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A Comprehensive Study on Photovoltaic Irrigation System for Different Crop Cultivation: Financial Evaluation Perspective

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Abstract: This article investigates the feasibility of solar powered irrigation process in Bangladesh where photovoltaic technology could be used to gather solar energy for running a submersible pump and supply water for crop cultivation. It also depicts a comparative picture of irrigation costs for 27 Bangladeshi crops for diesel and photovoltaic irrigation systems. The researchers have collected data concerning required water height during farming of those crops and then have calculated water volume for 1 ha of land. Subsequently, two commonly used pumps (solar, diesel) with same power ratings (5 hp) have been chosen. Specific areas covered by these pumps for different crops are calculated furthermore from the attained water volumes. Finally, total irrigation costs (at present condition) of these types of irrigation choices for a period of 10 years have been computed and analyzed. The study highlights that irrigation with solar energy for certain crops, namely potato, cotton, soybean, sunflower, strawberry, lentil, mustard etc. are very much lucrative compared to diesel powered irrigation.

Key words: Solar irrigation, renewable energy, green farming, photovoltaic pumping, solar for agriculture.

1. Introduction

Due to the fossil fuel resources decline and their great share in environmental pollution and issues, many countries and researchers are looking for green energy resources based on each region's potentials. So far, many kinds of renewable energy sources such as solar, wind, geothermal and others are utilized for power generation. In general, to meet electricity demand and to cope with environmental problems using green energies, there are two steps: first, finding renewable energy resources in a special region; second, to utilize these energy resources economically and efficiently.

Being a tropical country, Bangladesh endowers with abandon supply of solar energy. The range of solar radiation is between 4 $kWh{\cdot}m^{-2}{\cdot}day^{-1}$ and 6.5 $kWh{\cdot}m^{-2}{\cdot}day^{-1}$ and the bright sunshine hours vary from 6 to 9 $h{\cdot}day^{-1}$ [1]. Being an agrarian economy, the agricultural sector alone accounts for 20% of GDP and provides employment for more than half of the labor force. Furthermore in Bangladesh, about 59% land is under irrigation system, based on diesel and grid electricity. However, there remains vast area of cultivable land which is needed to be irrigated where grid connection is not available. Solar PV (photovoltaic) pump may be used for irrigating these lands for better crop production. This study presents the scenario of solar pump irrigation system in Bangladesh along with its economic feasibility for different crops [2].

The government of Bangladesh is planning to install close to 19,000 solar-powered irrigation pumps by 2016 [2-3], in a bid to expand the country's irrigated land area and boost food production, while limiting its reliance on fossil fuels. Once installed, the planned 18,750 solar-powered pumps will irrigate an additional 590,000 ha (1.5 million acres) of land for cultivating rice and vegetables, without requiring any

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grid electricity or diesel fuel [2-3]. The government estimates that, once all the pumps are in place, their solar panels will save 675 MWh of electricity per day, cut imports of diesel fuel by 47,000 tons per year, save $45 million annually, and reduce carbon dioxide emissions by an annual 126,000 tons [3].

In this study, the main objective was to do an economical evaluation of different cultivated crops in Bangladesh in a 10 years' time period using both diesel and photovoltaic water pumping systems and hence to find out which crops are viable to the newest and environment friendly method of irrigation process.

2. Related Study

2.1 PV Technology

PV technology is best known as a method for generating electric power by using solar cells to convert energy from the sun into electricity. The photovoltaic effect refers to photons of light knocking electrons into a higher state of energy to create electricity. The term photovoltaic denotes the unbiased operating mode of a photodiode in which current though the device is entirely due to the transducer light energy. Virtually all photovoltaic devices are some type of photodiode [2-3].

