J. Sylhet Agril. Univ. 7(1&2):25-37, 2020 **ISSN: 2308-1597**

ECONOMIC PERFORMANCE EVALUATION OF LOW COST SOLAR IRRIGATION SYSTEM IN SYLHET REGION OF BANGLADESH

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(Available online at www.jsau.sau.ac.bd)

Abstract

This research shows that the lion's share of the energy used for irrigation and water management in Bangladesh is still fuel oil and non-renewable sources, which are by no means environmentally friendly and expensive compared to other sources. Research shows that in the last 10 years, 500000 hectares of new uncultivated land have been included under the irrigation and water management facilities of Bangladesh. Most of which came under irrigation with the help of fuel oil-powered pumps. 5% of the total diesel demand of Bangladesh is spent on irrigation only, which can be easily replaced with a solar-powered irrigation pump. This research work was carried out in the Shalla Upazila and Dharmapasa Upazila areas of Sunamganj District under Sylhet Division, where two solar-powered irrigation pumps were installed. It cost 280,000 Taka to install a complete solar pump, the lion's share of which was spent buying PV arrays. Compared to diesel-powered pumps it has been observed that the cost of a solar-powered power pump in 20 years where 342,742 Taka whereas the cost of a diesel pump 838,524 taka. Which is 60% cost-effective and demand of time for farming? This will release the right amount of water to the land at the right time, which can increase the yield by about 10% to 20% due to loss reduction of premature grains, and reduce the cost to the farmer – which can play a role in improving the living standards of the farmer. Replacing the current diesel-powered pumps with solar-powered pumps can reduce carbon emissions from Bangladesh. The amount of more than 108,6176.316 metric tons of carbon emission in just 20 years can be reduced only by this replacement.

Keywords: Solar irrigation, Cost, Carbon reduction, Yield increase, Sustainability

Introduction

Bangladesh has already had limited success in using solar energy, especially to provide electricity to rural people in remote areas. Now is the time to introduce solar energy into the irrigation system that demands the main power supply during the Boro season. Bangladesh has 1.55 million units of mechanical (diesel and electric) irrigation pumps (BADC 2009). Of these pumps, 16.30% are electric pumps, and 83.70% are diesel pumps (BADC 2009). 1.3 million diesel pumps consume 10 billion liters of high-speed diesel fuel annually. The government has to subsidize the price of diesel every year, which is around Tk 55 billion annually (Daily Prothom Alo November 2009).

Photovoltaic (PV) energy for irrigation is cost-competitive compared to conventional energy sources for small size water pumping requirements. Photovoltaic power is set to become more profitable in the future (Eker 2005), with fossil fuel consumption continuing to rise and mass production reducing the maximum watt consumption of solar cells. Ould-Amrouche et al. (2010) developed a model using experimental results obtained with different motor-pump subsystems of different types and technologies. The results are compared by

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considering the centrifugal and positive displacement motor-pump subsystem. Experimental tests are used to validate advanced models. Based on the motor-pump subsystem model, a method has been proposed to estimate the amount of carbon dioxide (CO2) emitted could be saved by using PV water pumps rather than diesel generators. Yahya et al. (2012) developed an optimal sizing model to optimize the capacitance size of the various components of an individual photovoltaic water pumping system using a water tank and analyzed a pumping system designed to supply drinking and irrigation water in Ghardia, Algeria. The optimal configuration of the pumping system is determined by the various desired system reliability requirements (LPSP) and cost of the life cycle (LCC). Jamil et al. (2012) proposed a $ 20,000 solar water pumping system to meet the water needs of an academic institution in New Delhi, India. A PV-based water pumping system is technically economically analyzed and compared with an existing system. Rezae and Gholamian (2013) conducted a technical and financial study of photovoltaic water pumping systems for irrigation of Gorgan farm fields in Iran using RET Screen software and concluded that the installation cost of PV water pumping project was very high, but substantial savings were observed. Foster et al. (2013) surveyed 46 water pumping systems installed under the Mexican Renewable Energy Program (MREP). The average investment payback for PV water pumping systems is found to be 5-6 years; some systems report payback within half of that time was estimated. McMahon and Osterwal (2002) say that the thin-film decay rate is about 1% per year, whereas the 25-year commercial warranty decay rate requires 0.5% per year.

Diesel has to be imported from there, which makes the price of diesel and its availability extremely risky. The irrigation season of 0.25 million electric pumps requires a daily supply of 1100 MW. In many rural areas,, electricity is unavailable or only occasionally available (Hartung et al., 2018). Solar irrigation solutions are attracting growing interest worldwide, as evidenced by the growing demand from agricultural organizations for installation, financing, and training in developing countries (Lin and Ya, 2014). Nigeria hasbeen provided with a

solar pumping network of up to 20 m^3/ day, which was considered satisfactory for the population (Wazed et al., 2018). The cost of solar-powered pump system for irrigation depends on the required photovoltaic capacity, photovoltaic solar power and related equipment, import tax, and water storage requirements and dimensions. Battery storage facilities (Schnetzer and Pluschke, 2017). In the United States, the investment cost of a photovoltaic panel is estimated at 2500 to 3000 USD / KW, with this varying from 500 to 800 USD / KW for fuel pumps, reflecting the high investment costs (Schnetzer and Pluschke, 2017). According to Hossain et al. (2015), the cost of modules is more important when considering solar pumping systems in Bangladesh (45%), than implementation, complete pump and other ancillary costs, representing 18%, 26%, and 4% of total costs respectively. In addition, the use of solar irrigation pumps can save the equivalent of 760 MW of electricity and 8 billion liters of diesel fuel per year in the paddy fields of Bangladesh (Biswas and Hossain, 2013). Replacing one million solar pumping systems with conventional pumping systems results in $ 300 million less diesel fuel imports per year, which saves $ 4.5 billion over the life of the pump (KPMG, 2014). In order to provide uninterrupted electricity to the farmers, the power companies have to carry out large-scale load shedding during the irrigation season. Our country's natural gas reserves are declining yearly, hampering power generation. So this study will help to analyze the performance of solar irrigation and also find out the economic feasibility of operating this system under study area in the near future. The main objective of the study was to use solar energy for irrigation in the Sylhet region and to study the economic feasibility of using solar energy-based pumping system for irrigation.

