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LIFE CYCLE COSTS COMPARISON BETWEEN SOLAR, DIESEL AND GRID-ELECTRICITY POWERED SMALL IRRIGATION PUMPS: EVIDENCE FROM NORTHERN BANGLADESH

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Abstract: Bangladesh Government has emphasized renewable energy generation and fixed a target to generate at least 150 MW of electricity from solar irrigation pumps (SIPs) by 2020; however, the generation was only about 46.98 MW. This study compared the life cycle costs (LCCs) between small solar, diesel and grid-connected irrigation pumps. The data on solar irrigation pump (SIP), diesel irrigation pump (DIP) and grid-connected irrigation pump (GIP) were collected from Birganj and Badarganj Upazilas of northern Bangladesh. The capital, maintenance, replacement and operational costs were calculated for the pumps. The outcome of annualized life cycle costs (ALCC) reveals that the average cost of the SIP (Tk.36848) is lower than DIP (Tk.105378) but marginally higher than GIP (Tk.34896). The GIP's ALCC is the lowest, mainly for the subsidy on electric tariffs for irrigation. Therefore, at first, DIPs should be replaced by SIPs. GIPs will be replaced in the future as the price of electricity appears to be increasing. However, a small SIP's operational cost is almost zero as it runs on solar radiation. In addition, the cost of solar irrigation will continue to fall since the price of PV panels has decreased by 12 times from 2010 to 2020.

Keywords: Diesel irrigation pump (DIP), grid-connected irrigation pump (GIP), life cycle cost (LCC), solar irrigation pump (SIP), sustainable irrigation.

Introduction

Bangladesh is one of the world's most densely inhabited countries (1,140 people per km^2), with 164.68 million in 2020 (World Bank, 2022). According to the United Nation's demographic projections, the country's population will be around 178 million in 2030 and 202 million in 2050. Providing food security for this rapidly expanding population has become a challenge. The most important strategies to meet the challenge are to raise the cultivable land's productivity and cropping intensity. Their cultivable land and cropped areas are approximately 8.52 and 14.943 million hectares (Power division, 2008). Of 8.52 million hectares of cultivable land, around 7.76 million have already come under the irrigation facility (Power division, 2021). An irrigation facility is critical for maintaining the optimal use of cultivable land and ensuring food security for the enormous population. However, many rivers suffer from water scarcity nowadays, especially in dry seasons. As a result, underground water has become the primary source of irrigation. The country's irrigation is mainly done with diesel and grid-connected water pumps. Approximately 1.57 million irrigation pumps are used in the country, with roughly 1.23 million diesel-powered, 0.34 million electric-powered and only 1,969 solar-powered pumps (BADC, 2020; Mitra *et al.*, 2021). Therefore, most current pumps are powered by diesel engines especially where electricity from the national grid is unavailable. For this purpose, Bangladesh imports roughly 1.06 million tons of diesel yearly (BADC, 2020). However, farmers have many problems with conventional irrigation pumps, particularly with DIPs. The DIPs' main problems are the diesel's price volatility and difficulties in reaching diesel in distant places.

Furthermore, it pollutes the environment by emitting smoke and creating sound.

On the other hand, those who use a GIP encounter frequent load shedding and low voltage problems, making it challenging to harvest at the highest possible level. Under these circumstances, the government has prioritized the installation of SIPs. Moreover, Bangladesh's government has the vision to generate 10% of its total power from renewable sources by 2021 and 20% by 2030 (Power division, 2021). Solar energy can play an essential role in fulfilling the vision because solar radiation is generously available in Bangladesh, with an average variation between 4 and 6.5 kW/m^2/day (Hossain *et al.*, 2015).

Therefore, this study conducted the life cycle cost analysis to examine the financial viability of small solar, diesel and grid-electricity-powered irrigation pumps. Small (4 HP) self-operated solar, diesel and grid-electricity powered irrigation pumps were selected for the LCC analysis because according to some studies, small SIPs are more profitable than medium and large SIPs in the case of India and Bangladesh (Surendra & Subbaraman, 2002; Islam & Hossain, 2022). This study has provided an effective financial comparison between small SIP, DIP and GIP in the context of Bangladesh, which is not available in the existing literature. Thus, it will help evaluate the potential of solar irrigation pumps (SIPs) to replace conventional irrigation pumps. The following components compose the paper's structure: Literature review, materials and methods, presentation and discussion of the findings and conclusion.