The photovoltaic system is composed of a variety of components in addition to the photovoltaic modules, a balance-of-system that wired together to form the entire fully functional system capable of supplying electric power; and these system elements are:

- PV cells represent the fundamental power conversion units. They are made from semiconductors and convert sunlight to electricity. To increase the power output of PV cells, they are connected together to form larger units called modules. Modules, in turn, are connected in parallel and series to form a larger unit called panel;
- A storage medium (battery bank) stores the electrical energy produced by the PV cells, and makes the energy available at night or on dark days (days of autonomy or no-sun-days);
- A voltage regulator (or charge/discharge controller) reverses current and prevents battery from getting overcharged and over discharged;
- An inverter converts a low DC-voltage into usable AC-voltage; it may be a stand-alone installation or grid-connected installation;
- AC or DC loads, appliances and devices, consume the power generated by the PV system.

Fig. 1 shows the configuration of the stand-alone PV system with all the functional components.

2.2 Solar Pumping System

The most common application of solar water

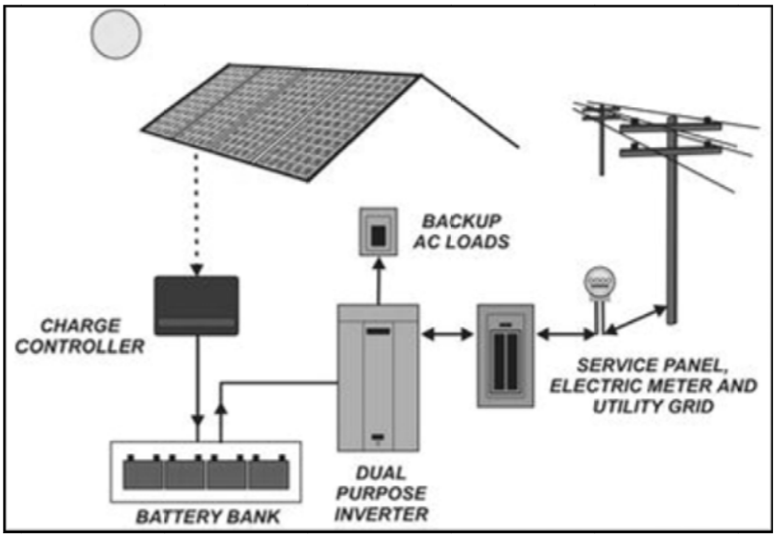

Fig. 1 Configuration of a stand-alone PV system.

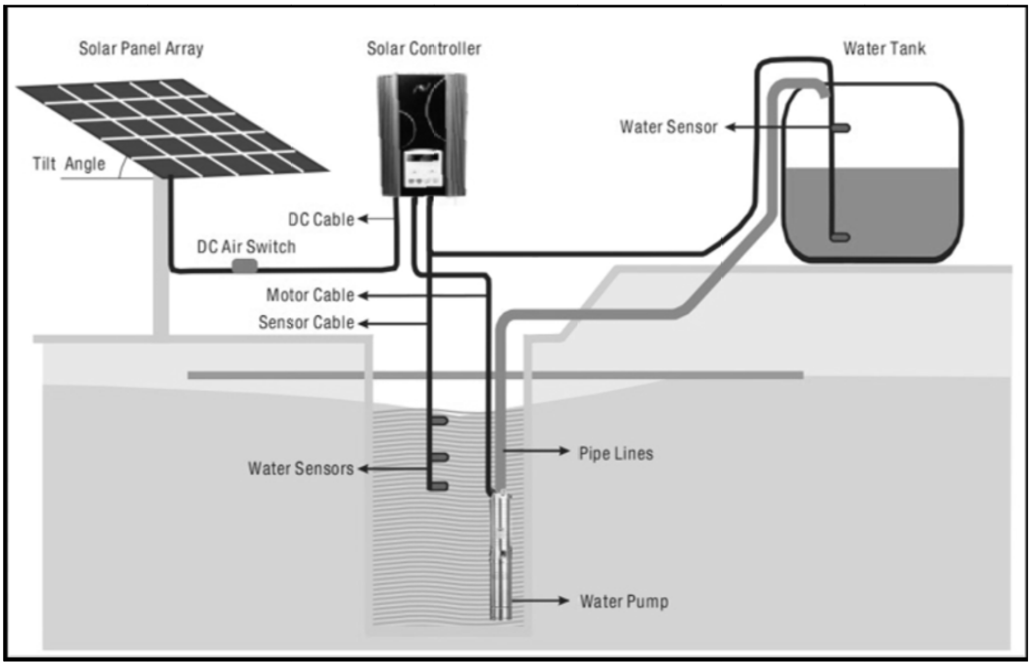

Fig. 2 A general setup for solar pump system.

pumping is to provide irrigation water or water for livestock, by pumping from groundwater wells or from surface water bodies. A well designed solar powered pumping system can transform the availability of irrigation water and reduce the money spent on generator fuel by farmers in areas where grid power is not available or is unreliable.

