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Environmental Benefits of using Solar Photovoltaic Power based Micro-irrigation System in Vegetable Cultivation: A Case Study

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ABSTRACT: One aspect of achieving sustainability in any human related activity is to look into the environment-friendliness against the emission of the greenhouse gases. The present study focusses and reveals the environmental benefits of using solar photovoltaic power for water pumping in the irrigation sector for the warm and humid climatic conditions. The environmental benefits of a small capacity (1 hp) directly coupled DC solar PV water pump have been studied for growing vegetables in an area of 1 acre with the integration of drip system. The system would be capable of replacing the current use of electric and diesel pump sets with the mitigation of emitting CO_2 in the irrigation sector. It is estimated that total annual CO_2 emissions can be mitigated in the tune of 70×10^7 kg by replacing the existing electric (2.00 lakhs) and diesel (3.00 lakhs) pump sets in the state of Odisha, India. Pay-back period of the developed set up was estimated to be only 1 year causing its easy acceptance among the small and marginal farmers despite high initial investment. The promotion of this technology would not only achieve assured water availability to the crops with improved water use efficiency measures by drip irrigation system in comparison to the usual practice of flooded method of irrigation but also protect the environment against the release of greenhouse gases and noise pollution by the use of rising electric and diesel pump sets in the state of Odisha.

Keywords: Solar photovoltaic water pumping system, Micro-irrigation, Drip irrigation, Vegetable cultivation, Greenhouse gases.

INTRODUCTION

Water pumping activities for irrigation purposes are at present widely undertaken in India by employing electric and diesel pump sets in the agricultural sector. The increasing price and uneven distribution of both diesel fuel and electric power from the non-renewable energy sources and their adverse effects have diverted the attention of researchers, policy makers and planners to go for using solar photovoltaic water pumps (SPVWP) for their promotion in a cost effective and sustainable way (Meah *et al.,* 2018). The source of energy to power the SPVWP is from the solar radiation which is reliably and abundantly available in the tropical country like India. Being a tropical country, there is the availability of about 300 clear sunny days in a year with the variations of solar insolation from 4-7 kWh/m^2/day in India depending upon the locations (Chandela *et al.,* 2017). Solar PV powered water pump has been proved to be technically feasible and economically viable particularly for small scale applications in the irrigation sector for vegetable cultivation (Badra, 2018). Moreover, solar PV water pumping system has been proved to be favourable to the environment with respect to emissions, requires very little maintenance and no cost involvement for the fuel (Chandel *et al.*, 2015). Hence, the present concerns of environmental protection and sustainable development have diverted the attention of using solar PV water pump because of vast potential to power water pumps using solar energy. The only difference in the use of solar pump lies with the source of power (solar energy) while the other components remain same as the conventional water pumps. Long-term benefits with respect to savings in cost are obtained from the PV system compared to the conventional pumping systems. Solar water pumps have been suggested by many researchers in the globe in order to fulfil the demands of energy and to curtail the environmental emissions in the agricultural sector (Gopal *et al.*, 2013). The total expenditures in installing a solar PV water pump lie in the cost of modules, pumps, inverters, pipes and electrical cables. The panels in the solar water pump involve higher cost compared to the other energy generating devices, such as diesel engines and electrical motors. On the other hand, a solar water pump does not require running costs throughout its life but to meet the maintenance cost which is very low (Ghosal *et al.*, 2020). In contrast, diesel powered and the grid connected water pumping systems require high running and maintenance costs. After the payback period, the solar water pump runs without a running cost. Solar PV water pumps have been considered to be the most viable choice for remote areas as compared to the diesel powered and grid connected systems due to shortage and erratic availability of electricity in those locations (Leah *et al.,* 2010). The future expansion of solar PV water pumps can be possible due to its easy installation and use, high reliability, durability and modular in nature. Installation of solar water pumps at the site of use avoids the spread of long pipelines and infrastructures (Khatib 2010). From an environmental stand point, the photovoltaic system can be replaced with the non-renewable fuel based electricity to offer significant benefits with respect to the mitigation of carbon dioxide (Sontake and Kalamkar 2016). Moreover, the photovoltaic electricity is attractive due to non-polluting in nature, free availability and is of high reliability (Narale *et al.,* 2013). During the operation of solar PV system, no harmful substance is emitted resulting into the favourable conditions both for the human health and environment. By the way, the conventional electricity is saved causing significant reduction in the emission. In India, the electricity is usually generated through coal based thermal power plant in which a lot of greenhouse gases are being released to the environment (Mahmoud and Munzer 2015). The use of fossil fuel in the diesel pump also emits carbon dioxide to the environment. Hence, one approach to reduce the emission of greenhouse gas (CO_2) is for using solar PV water pump (Ghosal *et al.*, 2020). The study focusses on the comparative environmental benefits of using SPVWPS against the existing diesel and electric pumps in the irrigation sector for small scale applications. Emphasis has been given on the affordable and low capacity solar PV operated submersible water pumps for the irrigation of small farmlands.