Materials and Methods

The study area was the Sunamganj district of Bangladesh. Several lands were selected for field experimental purposes. That land was irrigated by using a solar pump. Dharmapasha (Point A), is an Upazila of Sunamganj District in the Division of Sylhet, Bangladesh. Dharamapasha is located at 24.9000°N 91.0167°E. Sulla Upazila (Point B), area 260.74 sq km, located between 24°34' and 24°49' north latitudes and between 91°08' and 91°23' east longitudes.

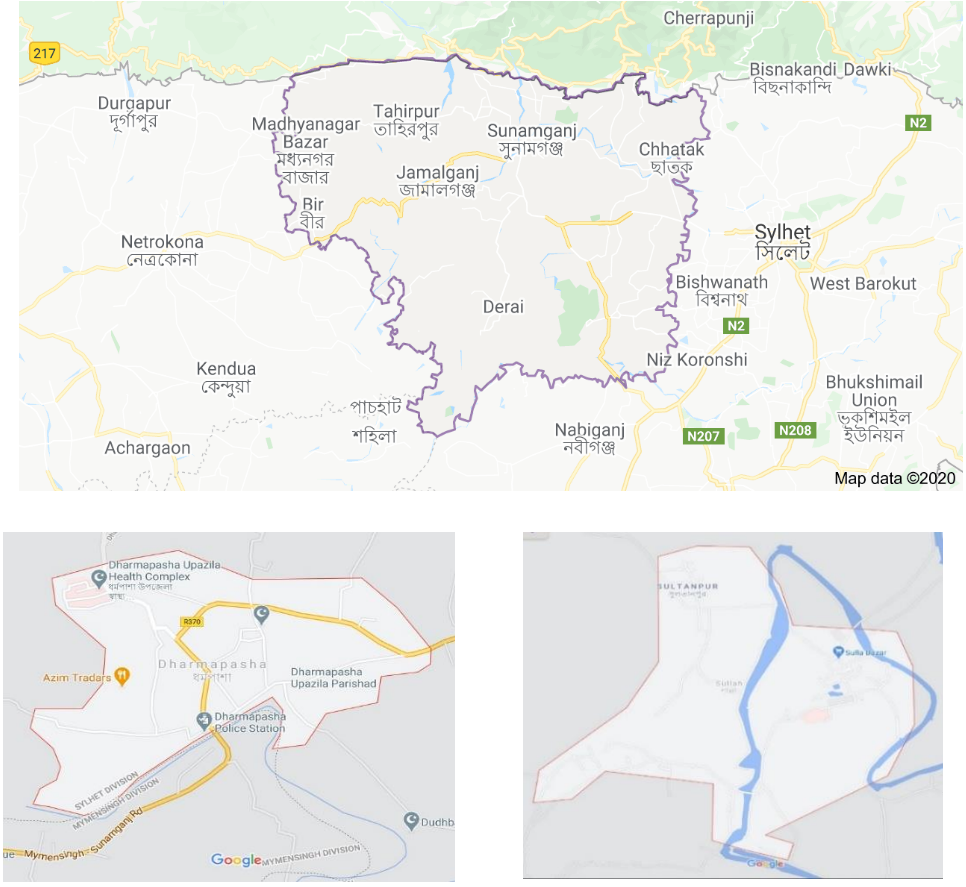


Figure 1. Study area; Dharamapasha and Sulla Upazila

A photovoltaic system or solar power system is a power system designed to supply usable solar power using photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity. Among the two types of PV panels-Monocrystalline and Polycrystalline Panels.

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 at field level, supplied and installed by BARI and Grameen Sakti, a non-government organization. Therefore, trader's data were collected from Rahimafrooz Renewable Energy Limited and Electro Solar Power Limited (a leading company that seals PV panels al around the country). Information on service providers was collected from the solar pump locations. Twelve solar pump users from each solar pump were randomly selected and directly interviewed. All primary data were collected from the experimental site (Sunamganj), and Secondary data were from each of the respondents using pre-tested interview schedules, books, journal articles, research reports, the internet, etc. Three sets of interview schedules (solar pump suppliers, service providers, and users) were prepared for primary data collection.

Economic analysis

The 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. The annual interest rate was considered 4 % of the capital price of the pump.

The initial capital cost was high due to the cost of the photovoltaic (PV) modules. The maintenance requirements differ and range from one year to five years. A perceived limiting factor of solar pumps was that they do not easily cater to the fluctuating water demands or increased water demand, although solutions for this are being offered.

This study aimed to compare the economic viability of PV water pumping systems and diesel water pumping systems. The interest rate is a function of supply and demand for money. For the base case, a value of 4 % was considered. A market interest rate includes components for nominal interest rate (i) and inflation rate (r) defined by the Fisher equation

$$i = (1+ i_n)(1+r)-1 \qquad (1)$$

Therefore, the life cycle cost approach was used for economic appraisal and comparison, where all future costs are discounted to their present worth by a discount rate of 4%. 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

$$P = f\frac{1}{(1+i)^n} \qquad (2)$$

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

$$a = p\,\frac{i(1+i)^n}{(1+i)^n-1} \qquad (3)$$

Where a is the annuity of a single payment.