At remote places, far away from electricity and clean water, electrical pumps with solar panels (solar pumps) can provide in a clever solution. While the initial capital cost of a PV system may be greater than a generator, over the life of the system the low maintenance and zero fuel costs will make a solar PV system the cheaper option in the long term. The solar pump system consists of solar panels on a mounting structure, a pump controller, an electric pump and an optional storage tank for water [3].

The big advantage of the solar pump is that it can be operated with or without the battery back-up for solar power [3]. The pump is connected to solar panels, so water is pumped from low to high level in case the sun shines. To obtain a good match between solar panels and the pump, a pump controller is connected in between. The controller converts the direct current from the solar panels into alternating current with a frequency that depends on the irradiation. At low irradiation, e.g., in the morning at sunrise, the pump will be driven by a slowly rotating engine [2-3]. The speed of rotation will increase when the sun rises in the course of the day.

2.3 Solar Energy

While a majority of the world's current electricity supply is generated from fossil fuels such as coal, oil and natural gas, these traditional energy sources face a number of challenges including rising prices, security concerns over dependence on imports from a limited number of countries which have significant fossil fuel supplies, and growing environmental concerns over the climate change risks associated with power generation using fossil fuels. As a result of these and other challenges facing traditional energy sources, governments, businesses and consumers are increasingly supporting the development of alternative energy sources and new technologies for electricity generation [3]. Renewable energy sources such as solar, biomass, geothermal, hydroelectric and wind power generation have emerged as potential alternatives which address some of these concerns. As opposed to fossil fuels, which draw on finite resources that may eventually become too expensive to retrieve, renewable energy sources are generally unlimited in availability.

Solar power generation has emerged as one of the most rapidly growing renewable sources of electricity. Solar power generation has several advantages over other forms of electricity generation:

- reduced dependence on fossil fuels;
- environmental advantages;
- matching peak time output with peak time demand;
- modularity and scalability;
- flexible locations;
- government incentives.

Despite the cost, an advantage of photovoltaic systems is that they can be used in remote areas. Anywhere, a diesel generator is the technology of choice, many times a photovoltaic system is a much better life-cycle cost option.

Stand-alone photovoltaic systems produce power independently of the utility grid. In some off-the-grid locations even one half kilometer from power lines, stand-alone photovoltaic systems can be more cost-effective than extending power lines [4]. They are especially appropriate for remote, environmentally sensitive areas, such as national parks, cabins, and remote homes.

The solar power market has grown significantly in the past decade. According to solar buzz, the global solar power market, as measured by annual solar power system installations, increased from 427 MW in 2002 to 1,744 MW in 2006, representing a CAGR (compound annual growth rate) of 42.2%, while solar power industry revenues grew to approximately USD10.6 billion in 2006 [4-5]. Despite the rapid growth, solar energy constitutes only a small fraction of the world's energy output and therefore may have significant growth potential. Solar buzz projects are in one of its forecasts that annual solar power industry revenue could reach USD31.5 billion by 2011 [4].

2.4 Irrigation and Water Requirement of Crops

Irrigation makes agriculture possible in areas previously unsuitable for intensive crop production. Irrigation transports water to crops to increase yield, keep crops cool under excessive heat conditions and prevent freezing. The process of irrigation varies crop to crop and in a crop cycle it needs 3-5 times irrigation. The common processes of irrigation in Bangladesh are as follows [5].

