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Research Article

"Economic Viability of Solar Irrigation Pumps: A Comparative Life Cycle Cost Analysis with Diesel and Electric Pumps"

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ARTICLE INFO	ABSTRACT
	In the present scenario economic viability of an irrigation pump is of extreme significance to set up it and get the sought after output in a more economic and better way. In this study investigation has been done about the economic viability of solar irrigation pump against the diesel and electric irrigation pump through the life cycle cost analysis. In LCC analysis, capital cost, future maintenance cost and replacement cost are converted to present worth value considering inflation rate and discount rate during its total life cycle. Annualized life cycle cost (ALCC) of solar irrigation pump has been further compared with grid connected electric and diesel irrigation pump. The results revealed that the annualized life cycle cost (ALCC) of solar irrigation pump is lower than grid connected electric and diesel irrigation pump. E.g., The ALCC of solar irrigation pump was estimated at 12383/year and 15435/year for 3 HP and 5 HP pump respectively, which is significantly leave behind electric pumps, which boast ALCC figures of 61641/year and 82371/year for 3 HP and 5 HP pumps. In the same way, when related to diesel irrigation pumps with ALCC values of 85891/year and 136088/year for 3 HP and 5 HP pumps respectively, the economic superiority of solar irrigation pumps becomes abundantly clear. . It has also been observed that the capital cost for solar irrigation pump is higher than grid connected electric and diesel irrigation pump. However, the maintenance cost and replacement cost are lower in case of solar. The comparison shows that the solar irrigation pump was more economic viable than the grid connected electric and diesel irrigation pump.

1. Introduction

In the tracking down of sustainable agricultural live out in the middle of emergent global challenges such as climate change and resource inadequacy, the choice of irrigation systems holds vital significance. As agriculture remains a foundation of economies worldwide, efficient water management through irrigation is essential for ensuring food security and livelihoods for millions. In this context, the comparative analysis of irrigation pump systems emerges as an important way for understanding the economic and environmental consequences of different technologies.

This study embarks on a comparative analysis of three primary irrigation pump systems: solar, diesel, and electric, take on a life cycle cost (LCC) perspective. The use of LCC methodology allows for a comprehensive assessment of the economic implications related with every system over their whole lifespan, encompassing capital cost, operational costs, and maintenance costs.

The importance of this study lies in its would-be to notify decision-makers, agricultural practitioners, and policymakers about the most economically viable and sustainable irrigation pump options. By evaluating the life cycle costs of solar, diesel, and electric irrigation pumps, this study objective to provide actionable discernments that endorse efficient resource utilization, economic prosperity, and environmental sustainability in agricultural practices.

To frame this argument efficiently, it is vital to explore the existing form of literature on irrigation pump systems, their economic aspects, and their environmental impacts. Thus, this introduction draws upon a diverse range of scholarly sources to found a tough ground for thoughtful the involvedness of the theme.

The transition towards sustainable irrigation methods, principally in agriculture, has lay down substantial consideration from researchers and policymakers worldwide. Solar irrigation pumps, for case in point, have increased traction due to their likely to harness renewable energy and decrease greenhouse gas emissions related with conventional pumping technologies (Chandel, S., Naik, M. N., & Chandel, R. 2015; Cui, S., Wu, M., Huang, X., Wang, X., & Cao, X. 2022).Studies have highlighted the economic benefits and environmental benefits of solar irrigation pumps, emphasizing their role in increasing agricultural productivity although moderating climate change impacts (Mudgal, V., Reddy, K. S., & Mallick, T. K. (2019).

On the contrary, diesel irrigation pumps, in spite of their general use in many agricultural perspectives, carriage important challenges in terms of operational costs, fuel dependency, and environmental contamination (Kumar, M., & Kumar, A. (2019); Kumar, A., Patel, R., & Yadav, A. (2022). Research shows that the life cycle costs of diesel pumps can be significant, considering fuel expenses, maintenance requirements, and associated environmental externalities (Armanuos, A. M., Negm, A., & Tahan, A. H. M. E. (2016).

Electric irrigation pumps, drawing power from the grid, epitomize a different prominent choice in agricultural water management. While electric pumps offer reliability and consistent power supply, their operational costs and dependence on grid infrastructure carriage challenges, mainly in isolated or off-grid agricultural regions (Lal, S. (2013).

By combining results from earlier research, this study aims to underwrite to the existing body of knowledge on irrigation pumps life cycle costs and sustainability effects. Through a comparative analysis of solar, diesel, and electric irrigation pumps, it seek out to offer nuanced insights that can guide participants in making informed decisions about irrigation infrastructure investments and resource allocation policies.