Literature Review

This section critically analyses earlier studies on the solar pump's financial feasibility compared to conventional pumps worldwide. This analysis helps to find the gaps in the earlier literature and enables the researchers to carry out a new study on the financial feasibility of the SIPs for irrigation in the country's agriculture. On a life cycle basis, several studies suggest that SIP is more cost-effective than DIP and even sometimes than GIP. In Iran's setting, according to the finding of Niajalili *et al.*, the SIP's initial outlay is around nine times that of a conventional system. However, A SIP's entire life cycle cost is around 66% of a conventional pumping system (Niajalili *et al.*, 2017). According to Nikzad *et al.* for rice cultivation in north Iran, the initial cost of a SIP in the off-grid area is 2.14 times higher than the conventional irrigation pump (CIP). Nevertheless, its operating and maintenance costs are 8.7 times lower than the cost of CIP (Nikzad *et al.*, 2019). In Bangladesh, the capital, operating and maintenance costs are not separately measured for the SIP, DIP and GIP.

In Egypt, Mahmoud and Nather conducted an economic feasibility study for SIPs. They found that SIP is the most efficient source of irrigation and their operating cost is lower than the DIP, especially in the sprinkler and drip irrigation methods (Mahmoud & El Nather, 2003). In Bangladesh, surface irrigation is the most widely used method; hence, a comparison of available surface irrigation choices is required.

In Jordan, Odeh *et al.* evaluated and compared the economic viability of solar and diesel water pumps. They found that the solar water pump was more efficient and cost-effective in fulfilling water requirements than the diesel water pump (Odeh *et al.*, 2006). In Sub-Sahara Africa, Wazed *et al.* concluded that developing SIP technologies (particularly the efficacy of photovoltaic solar panels) had surpassed DIP systems in terms of payback period and greenhouse gas reduction (Wazed *et al.*, 2017).

In India, Shinde *et al.* mentioned that SIPs are more cost-effective than DIPs, up to 3 kWp for village water delivery and roughly 1 kWp for irrigation (Shinde & Wandre, 2015). According to P.D. Narale *et al.*, a SIP is more economical than a DIP for horticultural crops since the photovoltaic (PV) or solar system's life cycle cost (LCC) is 132924/-. In contrast, the diesel engine's LCC is 759069/- (Narale *et al.*, 2013). Parajuli *et al.* evaluated the solar water pump's techno-economic feasibility and compared it to diesel and biodiesel-powered water pumps in Doti, Nepal. They revealed that the solar pump is the most viable energy source for pumping water (Parajuli *et al.*, 2014).

In Spain, García *et al.* found that solar pumps accounted for 37% of the diesel operated and 64% of the electricity run pump's life cycle cost (LCC) (García *et al.*, 2019). Meah *et al.* examined the costs of photovoltaic (PV), electric and gasoline-powered water pumping systems in the United States (Table 1). They found that the PV system had a higher fixed cost than the gasoline generator. However, a PV system's operating and maintenance costs are cheaper than a gasoline generator since the generator's efficiency decreases over time. In contrast, a PV system provides the same amount of electricity throughout its lifetime (Meah *et al.*, 2008). In Bangladesh, the LCCs of all available irrigation sources have yet to be determined.

In the case of Iran, Rizi *et al.* measured that 4.5 to 5.5 kW photovoltaic water pumps were more cost-effective than the grid-connected pump, even though subsidies for grid electricity are very high in Iran (Parvaresh Rizi *et al.*, 2019). However, solar pumps are not financially viable for high-capacity pumps. Solar pumps will be competitive with diesel and grid-connected pumps if a subsidy is provided for this new energy source (Parvaresh Rizi *et al.*, 2019). In Bangladesh, grid electricity and diesel are also heavily subsidized; thus, it needs to rethink the given amount of subsidy on the SIPs.

In India, Raghavan *et al.* examined the costs of several energy sources for 5 HP irrigation pumps. According to the study, the SIP had a life cycle cost of 516300 INR, a DIP cost of 927400 INR and a GIP cost of 560000 INR (Raghavan *et al.*, 2010). In Bangladesh, Hossain *et al.* (2015) compared SIP and DIP of the same capacity. After five years of operation, they found that SIP was more profitable than DIP, suggesting SIPs are more cost-effective.

From the above discussions, it is clear that a SIP would be the most cost-effective irrigation alternative. Nevertheless, DIPs and GIPs are now the primary sources of irrigation in Bangladesh. Thus, a detailed monetary comparison of solar, diesel and grid-connected pumps will help policymakers take initiatives for the widespread promotion of SIPs.