2.4.1 Furrow Irrigation

Furrow irrigation is conducted by creating small parallel channels along the field length in the direction of predominant slope. Water is applied to the top end of each furrow and flows down the field under the influence of gravity. Water may be supplied using gated pipe, siphon and head ditch or bank less systems [5]. The speed of water movement is determined by many factors such as slope, surface roughness and furrow shape but most importantly by the inflow rate and soil infiltration rate [5]. The spacing between adjacent furrows is governed by the crop species. Common spacing typically ranges from 0.75 m to 2 m.

Furrow irrigation is particularly suited to broad-acre row crops such as cotton, maize and sugar cane. It is also practiced in various horticultural industries such as citrus, stone fruit and tomatoes. Fig. 3 shows the furrow irrigation system.

2.4.2 Basin Irrigation

Level basin irrigation has historically been used in small areas having level surfaces that are surrounded by earth banks. The water is applied rapidly to the entire basin and is allowed to infiltrate [5]. Basins may be linked sequentially so that drainage from one basin is diverted into the next once the desired soil water deficit is satisfied. A "closed" type basin is one where no water is drained from the basin. Basin irrigation is favored in soils with relatively low infiltration rates.

The WR (water requirement) of crops depends upon retention and transmissivity of water in soil, absorption and transmission within plant, transpiration, effective rainfall, vapor pressure, and energy etc. For example in case of paddy [6], it is enough to impound 5 cm of water and recharge to the same level once in 4 days. Again, for maize irrigation frequency should be once in 4 days and 6 days in case of clay soils. Cotton and groundnut requires irrigation once in 10 days in red and 15 days in clay soils. Fig. 4 shows the basin irrigation systems.

3. Methodology

The information of this research was collected from many sources, i.e., books, journal/conference papers, websites, etc. In this study, the system has not been considered to recharge the rechargeable battery whereas it has been considered that the pump is run directly from solar power.

To compare the total cost for irrigation in the period of 10 years using PV technology and diesel pump, area covered by a 5 hp pump has been calculated first. In Fig. 5 the illustration of study process is shown. Then the required diesel has been evaluated to irrigate the same amount of land. It is noted that manufacturers of solar pump usually give a warranty of 10 years; hence the associated cost for solar pump is fixed for this span of time. However, diesel price

Fig. 3 Furrow irrigation system.

Fig. 4 Basin irrigation systems.

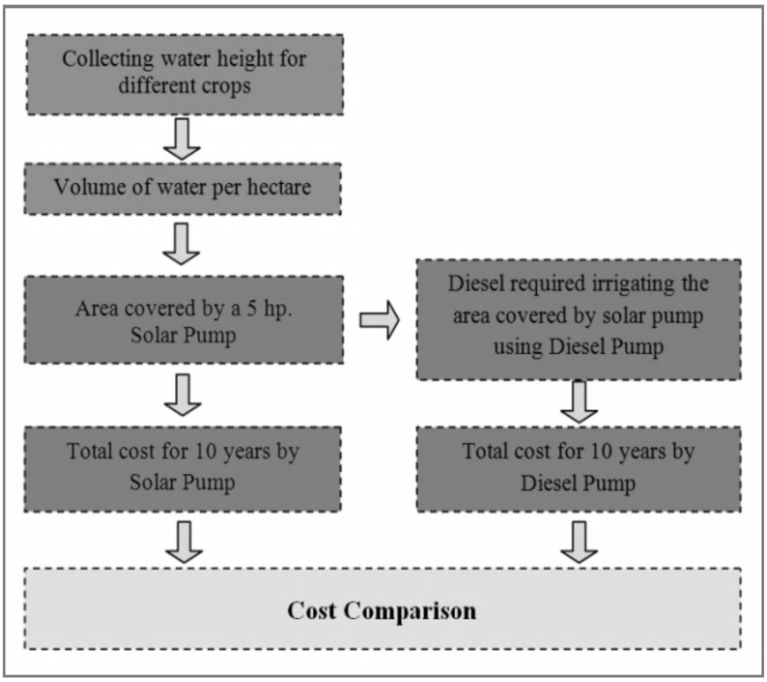

Fig. 5 Illustration of study process.

increases every year, so in order to find out the total present value, 10% inflation rate has been considered [7].