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

Again, the formula to calculate LCC is as follows:

LCC = Investment costs + Present value of future costs of operating, maintenance, and replacement costs… (4)

Several filed surveys were done for this purpose.

Results & Discussion

Input cost analysis

The cost of the solar water pump operated by an AC Motor pump is compared with that of the diesel-based operator motor pump. This is carried out by comparing the AC motor with the diesel water pump for the total dynamic head (TDH) of 25 m well and a daily flow rate of 750 lt/min for irrigating the rice field of 16 acres. The life cycle costs (LCC) were calculated over 20 years, and these are:

- The initial upfront cost;

- The operating costs (operational cost, inspection cost of solar water pumps, and fuel cost for the diesel pumps);
- Maintenance costs; and
- Replacement costs.

Table 1 shows the input parameters for the PV and the diesel water pumping systems. The parameters for the cost analysis are used for comparing the cost of AC-operated SWPS with that of the diesel-operated WPS. The project life for calculating the Life Cycle Cost (LCC) is 20 years.

Table 1: Main input parameters for the cost analysis

Sl. No.	**Parameters**	**Value**
1	Pumping head	25 m
2	Daily pumping rate	777 m^3/day
3	Daily average solar irradiance level	5.3kWh/m^2/day
4	Tracking angle of the solar panels	13.5 degree
5	Type of motor	AC motor
6	Diesel pump selection	Long/short lifespan
7	Pumping hours / day for diesel pump	6
8	Cost of fuel	Tk. 65/L
9	Annual diesel price escalation	4%
10	Project life	20 years

The initial cost of setup

The amount of initial setup cost is shown in table 2 below. The total amount was 280000. All components are bought from the local market.

Table 2: Initial costs for the AC SWPS

PVP System Components	**AC Motor controlled SWPS**
PV Array Power for 25m TDH for delivering 777 m3 /day	3200 W
PV array	Tk 170,000
PV array structure	Tk 10,000
PV pump with controller	Tk 55,000
Pipe, cable, and rope	Tk 15,000
Accessories	Tk 20,000
Installation	10000 tk
Total PVP installation cost (VAT included, TK)	**280000 tk**

Figure 2 shows that the major amount of cost is spent on the PV array. About 61% cost spend on it. Other items like installation required around 4%, accessories 7%, etc. So the main component is to take the lead in cost. There are some other costs like the cost of Lock, Fencing, etc. This cost is too small with respect to major components like solar panels or pumps, which shows similarities with the cost components by Hossain et. al. (2015).

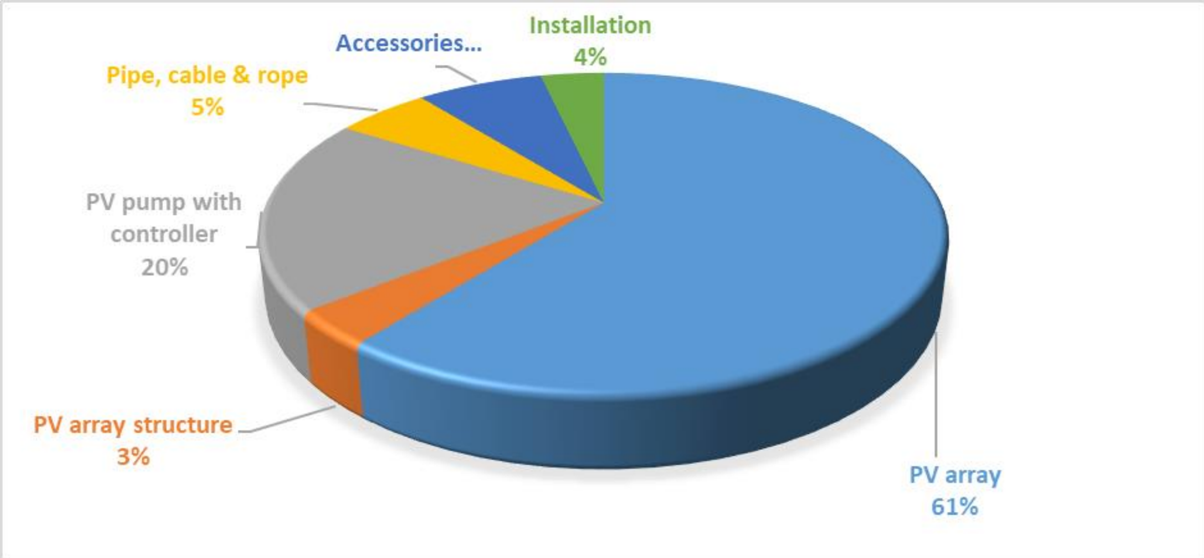


Figure 2. Cost component for the installation of solar pump

LCC cost of the SWPS and diesel-based WPS

The results are presented in this Section and include the LCC breakdown for an average water pumping installation, the life-cycle cost for a selected delivery head, and the breakeven for two options. All comparisons are based on the assumption that the pumping systems are fully utilized, i.e. the solar pump is used every day of the year, and the diesel pump is used according to the selected pumping schedule to meet the average daily delivery of the solar pump.

The LCC cost of the AC motor-operated solar water pump can be compared with the diesel pump operating at 25 m TDH and delivering 777 m^3 /day. Table 3 shows the calculated values of the diesel and AC SWPS systems is shown in Table 3.

