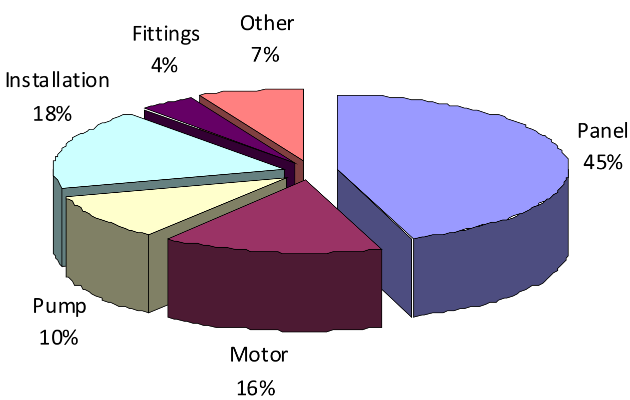

Fig. 1 Cost component for installation of solar pump

PV-operated pumps are about US$ 512 and US$ 769, respectively. Custom hire basis, irrigation charge per hectare is considered US$ 385 per season. This charge has been assumed on the basis of personal interviewing of the farmers.

Operation cost of solar pump is very low but it is higher for diesel pump due to diesel and oil costs including repair and maintenance cost. Life of diesel engine and pump is 10 years and overhauling of diesel engine is done in every 5 years. After 10 years, new engine and pump are to be purchased. The life of solar panel is 20 years and after 10 years pump and motor are to be changed. During the project period both the pumps are used for providing service (irrigation) on custom hire basis. Total cash inflow (earning) per year for 4 hectare irrigated area is US$ 462. Diesel fuel is a pollutant to the environment. About 3,744 kg of carbon dioxide is emitted from the diesel engine. Also lot of sound pollutes the environment during operation of diesel pump. But solar pump is pollution-free and environment-friendly irrigation device.

Life cycle costs of diesel- and solar PV-operated pumps are shown in Fig. 2. It is observed from the figure that life cycle cost of diesel-operated pump is lower than solar pump up to 5 years and then (after 5 years or more) solar pump becomes more economic. For long-term project (more than 5 years) solar pump is more economic than same sized-diesel pump. Abu-Aligah [4] studied the economic performance of diesel-powered pump and PV-powered pump for irrigation in Jordan. He reported similar results for diesel-powered pump and PV-powered pump for irrigation. Biswas and Hossain [3] reported that a 10 hp solar pump became more economic than 10 hp diesel engine-operated pump after 10 years of operation.

There are clear differences between diesel engine-operated pump and solar pump in terms of cost and reliability. Diesel engine-operated pump is typically characterized by a lower initial cost but a very high operation and maintenance cost. Solar pump has, rather, higher initial cost but very low operation and maintenance costs. In terms of reliability, it is much easier (and cheaper) to keep a solar panel going than a diesel engine. Solar pumping has clear advantages for a number of years but the differences are becoming more striking in a world of rapidly escalating fuel costs.

Project analysis

Net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR) at 15 % discount factor is shown in Table 7. The project analysis is done for 20 years project period. The project cost was the sum of capital cost and operating cost of diesel engine-operated pump and solar pump. The cash inflow or earning of the project comes from custom hire of irrigation service to the farmers. The hire rate is equal for both diesel pump and solar pump. BCR of solar pump (1.91) is found higher than diesel-operated pump (1.31). So, solar pump is more profitable than diesel-operated pump. NPV of solar pump is higher

Table 6 Cost components of solar PV- and diesel power-operated pumps

Items	Diesel pump (STW)	Solar pump (submersible)
Power	4 hp diesel engine	4 hp dc motor powered by 5 kW_p PV panel
Discharge	150,000 L/day by 760 mm discharge pipe	150,000 L/day by 760 mm discharge pipe
Diesel consumption	1,440 L/year	–
Price of diesel in 2013	0.87 US$/L with 5 % price increase each year	–
Irrigation area	4 ha	4 ha
Uses of pump (100 days/per season × 6 h per day × 3 crops per year)	1,800 h	1,800 h
Life (years)	10 years with engine overhauling after 5 years	Panel 20 and pump 10 years
Initial cost (Including installation cost)	US$ 512	US$ 769
Income from irrigation by custom hire per season (US$ 385 per ha)	US$ 462 per year	US$ 462 per year
CO_2 emitted from diesel fuel per year	3,744 kg	–