4. Analysis of the Study

To draw comparative picture of irrigation costs of different Bangladeshi crops for diesel, grid electricity and solar power based irrigation systems, there are several steps of calculation needed to be considered.

4.1 Calculation of Water Volume

For basin irrigation process,

$$Water\ volume\ = Required\ water\ height\ \times Area \quad (1)$$

For furrow irrigation process,

$$Water\ volume\ = [\{(Required\ water\ height \times Bed\ to\ bed\ distance\ \times 100\ \times No.of\ canals) \div 100\} \div 100] \quad (2)$$

where,

$$No.of\ canals\ = [\{100 - Bed\ to\ bed\ distance \div 100\} \div \{(Width\ of\ bed + Bed\ to\ bed\ distance) \div 100\} + 1] \quad (3)$$

[No. of canal calculation]

4.2 Calculation of Covered Area (ha)

For the simplicity of the research calculation, the area of the field has been considered as 1 ha which has the dimension of 100 m × 100 m. Again, from the personal communication of different agricultural scientists, it has been ensured that water required for single irrigation could be supplied in about 5 days [8].

So,

$$Area\ covered\ = Discharge\ rate \div Water\ volume$$

$$Area = \pi r^2$$

$$Area\ covered = \frac{Discharge\ rate}{Water\ volume} \quad (4)$$

For 5 days cycle,

$$Total\ cover\ area\ = Area\ covered\ \times 5 \quad (5)$$

Different crops need different amount of water at cultivation process with different irrigation process [8]. Calculation of required water per hectare of different crops as well as area covered by a 5 hp PV pump has been tabulated in Table 1 and Table 2 consecutively.

4.3 Calculation for Solar Powered Irrigation

In order to find out the total cost of a solar powered irrigation system in a span of 10 years, the future

Table 1 Calculation of required water for different crops.

Name of crops	Method of irrigation	Width of bed (cm)	Bed to bed distance (cm)	No. of canals	Required water height (cm)	Water volume ($m^3 \cdot ha^{-1}$)
Rice	Basin	n/a	n/a	n/a	8.5	850
Wheat	Basin	n/a	n/a	n/a	7	700
Potato	Furrow	25	60	117.9	4	283.1
Maize	Furrow	110	30	72.2	7	151.7
Onion	Furrow	100	30	77.7	2.5	58.3
Tomato	Furrow	100	30	77.7	3.5	81.6
Sugarcane	Furrow	120	30	67.5	12.5	235
Cotton	Basin	n/a	n/a	n/a	7	700
Chill	Furrow	100	30	77.7	5	116.5
Carrot	Furrow	100	30	77.7	5	116.5
Soybean	Basin	n/a	n/a	n/a	6	600
Garlic	Furrow	90	30	84.1	6.5	164
Brinjal	Furrow	100	30	77.7	3	69.9
Gourd	Furrow	560	40	17.6	4	28.2
Sunflower	Basin	n/a	n/a	n/a	8	800
Ginger	Furrow	100	30	77.7	3.5	81.6
Strawberry	Basin	n/a	n/a	n/a	6	600
Turmeric	Furrow	90	30	84.1	4.5	113.5
Lentil	Basin	n/a	n/a	n/a	5	500
Pumpkin	Furrow	330	30	28.7	6	51.7
Cabbage	Furrow	90	30	84.1	5	126.1
Cauliflower	Furrow	100	30	77.7	4	93.2
Mustard	Basin	n/a	n/a	n/a	3	300
Banana	Furrow	105	30	74.9	4	89.8
Ladyfinger	Furrow	100	30	77.7	3	69.9
Papaya	Furrow	200	30	44.3	5	66.5
Groundnut	Furrow	40	20	167.3	4	133.9

maintenance costs of next 9 years should be added at the present time. It is a general concept of engineering that every year 5% maintenance cost should be considered for any system.

So,

$$Cost\ of\ first\ year\ = Pump\ cost + 5\%\ Maintenance\ cost \quad (6)$$

Now, to consider the future maintenance cost at present, *PV* (*present value*) is a formula that calculates the present day value of an amount that will be spent at a future date.

$$Present\ value = (Future\ value)/(1+i)^n \quad (7)$$

where,

i = inflation rate;

n = number of year.