2. Methodology

The economic viability of solar energy has been evaluated through Life Cycle Cost Analysis and Annualized Life Cycle Cost Analysis.

2.1 Life Cycle Cost

Life Cycle Cost (LCC) analysis offers an inclusive method to calculating the economic implications of irrigation pump all through their working lifespan. This analysis includes four main cost components: Total Capital Cost, Maintenance Costs, Replacement Costs of AC Pump, and Replacement Costs of Inverter, and operating costs of the pump.

Life Cycle Cost can be expressed mathematically as:

$$\mathbf{LCC = C_{TCC} + C_{LMC} + C_{RC} + C_{RI} + C_{OP}} \quad \text{..........................}\textbf{Eq.1}$$

Where,

C_{TCC} = Total Capital Cost

C_{LMC} =Discounted Lifetime Maintenance Cost

C_{RC} = Discounted Replacement Cost of AC pump

C_{RI} = Discounted Replacement Cost of Inverter

C_{OP} = Operating costs

In the above life cycle cost equation 1,

2.1.1 Total Capital Cost (C_{TCC})

In case of solar irrigation pump, the total capital cost of solar pump includes the amount paid by beneficiary to Department of Renewable Energy Haryana. It is calculated as:

C_{TCC} = L1 Rate for Haryana + GST - MNRE Share - State Share

Or

C_{TCC} = L1 Rate for Haryana + GST – Total Subsidy

GST = 13.8 % and MNRE Share = 30% of Cost

Total Subsidy = MNRE share + State share

In case of electric irrigation pump, the total capital cost includes two main cost components; i) Cost of AC pump, and ii) Cost of Electric Connection at field (include the installation costs)

Similarly in the case of Diesel irrigation pump, the capital cost taken market price of diesel engine in which merged other installation costs.

2.1.2 Discounted Lifetime Maintenance Cost (C_{LMC})

The lifetime maintenance cost accounts for variable costs which occurring during the working lifespan of a pump. It was assumed 1% of total capital cost per year. Discounted lifetime maintenance cost calculated as:

$C_{LMC} = \sum_{t=1}^{n} \frac{MCt}{(1+d)t}$

Where,
MC = Maintenance cost (1% of C_{TCC} per year)
n = time period (years)
t = thyear
d = discount rate was assumed @10%

2.1.3 Replacement Cost of AC Pump

It was scheduled that the solar irrigation pump needs to replacement of AC pump for two times in its life cycle; once is after 8 years and again after 16th year of its operation as well as electric irrigation pump. Similarly in case of diesel engine, it's usually perceived to work optimally for a span of around 6 to 7 years. Hence, over its life cycle of 25 years, three replacements are needed to endure its functionality. To account for these future replacement costs at the 6th, 12th, and 18th years from its setting up, a calculation was performed to determine their present value (Santra, et al., 2016). Therefore, the discount factor was calculated to estimate the present worth of these replacement costs, using the formula and assuming a discount rate of 10%.

Formula of Discount Factor as:

Discount factor = $\frac{1}{(1+d)t}$

Where,
d = discount rate
t = nth year
So discounted replacement cost of AC pump for 8th and 16th year as:
Present Cost of AC pump × Discount Factor

2.1.4 Replacement Cost of Invertor

It was scheduled that the solar pump needs to replacement of invertor for two times in its life cycle; once is after 10 year and again 20th year of its operation. Therefore, the discount factor for both years was calculated using the formula and considering the discount rate of 10% (Santra, et al., 2016).
So discounted replacement cost of Invertor for 10th and 20th year as:
= Present Cost of Invertor × Discount Factor

2.1.5 Operating Cost

In case of electric irrigation pumps, the operational cost was determined by combining the average energy charge of 6.62/kWh with MMC of Rs. 200 per brake horsepower (BHP), escalating price assumed at 5% per year. This cost estimation is assumed on an average operational duration of 6 hours daily across 200 days annually (Santra, et al., 2016).

Similarly For diesel irrigation pumps, the operational cost was calculated based on specific parameters. The average annual usage was assumed to be 200 days, with each day consist of 6 hours of operation. The energy value of diesel was recognized at around 10.5 kWh per liter. Diesel pump efficiency sorts from 30% to 35%, resulting in energy generation of about 3.4 kWh per liter (Santra, et al., 2016). As of February 10th, 2024, the diesel price in Jind, Haryana put up at 90 per liter.