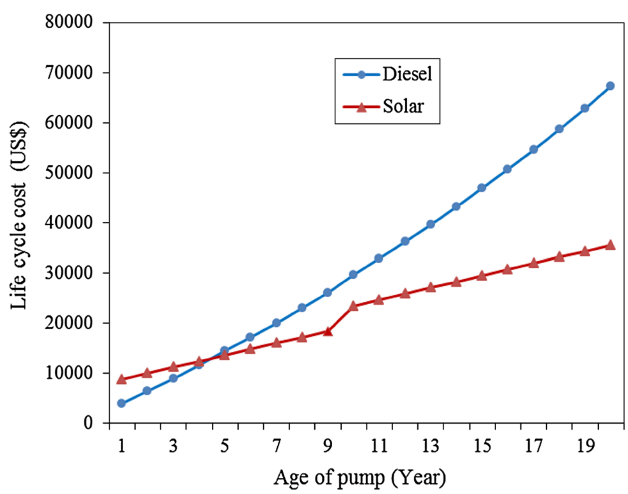

Fig. 2 Life cycle costs of diesel and solar PV-operated pumps

than diesel engine-operated pump which indicates that invest on solar pump is more profitable than diesel pump. Again, IRR of solar pump (80 %) is found higher than diesel engine-operated irrigation pump (71 %). Therefore, investment on solar pump is more risk free with higher discount rate than diesel engine-operated irrigation pump.

Carbon dioxide emissions

Carbon dioxide emissions from irrigation pumps in different years in Bangladesh are shown in Fig. 3. It is observed from the figure that carbon dioxide emission from irrigation pumps was increasing linearly with the advancement of times. In 1990, CO_2 emission from irrigation pumps was 1.43 million tons and it was increased sharply to 6.73 million tons in 2012. This was due to the

Table 7 Net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR) at 15 % discount factor

Diesel pump			Solar pump		
BCR	NPV (US$)	IRR (%)	BCR	NPV (US$)	IRR (%)
1.31	13,423	71	1.91	13,756	80

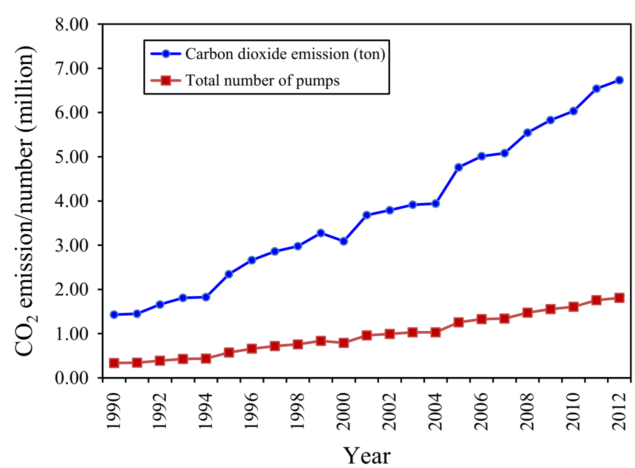

Fig. 3 Carbon dioxide emissions from irrigation pumps in different years in Bangladesh

increase of irrigation pumps over the years. In 1990, total numbers of irrigation pumps (DTW, STW and LLP) were 0.33 million and they were increased to 1.81 million numbers in 2012. Numbers of solar pumps as well as CO_2 emission are in increasing trend. Solar pump is pollution-free and a green irrigation pump to mitigate CO_2 emission. If these diesel- or electricity-powered irrigation pumps may be changed with solar pumps, Bangladesh can mitigate huge quantity of CO_2 emission each year. Therefore, solar pump may be used for irrigation in crop production for sustainable green agriculture.

Conclusion

There were about 150 solar pumps in Bangladesh among them 65 % solar pumps were used for supplying drinking water to the poor people of the locality and about 35 % solar pumps were used for irrigation purposes. Panel cost was the major cost (45 %) in solar pump followed by installation cost (18 %), motor cost (16 %), pump cost (10 %), and pipes and fitting cost (4 %). Considering the operating cost, diesel engine-operated pump is profitable for the period of less than 5 years. For the period of 5 years or more, solar pump becomes more profitable than diesel engine-operated pump of same capacity. The benefit cost ratio of solar pump (1.91) was found higher than diesel-operated pump (1.31). Net present value of solar pump was higher than diesel engine-operated pump which indicates that investing on solar pump is more profitable than diesel pump. Internal rate of return of solar pump (80 %) was found higher than diesel engine-operated irrigation pump (71 %). Numbers of irrigation pumps and carbon dioxide emissions from irrigation pumps over the years are increasing. Diesel engine-operated irrigation pump emits carbon dioxide and pollutes environment, but solar pump is an environment-friendly irrigation technology.

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