Using solar energy, we calculated the cost in taka for total 10 years. It will fix for all crops, because we implement one system. Our module is fixed for all cops.

4.4 Calculation for Diesel Powered Irrigation

For diesel powered irrigation,

$$Cost\ (first\ year) = Pump\ cost + (Diesel\ requirement \times Number\ of\ irrigations\ in\ a\ crop\ cycle \times Present\ diesel\ rate) \times 3 \quad (8)$$

But for the second to next 10 years (lifetime of diesel module), it depends on diesel price of that year, 5% maintenance cost, and number of irrigation in a crop cycle.

Table 2 Calculation of area covered by a 5 hp solar pump for different crops.

Name of crop	Water volume ($m^3 \cdot ha^{-1}$)	Area covered (ha)	5 days cycle (ha)
Rice (*Oryza sativa*)	650	0.4	1.9
Wheat (*Triticum aestivum*)	700	0.4	1.8
Potato (*Solanum tuberosum*)	283.1	0.9	4.4
Maize (*Zea mays*)	151.7	1.6	8.2
Onion (*Allium cepa*)	58.3	4.3	21.5
Tomato (*Solanum lycopersicum*)	81.6	3.1	15.3
Sugarcane (*Saccharum officinarum L.*)	235	1.1	5.3
Cotton (*Gossypium spp.*)	700	0.4	1.8
Chill (*Capsicum annum L.*)	116.5	2.1	10.7
Carrot (*Daucus carota*)	116.5	2.1	10.7
Soybean (*Glycine max*)	600	0.4	2.1
Garlic (*Allium Sativum*)	164	1.5	7.6
Brinjal (*Solanum melongena*)	69.9	3.6	17.9
Gourd (*Lagenaria siceraria*)	28.2	8.9	44.4
Sunflower (*Helianthus annus*)	800	0.3	1.6
Ginger (*Zingiber officinale*)	81.6	3.1	15.3
Strawberry (*Fragaria ananassa*)	600	0.4	2.1
Turmeric (*Curcuma longa*)	113.5	2.2	11
Lentil (*Lens culinaris*)	700	0.4	1.8
Pumpkin (*Cururbita maxima*)	51.7	4.8	24.2
Cabbage (*Brassica oleracea*)	126.1	2.0	9.9
Cauliflower (*Brassica oleracea*)	93.2	2.7	13.4
Mustard (*Brassica juncea*)	300	0.8	4.2
Banana (*Musa paradisiac*)	89.8	2.8	13.9
Ladyfinger (*Abelmoschus esculentus*)	69.9	3.6	17.9
Papaya (*Carica papaya*)	66.5	3.8	18.8
Groundnut (*Arachis hypogaea*)	133.9	1.9	9.3

Table 3 Calculation of total cost of a 5 hp solar pump.

Price of the solar module (panel + pump)	2,00,000.00	
Maintenance cost at present (taka)	Year 1	2,10,000.00
	Year 2	9,090.90
	Year 3	8,264.46
	Year 4	7,513.14
	Year 5	6,830.13
	Year 6	6,209.21
	Year 7	5,644.74
	Year 8	5,131.58
	Year 9	4,665.07
	Year 10	4,240.97
Total present value (taka)	2,67,590.24	

$$Cost\ (for\ 2nd\ year\ and\ onwards) = \{(Diesel\ requirement \times Number\ of\ irrigations\ in\ a\ crop\ cycle \times Present\ diesel\ rate \times 3) + 5\%\ maintenance\ cost\} \quad (9)$$

Now, if anyone wants to calculate the total cost for 10 years period, present value of money for the future years should be calculated (Table 3).