Table 3: LCC of diesel pump and AC SWPS

	Initial cost (Tk)	Operating cost (Tk)	Maintenance cost (Tk)	Replacement cost (Tk)	Total (Tk)
Diesel Pump	52,924	624,000	16,592	93,738	838,524
AC Motor SWPS	280,000	4,192	10,934	47,616	342,742

Figure 3 compares the LCC of the AC motor-controlled solar water pumping systems. The LCC comparison was calculated with the AC motor-operated solar water pumping system with a replacement period of 18 years and a maintenance period of 10 years. These water pumps operate at 25 m TDH and deliver an average output of 777 m^3 /day. The breakeven point of cost between these two systems is 7 years from the starting of time count, which is 2 years differ from the findings of Hossain *et. al.* (2015).

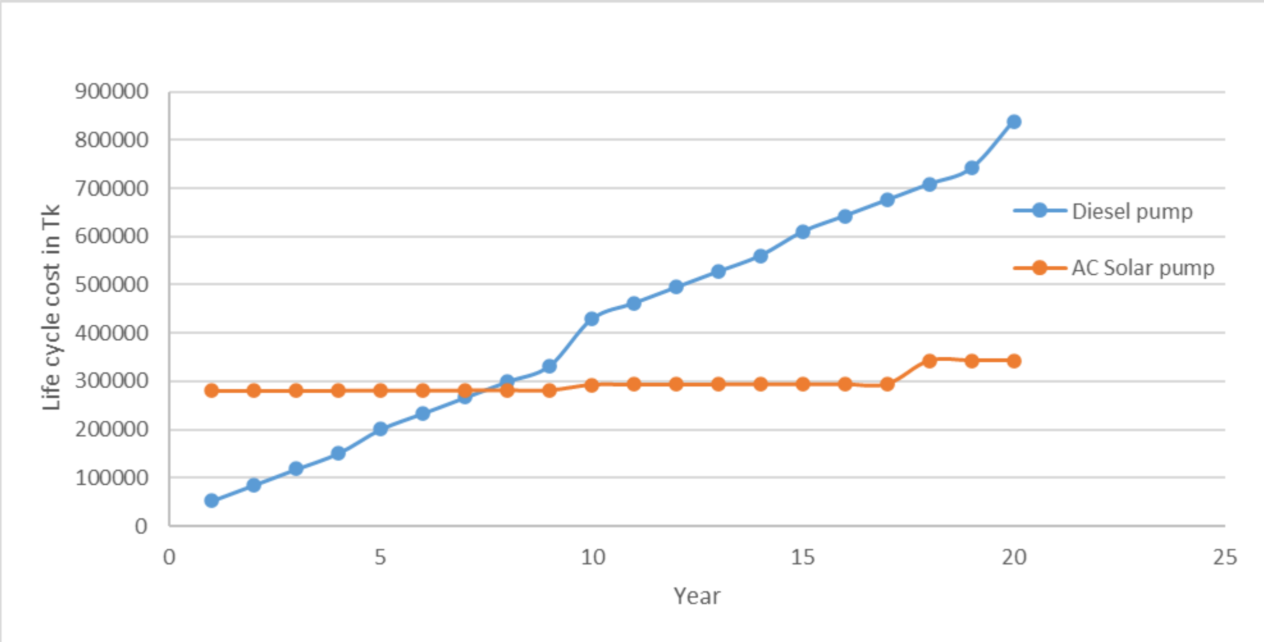


Figure 3. LCC of diesel pump and AC SWPS

The operation cost of the solar pump is very low, but it is higher for diesel pump due to diesel and oil costs, including repair and maintenance cost. The life of the diesel engine and the pump is 10 years, and overhauling of the diesel engine is done every 5 years. After 10 years, a new engine and pump are to be purchased. The life of a solar panel is 20 years, and after 10 years pump and motor are to be changed. Diesel fuel is a pollutant to the environment.

Figure 4 shows the overall cost of irrigation systems both solar irrigation and diesel-based irrigation. It is clearly shown that solar irrigation is much more than cost-efficient diesel-based irrigation.