2.2 Annualized Life Cycle Cost

Annualized Life Cycle Cost of solar pump was also calculated. An annuity factor was calculated for a period of life cycle of the pump to calculate the annuity of total cost as follows:

$AF = \{\frac{\frac{1+i}{1+d}-1}{\frac{1+i}{1+d}}\left[\frac{1+i}{1+d}-1\right]\}$

Where,
AF = Annuity Factor
i = Inflation Rate
d = Discount Rate
Annualized Life Cycle Cost = Total Life Cycle Cost × AF

3. Results and Discussion

3.1 Solar Irrigation Pump

3.1.1 Capita Cost of Solar Irrigation Pump

The capital cost of a solar pump system is the sum of miscellaneous costs including PV panels, AC pump motor, inverter, mounting structure, various accessories/equipment cables and profits of empanelment agency. Life cycle costs for 3 HP and 5 HP. The HAREDA provides these under the PM-KUSUM scheme. The capital cost of solar pump of various capacities to farmers after the subsidy provided by MNRE at 30% of the total cost and state's share at the rate of about 40% as follows:

Table: 1 Capital Cost of Solar Irrigation Pump

S.No	Parameter	3 HP	5 HP
1.	L1 Rate for Haryana	1,79,500	2,47,000
2.	GST @ 13.8%	24771	34086
3.	Total Coat	204271	281086
4.	MNRE share	56774	80099
5.	State Share	81680	116247
6.	Farmers Share	65817	84740

Source: HAREDA, 2022-23.

Table 1 show that the total cost of solar pump with capacities of 3 HP and 5 HP is Rs. 2, 04,271 and Rs. 2, 81,086 respectively, which include 13.8% Goods and Services Tax (GST). After the subsidy provide by Ministry of New and Renewable Energy (MNRE) at 30% and state's share is about 40% of the total cost. The capital cost of solar pumps of 3 HP and 5 HP was Rs. 65,817 and Rs. 84,740 respectively which are approximately 30% of total cost. The initial capital cost of solar pump is very high for farmers.

3.1.2 Maintenance and Replacement cost of Solar Irrigation Pump

Life maintenance cost of solar pump is considered 1% of total cost. It is a provision for various costs regarding the items can be expected to include bearings, coupling wear, seals, valve, impeller, port wear, motor features and some other items that make the complete system. The nature of maintenance cost is recurring and need to be spent throughout the whole life of the pump. Thus the discounted maintenance cost calculated to a discount rate of 10% and relative rate of inflation of zero for each year and sum of all the costs for 25 years getting lifetime maintenance cost of the pump. It is also consider that the AC pump motor of solar pump system needs to be changed after 8 years of its installation and thus needs replacement for two times in its whole life; once at 8^{th} year and again at 16^{th} year. Therefore, the discount factor for both years is 0.47 and 0.22 respectively and considering the discount rate of 10% and relative rate of inflation of zero. Similarly, the replacement cost for inverter of solar pump at 10^{th} and 20^{th} year of its operational life. Therefore, the discount factor for both years is 0.38 and 0.14 respectively and considering the discount rate of 10% and relative rate of inflation of zero (Table 2).

Table: 2 Maintenance and Replacement cost

S.No	Parameter	3 HP	5 HP
1.	Lifetime maintenance cost (1% of the capital cost)	18541.76	25514.29
2.	Replacement cost of AC pump (at 8th year and 16th year)	23414.57	25261.74
3.	Replacement cost of inverter (at 10th year and 20th year)	4807.682	4807.682

The maintenance cost occurring during the whole life of a 3 HP and 5 HP was found Rs. 18541.76 and Rs. 25514.29 respectively. The replacement cost of AC pump motor for 3 HP and 5 HP was found Rs. 23414.57 and Rs. 25261.74 respectively. The replacement cost of inverter for 3 HP and 5 HP was found Rs. 4807.682 and Rs. 4807.682 respectively.

3.1.3 Life Cycle Cost of Solar Irrigation Pump

The life cycle cost is sum of capital cost, lifetime maintenance cost, replacement cost of AC pump motor and replacement cost of inverter.