5. Findings and Conclusions

The analysis of this study discovered that irrigation with solar power of certain crops like potato, cotton,

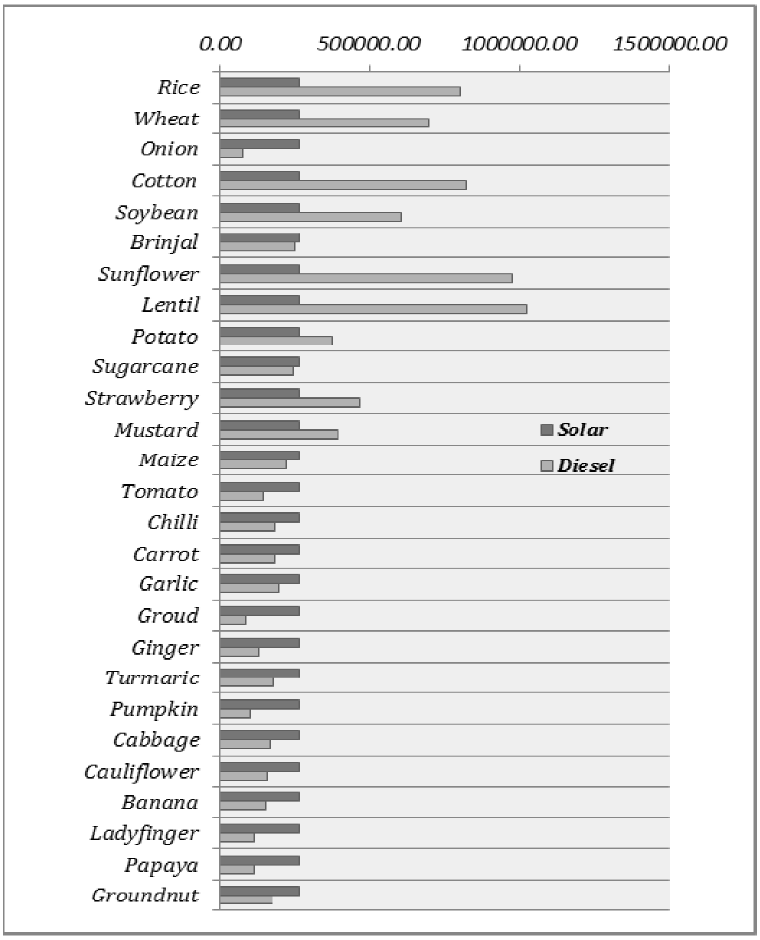

Fig. 6 Comparison between diesel and solar irrigation for different crops.

Table 4 Cost calculation of diesel powered irrigation.

Crop	Water volume (m^3)	Water volume (L)	Diesel requirement (L)	No. of irrigation in a crop cycle	Present value calculation for 10 years (thousand taka)										Total present value (in thousand taka)
					Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	
Rice	850.0	850,000	96.59	5	137.5	104.8	109.3	114.0	119.0	124.3	129.7	135.5	141.5	147.8	1263.5
Wheat	700.0	700,000	79.55	4	103.9	69.6	72.6	75.6	78.9	82.3	85.9	89.6	93.5	97.7	849.6
Potato	283.1	283,060	32.17	5	71.8	36.1	37.5	39.0	40.5	42.2	43.9	45.8	47.7	49.8	454.3
Maize	151.7	151,650	17.23	5	56.6	20.1	20.8	21.5	22.3	23.2	24.0	25.0	26.0	27.0	266.6
Onion	58.3	58,270	1.28	6	40.6	3.4	3.3	3.3	3.2	3.2	3.1	3.1	3.1	3.2	69.5
Tomato	81.6	81,580	9.27	5	48.5	11.7	11.9	12.3	12.6	13.0	13.4	13.9	14.4	14.9	166.7
Sugarcane	235.0	235,000	26.70	4	39.0	24.6	25.4	26.4	27.4	28.4	29.5	30.7	32.0	33.3	296.7
Cotton	700.0	700,000	79.55	5	81.1	86.6	90.3	94.2	98.3	102.5	107.0	111.8	116.7	121.9	1010.4
Chill	116.5	116,540	13.24	5	52.5	15.9	16.4	16.9	17.5	18.1	18.7	19.4	20.2	21.0	216.5
Carrot	116.5	116,540	13.24	5	52.5	15.9	16.4	16.9	17.5	18.1	18.7	19.4	20.2	21.0	216.5
Soybean	600.0	600,000	68.18	4	94.6	59.9	62.4	65.0	67.8	70.7	73.7	76.9	80.3	83.8	735.3
Garlic	164.0	163,960	18.63	4	54.2	17.7	18.2	18.8	19.5	20.2	20.9	21.8	22.6	23.5	237.4
Brinjal	69.9	69,923	7.95	4	45.5	8.6	8.7	8.9	9.1	9.3	9.6	9.9	0.1	10.5	120.1
Gourd	28.2	28,160	3.20	5	42.3	5.2	5.2	5.2	5.2	5.3	5.4	5.5	5.6	5.7	90.4
Sunflower	800.0	800,000	90.91	5	131.7	98.7	103.0	107.4	112.1	117.0	122.2	127.6	133.2	139.2	1192.1
Ginger	81.6	81,570	9.27	4	46.6	9.7	9.9	10.1	10.4	10.7	11.0	11.3	11.7	12.1	143.4