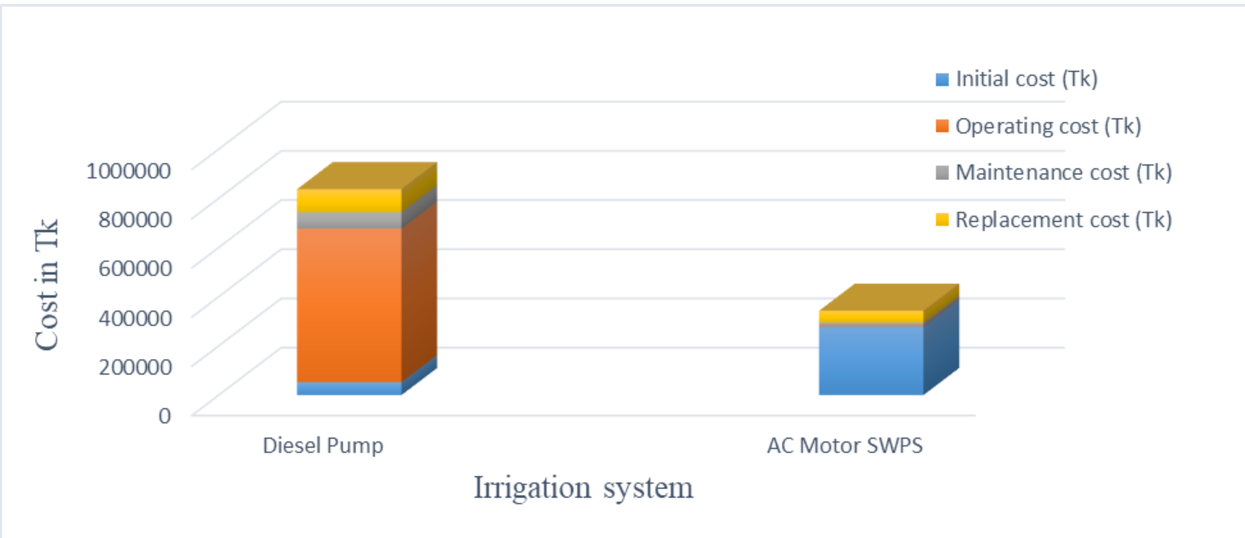


Figure 4. The overall cost of the diesel WPS and AC SWPS

Life cycle costs of diesel- and solar PV-operated pumps are shown in Figure 4. It is observed from Figure 4, that the life cycle cost of a diesel-operated pump is lower than a solar pump up to 7 years, and then (after 7 years or more) solar pump becomes more economic. For the long-term project (more than 7 years) solar pump is more economical than the same sized diesel pump. There are clear differences between diesels operated pumps and solar pumps 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. The solar pump has, a 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.

The unit cost of irrigation per Boro season using solar power

Table 4 and Figure 5 show the total unit cost of solar irrigation during a Full Boro season. The cost is 60% less than compared to conventional diesel-based irrigation. The total cost was Tk 4,335, for one season, which is very low compared with the findings of Muhammad D. *et. al.* (2014). According to Muhammad D. *et. al.* (2014), farmers from the northern rural part of our country and found out that they have to pay Tk 8,000-12,000 for each 1 Acre of land as irrigation charge for a crop season. Whereas by using this low-cost technology, it can irrigate 1 Acre land by only Tk 1,063 for an entire year. This might be the cheapest irrigation system among all other existing in the market and bring bake the fortune for poor and marginal farmers of our country

Table 4: Unit cost of irrigation per Boro season using solar power compared with conventional one.

Sl. no	Time	Tk needed for solar-based irrigation	Tk needed for diesel-based irrigation
1	20 years	346,934	853,622
2	1 year	17,347	42,681
3	1 month	1,445	3,556
4	3 month (1 Boro season)	4,335	10,668

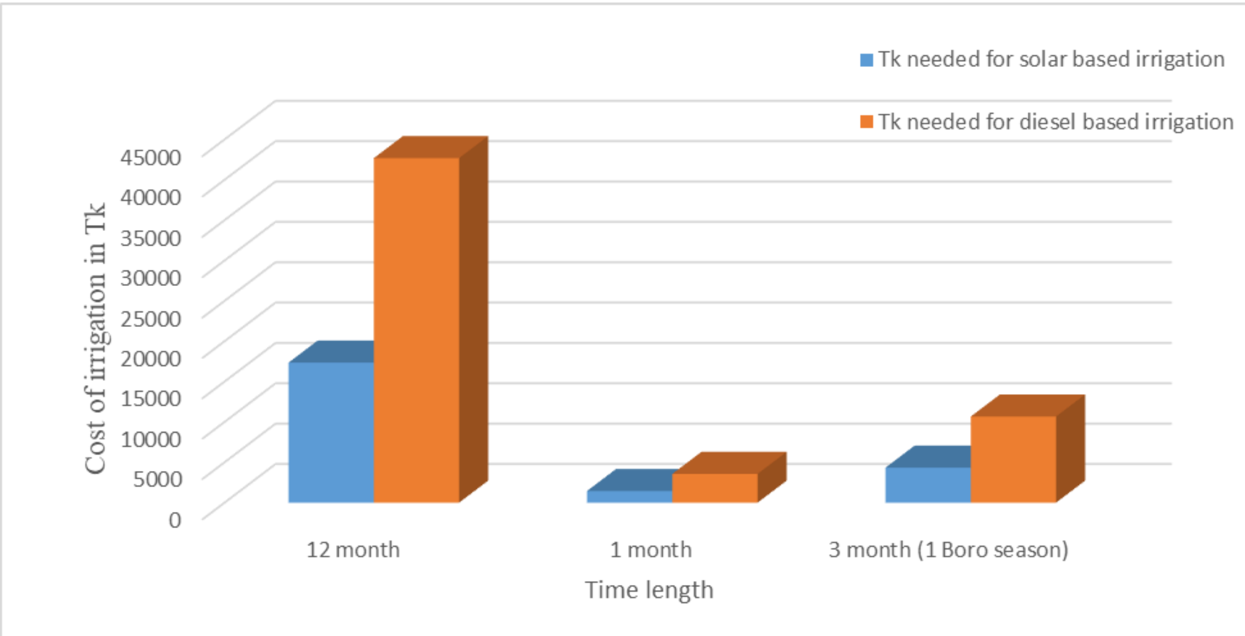
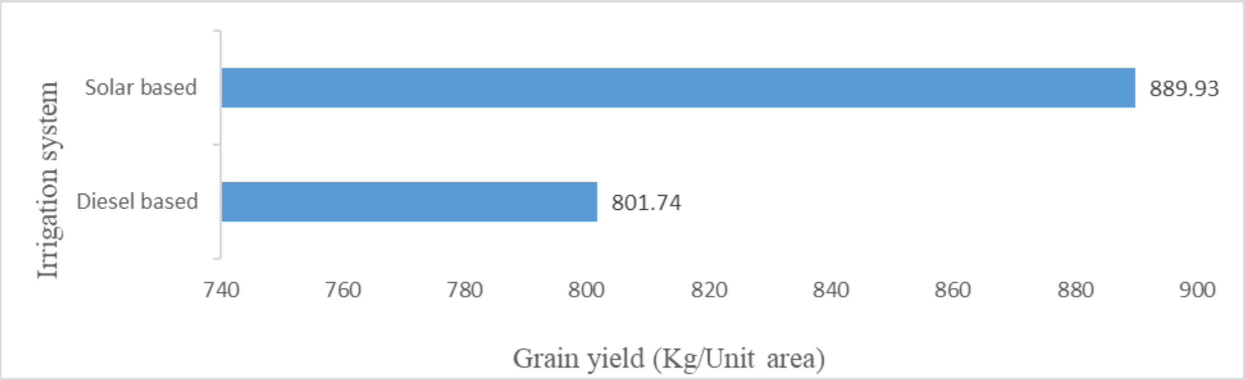