Materials and Methods

System Components of Solar Irrigation Pump (SIP)

Solar PV panels convert sunlight into direct current (DC), which powers the SIP. The higher the number of PV panels connected, the more electricity is generated. Electric wires connect the PV panels and deliver the electricity to the water pump via a controller. The controller regulates and stabilizes the power.

The capacity of a SIP is determined by the number of solar panels (Figure 1). Solar panels, a tracking structure, a submersible pump, a controller and pipes are required to install a SIP (World Bank, 2018). Table 2 lists the components of a typical solar irrigation pump.

Solar panels account for around 45% of the total cost of a SIP while installation and pump costs account for 18% and 16% of the total cost, respectively (Hossain *et al.*, 2015).

Table 1: Comparison of energy options of a pump

Energy Source	Estimated Capital Cost ($/W)	Operation Cost ($/kWh)	Maintenance
PV system (solar)	6.8	None	Low
Grid electricity	22	0.05–0.13	Low
Gasoline generator	2.5	0.60	High

Source: Meah *et al.* (2008)

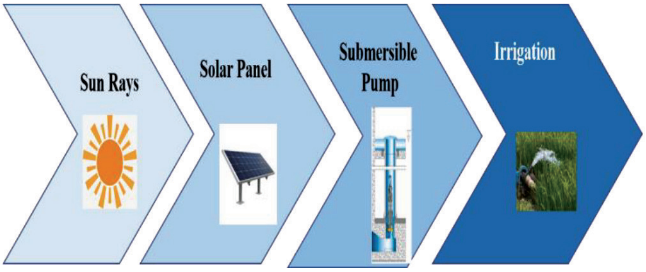

Figure 1: Features of a Solar Irrigation Pump (Islam & Hossain, 2022)

Table 2: System components of a small SIP

Sr. No.	Description	Quantity
1	Solar modules/panels 100 Wp	35
2	Array tracking structure	1
3	Submersible pump 3 HP	1
4	Motor/pump controller	1
5	Installation kit	1
6	2″HDPE pipe (meter)	10

Source: World Bank, Solar Pumping the Basics (2018), (World Bank, 2018)

In Bangladesh, Rahimafrooz Renewable Energy Limited, Electro Solar Power Limited and others are now manufacturing solar panels and submersible pumps. As a result, the total investment cost of SIP is expected to fall daily. The system components of DIP and GIP are similar to SIP except for the solar panels. In detail, this study calculated the life cycle cost (LCC) of solar, diesel and grid-connected irrigation pumps.

Life Cycle Cost (LCC) Analysis

Life cycle cost estimates how much money would be spent on an asset throughout its life span. LCC of an asset includes all expenditures associated with it from purchase to disposal. The main LCC components are planning, design, construction, operations, maintenance, renewal and replacement. This study compared the LCCs of small irrigation pumps powered by solar, grid electricity and diesel. The cost of the pumps has been gathered for this purpose from two agroecological districts, Dinajpur and Rangpur Bangladesh. Information from these two districts has been collected from 15 small pumps (5 solar, 5 diesels and 5 electric pumps) from Birganj and Badarganj Upazilas. The installation and maintenance expenses are practically similar for the small pumps. Therefore, it was unnecessary to visit more pumps to get cost information.

In LCC analysis, all costs are converted to present value by considering the inflation and discount rate during the entire life of an investment. All future costs (C) of the pumps are transformed into present value using the discount rate and relative inflation rate as follows (Santra *et al.*, 2016):

$$\text{PV} = C\left[\frac{(1+r)}{(1+i)}\right]^{n} \qquad \textbf{(1)}$$

PV is the present value of any future cost (C), ‘r’ is the relative inflation rate, ‘i’ is the discount rate per year and ‘n’ is the time in years. Compared to the general inflation rate, the relative inflation rate (r) accounts for the accelerated increase in the price of a commodity. If the price of any commodity is predicted to rise at the same rate as the general inflation rate, the relative inflation rate will be zero. The discount rate (i) determines the actual value of money in the future and generally ranges between 10% to 12% in most economies in Asia (Zhuang *et al*., 2007). As a result, 10% has been considered as a discount rate in this study. A 10% annual discount rate makes no difference to whether an investor possesses Tk.100 now or Tk.110 after a year. So, a cost of Tk. 110 after one year is worth Tk.100 now. Equation 1 calculates the present value of an expense in the 'n'th year. For multiple future payments, expenditures must be converted to present value for each year and then cumulated. Moreover, annualized life cycle costs (ALCC) of all accessible irrigation sources such as solar, electric and diesel pumps were also calculated for the comparison. For that purpose, annuity factor (AF) was calculated for (n) years of the pump as follows (Santra *et al.*, 2016):