Experimental site. The performance evaluation of solar PV water pump was conducted in the warm and humid climatic conditions of Odisha during January 2108 to May 2018 at the location of 20.29ºN latitude and 85. 82ºE longitude and at an elevation of 25.9 m above mean sea level. The place under study also receives a good amount of solar radiation for about 4-5 hours in a day over a period of nearly 300 days in a year (Solar Policy 2013, Govt. of Odisha). The field of 1-acre (0.4 ha) area was developed by installing solar water pump (1 hp capacity) in the bore well existing 30 m away from the experimental plot and laying drip irrigation lateral pipes with the inbuilt inline drippers of 1.2 lph capacity with a spacing of 0.4 m. One electric pump of same capacity was also present in the campus. The performance of both solar PV and grid-tied electric pumps has been compared. Tomato (Utkal Kumari, BT-10) was cultivated both in rabi and summer season. A submersible DC solar pump was placed inside the bore well at the depth of 150 feet (45 m). The layout of the experimental study is shown in Fig. 1.

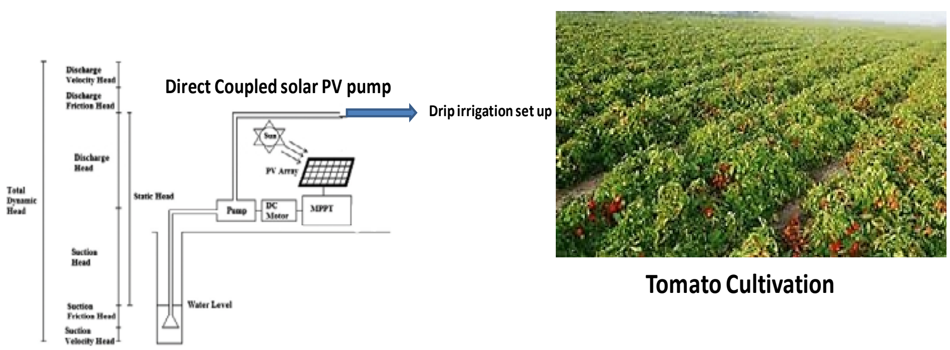

Fig. 1. Layout of the experimental study for solar PV water pumping based drip irrigation system in tomato cultivation.

Table 1: Cost of Experimental Solar Photovoltaic Powered Drip Irrigation System.

Sr. No.	Item	Price (Rs.)
1.	Solar PV panel (3 × 300 W_p) = 900 watt @ Rs. 45 per W_p	40,500
2.	MPPT based charge controller (8.85 A)	6000
3.	1.0 hp submersible DC solar water pump	70,000
4.	Drip irrigation set up for 1-acre land	1,00,000
5.	Pipes, fittings, wiring etc.	3500
Total		**2,20,000**

Table 2: Hourly Cost of Operation of Various Water Pumping Devices.