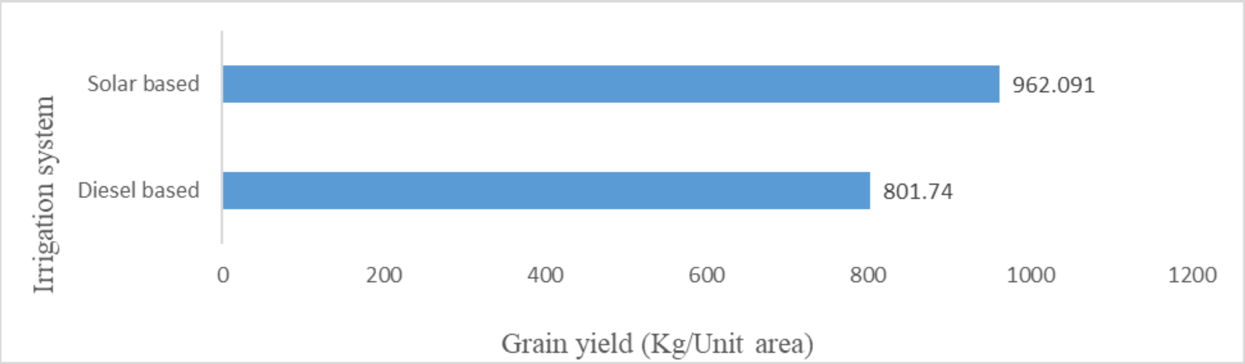
Figure 5. The unit cost of irrigation for a single Boro season using solar power compared with a conventional one.

The yield difference between Solar Irrigation and Diesel based irrigation

The yield variation is visible between these two systems. Figure 6 shows that the yield of the same field is far better in the case of solar irrigation rather than a diesel-based irrigation system. This happens for only the timeliness of irrigation to the crop field. It is clear that by adopting solar irrigation, yield increases about 10% to 20% of all environmental inputs remain the same.



(a)



(b)

Figure 6. The yield difference between Solar based irrigation and Diesel based irrigation systems. (a) 2019, (b) 2020.

Production difference of carbon dioxide between diesel pump and solar pump

Solar pumping has had clear advantages for several years, but the differences are becoming more striking in a world of rapidly escalating fuel costs. The numbers of solar pumps as well as CO_2 emission is on an increasing trend. About 2.64×9600 = 25344 kg of carbon dioxide is emitted from the diesel engine. Also, a lot of sounds pollute the environment during the operation of a diesel pump. But the solar pump is a pollution-free and environment-friendly irrigation device. The solar pump is pollution-free and a green irrigation pump to mitigate (CO_2) emissions. If these diesel-powered irrigation pumps could replace with solar pumps, Bangladesh could mitigate a vital carbon dioxide (CO_2) emission source. Figure 7 below shows the production difference of carbon dioxide (CO_2) between diesel pump and solar pump.

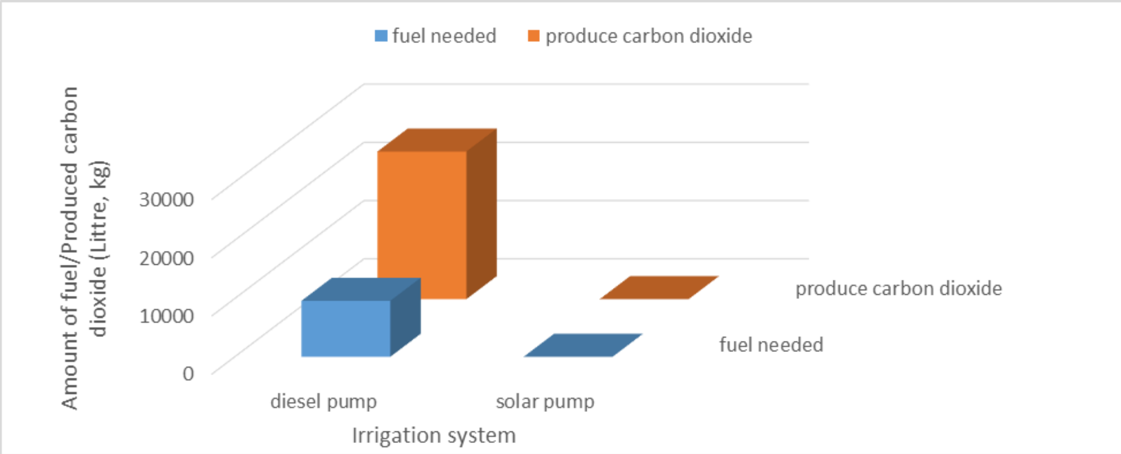


Figure 7. Production difference of carbon dioxide (CO_2) between diesel pump and solar pump.

In 2018, the total area equipped for irrigation for Bangladesh was 5,550 thousand hectares. The total area equipped for irrigation in Bangladesh increased from 1,457 thousand hectares in 1969 to 5,550 thousand hectares in 2018, growing at an average annual rate of 3.05%.