$$\mathrm{AF} = \frac{\frac{1+r}{1+i}-1}{\frac{1+r}{1+i}\left[\left(\frac{1+r}{1+i}\right)^{n}-1\right]} \qquad \textbf{(2)}$$

$$\mathrm{ALCC} = \mathrm{LCC}\times\mathrm{AF} \qquad \textbf{(3)}$$

The LCC of a SIP has been calculated for 20 (n) years because solar panels last at least that long (IRENA, 2022). Furthermore, the SIP has the most extended lifetime among the three pumping systems (Hossain *et al*., 2015). As a result, LCCs for both DIP and GIP have also been calculated for 20 years.

Life Cycle Cost (LCC) Analysis of Solar, Diesel and Grid-connected Irrigation Pump

LCCs of 4 HP solar irrigation pump (SIP), diesel irrigation pump (DIP) and grid-connected irrigation pump (GIP) were calculated in this study. This analysis will be helpful for the comparison of the available energy options for irrigation. Table 3 summarizes the LCCs of 4 HP SIP, DIP and GIP. The table illustrates the pumps' capital, maintenance, replacement and operational costs. A summary of these four types of costs is given below:

Capital Cost of Solar, Diesel and Grid-connected Irrigation Pumps

The one-time spending on land, buildings, construction and equipment required to generate irrigation water is a pump's capital cost. The primary capital cost components for SIP are the costs of solar photovoltaic (PV) panels, DC pumps, mounting structures, accessories and wires. The average solar radiation rate in northern Bangladesh is around 5 kWh/m^2/day (Tanvir *et al.*, 2017) and the average daily sunshine hour is around seven hours without rainy-monsoon season (June to September) (Farukh *et al.*, 2021).

In the rainy season, the need for irrigation is minimal because of the cloud cover. The PV panel's capacity relies on the sunshine hours it receives during the other eight months of the year. Without the rainy season, the average daily radiation level is approximately 690 W/m^2. Because of this, the PV panel size of a SIP is calculated using a factor of 0.69. The PV panel size of a 4 HP SIP was calculated by dividing the pump wattage (4 HP or 2982 w) by 0.69, which is approximately 4300 Wp.

The cost of 4300 Wp PV panels is around Tk.172000 based on the current PV panel price of about Tk.40/Wp. Thus, SIP's total capital cost is approximately Tk.279400, as shown in the first row of Table 3. The main capital cost components of the 4 HP DIP are the diesel engine, boring, pipe and tube well cost and the estimated total capital cost is Tk.41800 for the DIP.

At last, the key capital costs of the GIP are the submersible pump, transformer, connection, pipeline, cables and switchboard expenses. The most crucial capital expenditure for the GIP is establishing an electricity connection in the field site. The total capital cost of a 4 HP GIP is around Tk.112200 (Table 3).

Maintenance Cost of Solar, Diesel and Grid-connected Irrigation Pumps

The repairing and cleaning costs are the most significant maintenance costs, these costs are necessary to keep a pump in good working condition. The maintenance cost is recurring and needs to be spent throughout the pump's life.

Table 3: Life cycle cost of small solar, diesel and grid-connected pumps for 20 years

Components (In Taka)	**Solar Irrigation Pump (4 HP)**		**Diesel-operated Irrigation Pump (4 HP)**		**Grid-connected Irrigation Pump (4 HP)**	
Capital cost (Tk.)	PV panel cost (Tk.40×4300 Wp)	172000	Diesel machine	20000	AC submersible pump cost	20000
	DC pump cost	20000			Transformer	30000
	Mounting structure	40000	Construction of shed	5000	Connection cost (pillar cost)	20000
					Security payment	10000
	Construction of shed	5000			Construction of shed	5000
	Boring cost with pipe	12000	Boring cost with pipe	12000	Boring cost with pipe	12000
	Cables, switchboard, switch, etc.	5000	Tube well cost	1000	Cables, switchboard, switch, etc.	5000
	Miscellaneous (transport, installation, etc.) cost (10% of total cost)	25400	Miscellaneous (transport, installation, etc.) cost (10% of total cost)	3800	Miscellaneous (transport, installation, etc.) cost (10% of total cost)	10200
	Total capital cost	**279400**	Total capital cost	**41800**	Total capital cost	**112200**
Maintenance cost (Tk.)	**23787**		**17793**		**9552**	
Replacement cost (Tk.)	**10515**		**8762**		**10515**	
Operational cost (Tk.)	**0**		**828786**		**164821**	
Life cycle cost (LCC)	**313701**		**897142**		**297088**	
Annualized life cycle cost (ALCC) (Tk.)	**36848**		**105378**		**34896**	