Table: 3 Life Cycle Cost of Solar Irrigation Pump

S.No.	Parameters	Solar Pump Capacity (DC Surface Pump)	
		3 HP	5 HP
1.	Benchmark Cost	179500	247000
2.	GST@13.8%	24771	34086
3.	Total Cost	204271	281086
4.	MNRE Share@30%	56774	80099
5.	State Share	81680	116247
6.	Farmers Share	65817	84740

7.	**Total Initial Capital Cost for Farmers**	65817	84740
8.	Lifetime maintenance cost (1% of the capital cost)	18541.76	25514.29
9.	Replacement cost of AC pump (at 8th year and 16th year)	23414.57	25261.74
10.	Replacement cost of inverter (at 10th year and 20th year)	4807.682	4807.682
11.	Total life cycle cost for farmers	112581	140323
12.	ALCC	12383.91	15435.61

Total life cycle cost for 3 HP and 5 HP was found Rs. 1,12,581 and Rs. 1,40,323 respectively. It is clear from above Table 3 that the initial cost of installation of solar pump of mentioned capacity was very high and the subsidy was given by the MNRE and state share was very high.

3.2 Grid-Connected Electricity Irrigation Pump

3.2.1 Capital cost of electric irrigation pump

Capital cost of an electric irrigation is mainly sum of cost of electric connection on field and AC pump cost. Normally, it's noted that rural areas undergo from a significant distance between their field sites and the nearest electric grid connection. Subsequently, covering the existing infrastructure to reach these sites becomes vital, requiring an initial investment. As well, farmers are burdened with the costs associated with obtaining a new electric connection and buying an AC pumping system. Considering these costs, the total cost of a 3 HP and 5 HP electric irrigation pumps was estimated 249201 and 256326 respectively, representing the capital cost for the farmers (Table 4).

Table: 4 Capital cost of electric irrigation pump

S.No	Parameter	3 HP	5 HP
1.	AC pump Cost	20600	27500
2.	Electric Connection Cost at field	228601	228826
3.	Total Capital Cost	249201	256326

3.2.2 Maintenance, replacement and operating cost of electric irrigation pump

Table 5 show that the Maintenance costs for electric irrigation pump was estimated like the maintenance cost of solar irrigation pump, which was 1% of the capital cost per year and it was estimated 22390 and 23046 respectively for 3 HP and 5 HP pumps. Replacement cost of AC pump was also was estimated like the cost for replacement of pumps in a solar irrigation pump.

Replacement cost of AC pump was also considered similar with the cost for replacement of pumps in a solar PV pumping system. The operational cost of an electrified pumping system is the cost towards electric energy consumption from grid with an average tariff of an average energy charge of Rs. 6.62/kWh + MMC 200/BHP/yrs with escalated price of 5% and average hours of operation in a year is 6 hours per day for 200 days. Since the conventional source of energy is becoming scarce, it is expected that the energy tariff will be increased at a faster rate than the general inflation rate. Relative rate of inflation for energy tariff was considered 5% while calculating the total operational cost in its life cycle. The discount rate was considered 10% as similar with other cases. Calculation as per above considerations led to an operational cost of 267079 for 3 HP pumping system and 445129 for 5 HP pumping system.

Table: 5 Maintenance, replacement and operating cost of electric irrigation pump

S.No	Parameter	3 HP	5 HP
1.	Lifetime maintenance cost (1% of the capital cost)	22390	23046
2.	Replacement cost of AC pump (at 8th year and 16th year)	21,700	24,150
3.	Operational cost (Average energy charge @ 6.62/kWh + MMC 200/BHP/yrs with escalated price of 5% and average hours of operation in a year is 6 hours per day for 200 days)	267079	445129

3.2.3 Life cycle cost of electrified pumps for irrigation

Life cycle cost of electric irrigation pump is presented in the Table 6. Calculation the capital cost, maintenance cost, replacement cost and operating cost lead to an annualized life cycle cost of 61641/yrs for 3 HP electric irrigation pump, which is higher by 12383 per year than the ALCC for 3 HP solar irrigation pump.

When the 5 HP pump were compared, ALCC was found very higher for electric irrigation pump 82371 per year and solar irrigation pump 15435 per year.

Table: 6 Life cycle cost of electrified pumps for irrigation

S.No.	Parameters	Electrified Pump	
		3 HP	5 HP
1.	Life cycle/span	25 yrs	25 yrs
2.	AC pump Cost	20600	27500
	Electric Connection Cost at field	228601	228826
	Total Capital Cost	249201	256326
3.	**Total Initial Capital Cost for Farmers**	249201	256326
4.	Lifetime maintenance cost (1% of the capital cost)	22390	23046
5.	Replacement cost of AC pump (at 8th year and 16th year)	21,700	24,150
6.	Operational cost*	267079	445129
7.	Total life cycle cost	5,60,369	748825
8.	Annualized life cycle cost	61641 /yrs	82371 /yrs

*Average energy charge @ 6.62/kWh + MMC 200/BHP/yrs with escalated price of 5% and average hours of operation in a year is 6 hours per day for 200 days.