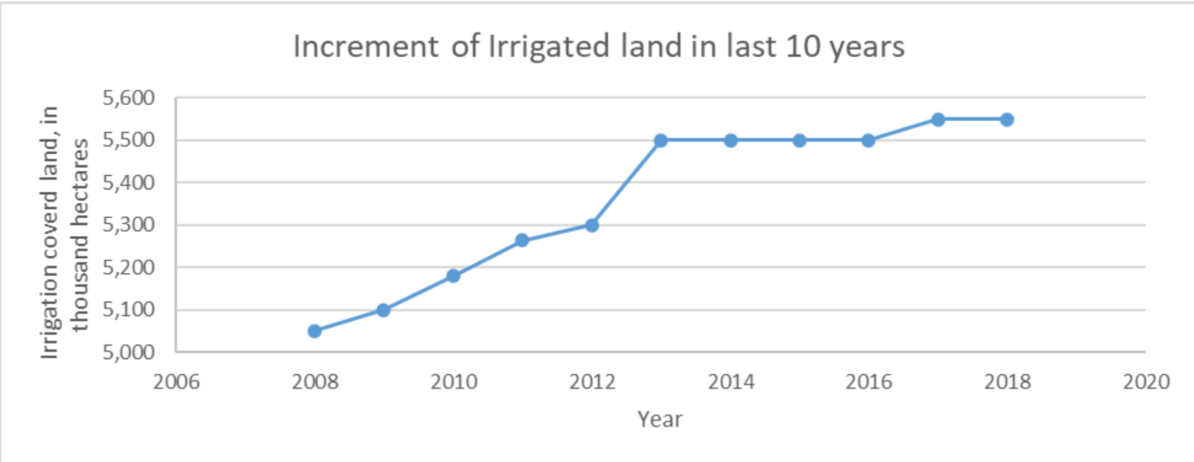


Figure 8. Increment of Irrigated land in last 10 years

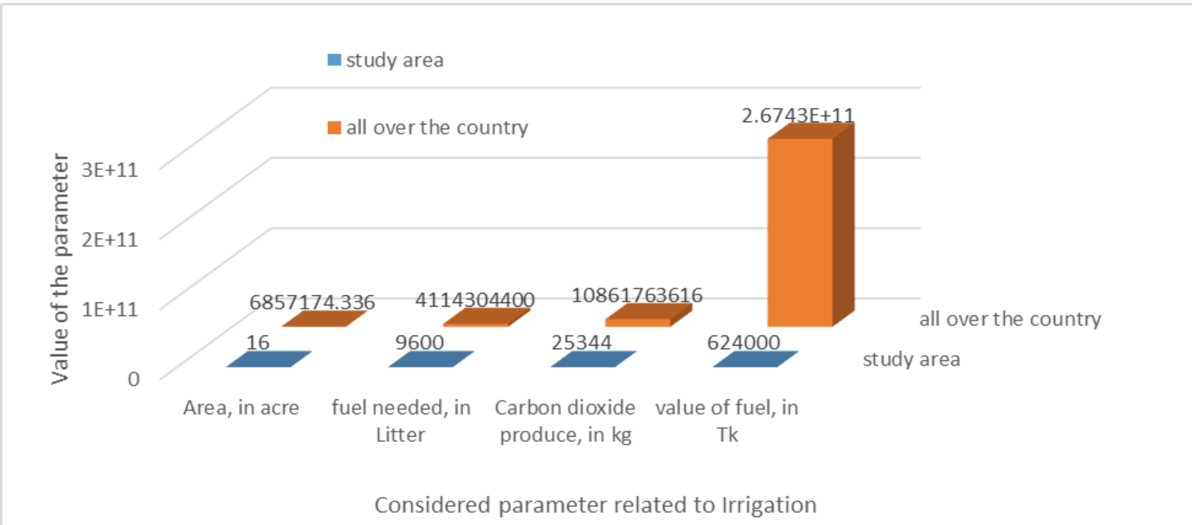


Figure 9. Production of carbon dioxide (CO_2) due to using diesel-based irrigation pump all over Bangladesh.

So if 50% of this largely equipped area is under a diesel-based irrigation system, then the total area becomes 2775 thousand hectares which is equivalent to 6857174.336 acres of land. So the total carbon dioxide (CO_2) produce from this amount of land due to using diesel-based irrigation is 1086176316 kg or 1086176.316 M, Ton. Which is linearly related to the findings of Hossain M. and Karim A (2020). This calculation has been based upon the conversion estimates from U.S. EPA Centre for Corporate Climate Leadership, 2016 report i.e. 1-liter diesel burnt = 2.68 Kg carbon-di-oxide.

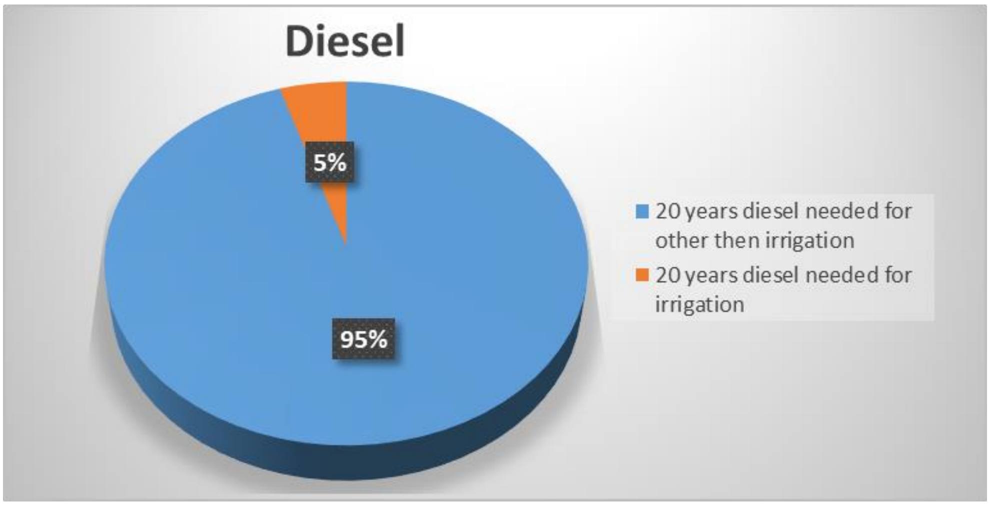


Figure 10. Total diesel demand in Bangladesh for 20 years for Irrigation and others.