Source: Author's calculation based on field survey data, 2021; **Tk.80 = USD1**

A SIP's annual maintenance cost is considered 1% of its capital cost (Santra *et al.*, 2016; Rule of Thumb, 2022). For 20 years, the cumulative discount factor is 8.51, corresponding to a 10% discount rate and a zero relative inflation rate. Thus, 4 HP SIP's maintenance cost is Tk.23787 during its lifetime. Moreover, the GIP's maintenance cost is similar to SIP, with 1% of the capital cost per year. Thus, a 4 HP GIP has a lifetime maintenance cost of Tk.9552.

The DIP's maintenance cost is projected to be 5% of its capital cost, owing to the machine's frequent breakdowns (about Tk.2090 each year). This annual maintenance cost was multiplied by the cumulative discount factor for 20 years (8.51) to obtain the pump's lifetime maintenance cost of Tk.17793. The maintenance costs are shown in the second row of Table 3.

Replacement Cost of Solar, Diesel and Grid-connected Irrigation Pumps

The replacement cost is necessary as most assets wear out and must be replaced after the expected life period. In this study, the LCCs of SIP, DIP and GIP have been calculated for 20 years. The motor, wire and accessories have a 5 to 10 years life expectancy. Thus, these components must be replaced after a certain period of up to 20 years. At first, in the case of a SIP, the pump needs to be replaced after 10 years of operation and it requires one replacement in the 11th year of its life cycle. The present value of the prospective pump replacement is around Tk.7010.

Moreover, the present value of the shed and cable replacement cost is Tk.3505. Therefore, the total replacement cost of the SIP is Tk.10515. These expenses are listed in the third row of Table 3. Then, diesel engine replacement is the leading replacement cost of a DIP, which typically lasts for ten years. The shed for the DIP also lasts for about ten years. As a result, diesel engine and shed replacement will be required in the 11th year. The present value of the engine and shed replacement cost is roughly Tk.7010 and Tk.1752. Thus, the total replacement cost of the DIP is around Tk.8762. These expenses are listed in the third row of Table 3.

At last, in the case of a GIP, the submersible pump needs to be replaced after ten years of operation and it requires one replacement in the 11th year of the life cycle. The present value of the eventual pump replacement is around Tk.7010. Moreover, the present value of the shed and cable replacement cost in the 11th year is about Tk.3505. Hence, the total replacement cost of the GIP is almost Tk.10515. These costs are also shown in the third row of Table 3.

Operational Costs of Solar, Diesel and Grid-connected Pumps

Operational costs are the costs involved with the operation of a machine and the main operational cost of irrigation pumps is the fuel cost. All three types of irrigation pumps operate for a minimum of six hours from morning to afternoon every day for around 180 days per year. The SIP has a minimal operating cost because it is powered entirely by solar radiation. On the other hand, the overall operational cost of DIP and GIP is proportionate to the consumed amount of diesel and electricity. Furthermore, the owners operate all small pumps in the study areas. As a result, there is no need to hire an operator to operate the irrigation pump.

The operational cost of the DIP was calculated using a few assumptions such as the diesel engine's conversion efficiency into dynamic energy usually is about 30% and diesel has a calorific value of roughly 10.7 kWh per litre. Thus, the diesel pump's energy generation capacity is approximately 3.2 kWh per litre. Furthermore, operating a 4 HP pump for an hour consumes 3 kilowatts of energy as 1 HP is about 750 watts. According to the field survey, the pump operates approximately six hours daily and 180 days a year. Therefore, the daily and annual energy demands will be around 18 kWh and 3,240 kWh, respectively and to meet the daily and yearly energy demands, about 5.6 litres and 1,012 litres of diesel are required. Moreover, 1,012 litre diesel's annual cost was about Tk.64768, as the market price of 1 litre was Tk.64 during the field survey period (2021). Further, the relative inflation rate (r) for diesel is assumed at 5% since fossil fuel is becoming scarce. The discount rate (i) was set at 10%, resulting in a discount factor of 12.72 over 20 years. By multiplying the yearly cost and the discount factor, the total operational cost (primarily diesel and lubricant cost) of the DIP for 20 years was around Tk.828786.