3.3 Diesel Irrigation Pump

3.3.1 Capital cost of Diesel Irrigation Pump

The capital cost for establishing a diesel irrigation pump sum of the cost for diesel engine and for the provision to lift water form a well, which was estimated about 60000 for 3 HP and 70000 for 5 HP pump (Table 7).

3.3.2 Maintenance and Operating cost of Diesel Irrigation Pump

Maintenance cost for diesel irrigation pump was estimated as uniform rate of 1% of capital cost per year, which was found about Rs. 600 and 700 per year for 3 HP and 5 HP respectively. Since a discount rate of 10% and relative rate of inflation of zero, discount factor for respective years was calculated, which was multiplied with annual maintenance cost so obtain the lifetime maintenance cost of 5390 for a 3 HP pump and 6289 for a 5 HP pump. A diesel pump usually carry out optimally for a period of about 6-7 years and consequently three replacements will be required in its life cycle of 25 years. Calculation of these future replacement costs at 6th, 12th and 18th year of its establishing to the present value lead to in total replacement cost of 63,600 and 74,200 for 3 HP and 5 HP pump, in turn. Although computing the operational cost of diesel irrigation pump, few assumptions were made. Bearing in mind the high in calories value of diesel as 10.5 kWh per litre and diesel engine efficiency of 30-35%, the energy generation capacity by a diesel pump was calculated as 3.4 kWh per litre of diesel. With this value, diesel consumption per year was considered for an average operation of 6 hours per day and 200 days per year. As well, the relative rate of inflation for diesel was assumed as 5%, since this fossil fuel is becoming infrequent and increased price in future is likely. Discount rate was well thought-out 10%. As a result, the total operational cost was found 651841 for 3 HP diesel pumping system and 1086677 for 5 HP diesel irrigation pump in its life cycle of 25 years (Table 7).

Table: 7 Life cycle cost of Diesel Irrigation Pump

S.No.	**Parameters**	**Diesel Pump**	
		3 HP system	**5 HP system**
1.	Life Cycle/Span	25 yrs	25 yrs
2.	Capital cost	60,000	70,000
3.	Maintenance cost (1% of capital cost)	5390	6289
4.	Replacement cost of diesel (at 6th, 12th and 18th year)	63,600	74,200
5.	Operational cost**	651841	1086677
6.	Life cycle cost (LCC)	7,80,831	12,37,166
7.	Annualized life cycle cost (ALCC)	85891/year	136088/year

** Average use of diesel pump in a year for irrigation = 200 days × 6 hrs per day; Diesel price at Jind, Haryana as on 10th February 2024 = 90 per litre; Energy value of diesel = 10.5 kWh per litre; Diesel pump efficiency = 30-35%; Energy generation by diesel pump = 3.4 kWh per litre.

3.3.3 Life Cycle Cost of Diesel Irrigation Pump

Table 7 interpret the Component costs of diesel irrigation pump are given in Table. The ALCC for 3 HP and 5 HP diesel irrigation pump were found as 85891/year and 136088/year, in turn. As compared to ALCC for solar irrigation pump and even to electric irrigation pump, it is to a certain extent higher.

4. Conclusion

In the domain of agricultural sustainability, solar irrigation pumps have arose as a vital solution, particularly in Haryana. Widespread steps have been taken in this domain, showing a likely course for the region's agricultural energy security. Through meticulous study and analysis, it has been explicitly established that solar irrigation pumps offer superior effectiveness and economic viability compared to their diesel and electric irrigation pump. The annualized life cycle costs (ALCC) further emphasize the benefits of solar irrigation pumps. With ALCC estimated at 12383/year and 15435/year for 3 HP and 5 HP pump respectively, solar irrigation pumps significantly leave behind electric pumps, which boast ALCC figures of 61641/year and 82371/year for 3 HP and 5 HP pumps. In the same way, when related to diesel irrigation pumps with ALCC values of 85891/year and 136088/year for 3 HP and 5 HP pumps respectively, the economic superiority of solar pumps becomes abundantly clear. Given the indubitable benefits and remarkably lower life cycle costs, it is evident that solar irrigation pumps will duly arise as the preferred choice among farmers for crop irrigation. This shift in the direction of solar energy promises not only economic advantages but also contributes considerably to sustainable agricultural live out in the state.

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