Conclusion

A solar-powered pump is a pump running on the power of the sun. It makes efficient use of solar energy and converts it into electrical energy for pumping water to great heights. A solar-powered pump can be very environmentally friendly and economical in its operation. Using a solar pump may reduce pollution. If any electrical power comes from oil or coal production, then any use of solar, including a solar pump, reduces the use of these fossil fuels; it is highly reliable and durable.

Due to environmental conditions and lack of on-grid connection, there is a high potential for expansion of solar irrigation wings in the western part of Bangladesh, especially in the haor area of the Sunamganj district. The solar irrigation system has shown very promising effectiveness in this area and also opens up opportunities to increase the area under irrigated crops to meet the crop demand over time. According to the results of the study, a solar-powered irrigation system is highly recommended for high mechanical potential. If any electrical energy comes from oil or coal production, then using any solar with a solar pump reduces the use of this fossil fuel which is highly reliable and durable. In this age of climate change, solar irrigation can play a major role in reducing the spread of coal-fired thermal power plants and overhead grid lines among the endangered species of birds and other diversified inhabitants of Avis. This will not only improve the living conditions but also increase the quality of life of the local farmers without any hindrance to the environment. It will be possible to resolve local water conflicts among farmers as the use of solar irrigation systems will no longer be a major problem for water availability. It is also useful for clean drinking water, sanitation, and also irrigation. It creates wealth for farmers by increasing the number of crops.

Acknowledgement

Author acknowledges the support and significant contribution of Dr. Md. Anwar Hossen, Senior Scientific Officer, Farm Machinery and Postharvest Technology Division, Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh. Professor Dr. M. G. Mostofa Amin, Department of Irrigation and Water Management, Faculty of Agricultural Engineering & Technology, Bangladesh Agricultural University, Mymensingh-2200. Hussain Md. Khaledujjaman, Assistant Engineer, BADC Sunamgonj Zone, Sunamgonj.

Reference

BADC- Minor Irrigation Survey Report 2008-09: Bangladesh Agricultural Development Corporation, Survey and monitoring project for development of minor irrigation.

Biswas H, Hossain F 2013: Solar Pump : A Possible Solution of Irrigation and Electric Power Crisis of Bangladesh. *International Journal of Computer Applications* **62** 16.

Deen Muhammad, MukibMosleh, Shakir-ul Haque Khan 2014: Assessment and Evaluation of Solar Irrigation System in Bangladesh. Conference Paper. DOI: 10.1109/ICDRET.2014.6861651.www.researchgate.net/publication/269291315

Eker B 2005: Solar powered water pumping systems. *Trakia J Sci***3** 7–11.

Foster RE, Alma D, Ross MP, Avilez OM. 2013: Ten-year reliability assessment of photovoltaic water pumping systems in Mexico. Sandia National Laboratories.

Hartung H, Pluschke L 2018: The Benefits and Risks of Solar-Powered Irrigation—A Global Overview. Food and Agriculture Organization of the United: Rome, Italy.

Hossain MA, Hassan MS, Mottalib MA, Hossain M. 2015: Feasibility of solar pump for sustainable irrigation in Bangladesh. *International Journal of Energy and Environmental Engineering***6** 147–155.

Jamil M, Ahmed SA, Rizwan M 2012: SPV based water pumping system for an academic institution. *Am J Electr Power Energy Syst***1** 1–7.

KPMG 2014: Feasibility analysis for solar agricultural water pumps in India.

Linn S, Ya AZ2014: Solar/wind/diesel hybrid energy system with battery storage for rural electrification. *Int J SciEngTechnol Res***10** 5.

McMahon J, Osterwald CR 2002: Commonly observed degradation in field-aged photovoltaic modules. In: Proceedings of the 29th IEEE photovoltaic specialist’s conference. *New Orleans* 1436–1439.

Monzur H, AzreenKarim 2020: FINAL REPORT Impact Assessment of Solar Mini-grid, Solar Irrigation and Improved Cooking Stove Projects of IDCOL. Bangladesh Institute of Development Studies (BIDS), Dhaka-1207, Bangladesh.

Ould-Amrouche S, Rekioua D, Hamidat A 2010: Modelling photovoltaic water pumping systems and evaluation of their CO2 emissions mitigation potential. *Appl Energy***87** 1–9.

Rezae A, Gholamian A 2013: Technical and financial analysis of photovoltaic water pumping system for Gorgan. *Int J Cybern Inform* 2.

Schnetzer J, Pluschke L 2017: Solar-powered irrigation systems: a clean-energy, low-emission option for irrigation development and modernization. Solar-powered irrigation systems: a clean-energy, low-emission option for irrigation development and modernization.

Wazed SM, Hughes BR, Connor DO, Calautit JK 2018: A review of sustainable solar irrigation systems for Sub-Saharan Africa. *Renewable and Sustainable Energy Reviews***81** 1206–1225.

Yahia B, Arab AH, Azoui B 2011: Optimal sizing of photovoltaic pumping system with water tank storage using LPSP concept. *Sol Energy***85** 88–94.