Information for economic evaluation of the devices

Sr. No.	Parameters	Information
1.	1 hp electric pump set cost	Rs. 8,000
2.	1 hp diesel pump set cost	Rs. 12,000
3.	1 hp PV powered pump set with drip irrigation system cost	Rs. 2,20,000
4.	Prevailing interest rate	10%
5.	Motor efficiency (70-80 %)	75 % assumed
6.	Pump efficiency (70-80 %)	75 % assumed
7.	Diesel engine efficiency (30-40 %)	40 % assumed
8.	PV panel useful life (20-25 years)	22 years
9.	Diesel engine pump set useful life	8 years
10.	Electric pump set useful life	8 years
11.	PV system with drip maintenance	0.5 % of capital cost per year
12.	Diesel engine pump set maintenance	10 % of capital cost per year
13.	Electric pump set maintenance	10 % of capital cost per year
14.	Working hours of electric, diesel pump set and PV system	500 hours/year
15.	Fuel consumption of diesel engine	250 ml. per hour per hp
16.	Diesel fuel present price	Rs. 100/lit
17.	Prevailing tariff of electric energy	Rs. 5.00 per unit
18.	Diesel pump set salvage value	20 % of capital cost
19.	Electric pump set salvage value	20 % of capital cost
20.	PV powered pump set salvage value	5 % of capital cost
21.	Time involvement of operator to run the device	1 hr/day
22.	Prevailing labour charges	Rs. 300/day
23.	Electric pump set energy consumption (kWh)	(BHP) / (motor efficiency × pump efficiency) × 0.746 × 1 hour
24.	Diesel pump set hourly cost of operation	(BHP) / (motor efficiency × pump efficiency) × fuel consumed in litres/hour/BHP × cost of fuel/lit

(i) Hourly operating cost of PV powered water pumping device with drip system

Fixed Cost

(a) Depreciation

(i) D = (C-S)/ (L × H) where C= capital cost (Rs. 2,20,000); S = Salvage Value (5% of C); L = Useful life of device (22 years); H= Annual working hour (500 hours)

Putting the values of all necessary data, D= Rs. 19.00/hour

(ii) Interest (I) = (C + S)/(2) × (Interest rate/100) × (1/H) = Rs. 23.10/hour

Insurance and taxes and housing are not applicable

Total fixed cost = 19.00 + 23.10 = Rs. 42.10/hour

Variable Cost

(b) Fuel cost = Nil

(i) Lubricants = Nil

(ii) Repair and maintenance = (C) × (0.5/100) × (1/H) = Rs. 2.2/hour

(iii) Operator's wages Rs. 300/8 = Rs. 37.5/hour

Total variable cost = 2.2 + 37.5 = Rs. 39.7/hour

Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = **Rs. 81.8 ≈ Rs. 82.00/hour**

(ii) Hourly operating cost of diesel pump set

Fixed Cost

(i) Depreciation

D = (C-S)/ (L × H) where C= capital cost (Rs. 12,000); S = Salvage Value (20 % of C); L = Useful life of device (8 years); H= Annual working hour (500 hours)

Putting the values of all necessary data, D= Rs. 2.4/hour

(ii) Interest (I) = (C + S)/ (2) × (Interest rate/100) × (1/H) = Rs. 1.44/hour

Insurance and taxes and housing are not applicable

Total fixed cost = 2.4 + 1.44 = Rs. 3.84/hour

Variable Cost

(i) Fuel cost = (1)/(0.4 × 0.75) ×0.25 × 100 = Rs. 83.33/hour

(ii) Lubricants = 20 % of cost of fuel = Rs. 16.66/hour

(iii) Repair and maintenance = (C) × (10/100) × (1/H) = Rs. 2.4/hour

(iv) Operator's wages Rs. 300/8 = Rs. 37.5/hour

Total variable cost = 83.33 + 16.66 + 2.4 + 37.5 = Rs. 139.89 ≈ 140/hour

Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = Rs. 143.84 ≈ **Rs. 144/hour**

(iii) Hourly operating cost of electric pump set

Fixed Cost

(i) Depreciation

D = (C-S)/ (L × H) where C= capital cost (Rs. 8000); S = Salvage Value (20% of C); L = Useful life of device (8 years); H= Annual working hour (500 hours)