In the case of a GIP, the main operational expense is the electricity cost. The electricity tariff is projected to rise faster than the general inflation rate due to the scarcity of conventional energy sources. When computing the overall operational cost for 20 years, the relative inflation rate (r) for electricity tariffs and the discount rate (i) was set at 5% and 10%. Thus, the discount factor has been computed as 12.72 for the GIP, similar to the DIP. Furthermore, a 4 HP motor that runs for an hour consumes 3 kWh of electricity, as 1 HP is around 750 watts. According to the field survey, the electric pump runs around six hours per day, 180 days per year, resulting in daily and annual consumption of 18 kWh and 3,240 kWh of electricity, respectively. Because the electricity tariff for irrigation is Tk.4/kWh (BERC, 2022), the annual cost of the consumed electricity is around Tk.12960. Moreover, by multiplying the annual cost of electricity by the discount factor (12.72), the total operational cost for the GIP over 20 years is estimated to be around Tk.164821.

Discussion

Table 3 shows the life cycle cost (LCC) and annualized life cycle cost (ALCC) of 4 HP solar (SIP), diesel (DIP) and grid-connected irrigation pumps (GIP). LCCs for a 4 HP SIP, DIP and GIP are at Tk.313701, Tk.828786 and Tk.297088, respectively. The LCCs have been converted to annualized life cycle costs (ALCCs), which was done by dividing them with a cumulated discount factor (8.51) for 20 years. The ALCCs for the SIP, DIP and GIP are Tk.36848, Tk.105378 and Tk.34896. The LCC and ALCC have been illustrated in the fifth and sixth rows of Table 3. The analysis revealed that the ALCC of the SIP is lower than the DIP but marginally higher than the GIP.

The lowest ALCC has been found for the GIP because Bangladesh Energy Regulatory Commission (BERC) fixed the lowest electricity tariff rate for irrigation at Tk.4/kWh. However, the average retail electricity tariff rate for other sectors is Tk.7.10/kWh (BERC, 2022). The electricity tariff subsidy for irrigation makes the lowest ALCC for the GIP.

However, the tariff rate would be regularly increased in the future because of the scarcity of conventional energy sources (BPDB, 2022). On the other hand, the operational cost of the solar pump will always remain almost zero (Gambone, 2022). Moreover, due to constant research and development, the PV panel's price has been reduced by 12 times from 2010 to 2020 (Zachary Shahan, 2022). As a result, solar irrigation has great potential in the country's agriculture sector. Furthermore, the ALCC of the DIP was determined to be Tk.105378, more than 2.5 times that of the SIP. Thus, replacing DIPs with SIPs can substantially reduce the farmers' irrigation costs.

Conclusion

This study calculates the life cycle cost (LCC) and annualized life cycle cost (ALCC) of 4 HP solar, diesel and grid-connected irrigation pumps. The calculated LCCs of SIP, DIP and GIP are about Tk.313701, Tk.828786 and Tk.297088. Moreover, the ALCC for the SIP, DIP and GIP are almost Tk.36848, Tk.105378 and Tk.34896, respectively. The ALCC analysis indicates that the cheapest option for irrigation is GIP while the most expensive alternative is a DIP. GIP has the lowest ALCC because Bangladesh Energy Regulatory Commission (BERC) fixed the lowest electricity tariff rate for irrigation at Tk.4/kWh. However, the average retail electricity tariff rate for other sectors is Tk.7.10/kWh.

Finally, the ALCC of a DIP is more than 2.5 times higher than a SIP. As a result, replacing DIPs with SIPs can substantially reduce farmers' irrigation expenditures. That is why as many DIPs as possible should be replaced with SIPs first. GIPs will also be phased out in the future as the electricity price is projected to climb regularly due to the continuing depletion of fossil resources. On the other hand, the SIP has almost zero operating costs because it is powered by solar radiation. Additionally, for continuous research and development, solar panels' price has decreased by 12 times in the previous decade (Zachary Shahan, 2022). As a result, solar irrigation pumps contribute significantly to the country's agricultural sector. The government should take a proactive approach and give incentives to encourage the widespread adoption of SIPs. In this context, rigorous cost-benefit and environmental impact evaluations of SIPs in the future will help in determining SIPs actual economic viability.

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