Table 4 continued

Crop	Water volume (m^3)	Water volume (L)	Diesel requirement (L)	No. of irrigation in a crop cycle	Present value calculation for 10 years (thousand taka)										Total present value (in thousand taka)
					Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	
Strawberry	600.0	600000	68.18	3	80.7	45.4	47.2	49.1	51.2	53.3	55.6	58.0	60.5	63.1	564.1
Turmeric	113.5	113510	12.90	5	52.2	15.5	16.0	16.5	17.1	17.6	18.3	19.0	19.7	20.5	212.3
Lentil	500.0	500000	56.82	6	108.5	74.5	77.6	80.9	84.4	88.1	91.9	95.9	100.2	104.6	906.7
Pumpkin	51.7	51650	5.87	4	43.8	6.8	6.8	6.9	7.1	7.2	7.4	7.5	7.7	8.0	109.2
Cabbage	126.1	126125	14.33	4	50.7	14.0	14.4	14.8	15.3	15.8	16.4	17.0	17.6	18.3	194.2
Cauliflower	93.2	93230	10.59	5	49.8	13.1	13.4	13.8	14.2	14.7	15.2	15.7	16.3	16.9	183.2
Mustard	300.0	300000	34.09	5	73.8	38.1	39.6	41.2	42.9	44.6	46.5	48.5	50.5	52.7	478.4
Banana	89.8	89822	10.21	5	49.4	12.7	13.0	13.4	13.8	14.2	14.7	15.2	15.8	16.4	178.5
Lady finger	69.9	69930	7.95	4	45.5	8.6	8.7	8.9	9.1	9.3	9.6	9.9	10.2	10.5	130.1
Papaya	66.5	66521	7.56	4	45.2	8.2	8.4	8.5	8.7	8.9	9.2	9.4	9.7	10.0	126.2
Ground nut	133.9	133867	15.21	4	51.4	14.7	15.2	15.6	16.2	16.7	17.3	17.9	18.6	19.3	203.1

soybean, sunflower, strawberry, lentil and mustard are very much lucrative compared to diesel powered irrigation (Fig. 6).

In this research, we have considered 27 crops. In this chapter, we calculate the total present value (taka) for solar powered, diesel powered [8], which is shown in Table 4. The diesel rate is unstable and it is not eco-friendly. Rather than diesel powered irrigation, solar powered irrigation is more eco-friendly, has low maintenance cost, long-term efficient and fast [8].

And electricity produced by solar cells is clean and silent. Because they do not use fuel other than sunshine, PV systems do not release any harmful air or pollution into the environment, deplete natural resources, or endanger animal or human health. Photovoltaic systems are quite and visually unobtrusive. Solar energy is a locally available renewable resource. It does not need to be imported from other region of the country or across the world [9]. This reduces environmental impacts associated with transportation and also reduces our dependence on imported oil.

The findings of this study have led us to believe that the time is now ripe to advance towards a new phase implementing solar powered irrigation system [9]. At this time, financing and technical support for individual pilot initiatives is recommended. Therefore, the government should more facilitate the development of this renewable water pumping sector so that private entrepreneurs come forward to take the initiatives to invest in this sector.

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