Putting the values of all necessary data, D= Rs. 1.6/hour

(ii) Interest (I) = (C + S)/(2) × (Interest rate/100) × (1/H) = Rs. 0.96/hour

Insurance and taxes and housing are not applicable

Total fixed cost = 1.6 + 0.96 = Rs. 2.56/hour

Variable Cost

(i) Energy consumption (kWh) = (1) / (0.75 × 0.75) × 0.746 = 1.32 kWh

(ii) Electric energy cost = 1.32 × 5 = Rs. 6.63/hour

(iii) Lubricants = 20 % of cost of fuel = Rs. 1.32/hour

(iv) Repair and maintenance = (C) × (10/100) × (1/H) = Rs. 1.6/hour

(v) Operator's wages Rs. 300/8 = Rs. 37.5/hour

Total variable cost = 6.63 + 1.32 + 1.6 + 37.5 = Rs. 47.05/hour

Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = **Rs. 49.61 ≈ 50.00/hour**

Mitigation of CO_2 Emission by Use of Solar Photovoltaic Powered Water Pumping System. Diesel and electricity are the two mostly used fuels to operate diesel and electric pump sets for water pumping in irrigating cultivable lands in our state of Odisha. Burning of diesel in the internal combustion engines and generation of electricity in power plants contribute a lot in the emissions of greenhouse gases to the atmosphere causing more to the present concerns of global warming and climate change. The existing diesel and electric pump sets in our state is 3.00 lakhs ad 2.00 lakhs respectively in the power rating range of 1-5 hp (Economic Survey, Govt. of Odisha 2015). Taking the average power rating of both diesel and electric pump sets as 3 hp, the amount of emissions of CO_2 has been estimated and as follows;

(i) One hp engine consumes about 250 ml of diesel per hour

(ii) Burning of 1 litre of diesel releases about 3 kg of CO_2 to the atmosphere (Sharma and Maréchal, 2019)

(iii) The average carbon dioxide emission for electricity generation from coal based thermal power plant is 1.58 kg/kWh (Chel *et al*., 2009)

(iv) Annual working hours of diesel and electric pump sets can be taken 500 hours

(v) Annual CO_2 emissions from 3.00 lakhs diesel pump sets to be 34 crore kg in our state

(vi) Annual CO_2 emissions from 2.00 lakhs electric pump sets to be 35 crore kg in our state

(vii) Total annual CO_2 emissions can be mitigated by 70 crore kg with the replacement of existing diesel and electric pump sets in our state by the adoption of solar photo voltaic powered system in irrigation sector.

(viii) Total annual electrical energy consumption from 2.00 lakhs electric pump sets can be saved in the tune of 22×10^7 kWh (saving around 22 crore units of electricity costing about Rs. 110 crores/annum)

(ix) Total annual diesel consumption from 3.00 lakhs diesel pump sets can be saved in the tune of 11×10^7 litres of diesel (saving around Rs. 1100 crores/annum)

RESULTS AND DISCUSSION

The data relating to the cultivation of tomato have been presented in this section. The crop tomato is cultivated widely in the state of Odisha as it is highly remunerative and having many nutritive values for human health. The crop is grown in an area of 97,018 ha (Agricultural Statistics, 2015, Govt. of Odisha) covering 11.02 % area of the total tomato cultivation in all India level. It ranks second in the state in vegetable production. Odisha also ranks fourth among the tomato producing states in India. It is considered as one of the most important supplementary sources of minerals and vitamins in human diet. However, targeted production and productivity is not achieved so far at par with the national level because of poor irrigation facilitates both in rabi and summer season. The most prevailing variety of tomato i.e. Utkal Kumari (BT-10) has been cultivated for the present study in order to evaluate the effectiveness of the developed solar PV drip irrigation device with respect to production, productivity and environmental benefits with a view to reduce the use of non-renewable sources of energy and to avoid the flooding method of irrigation. The cost of growing tomato in 1 acre of land has been calculated for finding out cost benefit ratio and its expected pay-back period. Likewise, the reduction in the emission of greenhouse gas (CO_2) with the use of the developed set-up has been estimated compared to the traditional electric and diesel pump sets in order to assess its contribution to reduce global warming and climate change and thereby achieving sustainable agriculture.

Table 3: Cost of cultivation of tomato in 1acre (0.4 ha) land (Anonymous 2017).

Sr. No.	Name of operation	Implements used	No. of operation	Man-hr/Ac	Operation cost (Rs.)	Input (kg)	Cost of input (Rs.)	Total cost (Rs.)
1.	Tillage	Tractor drawn rotavator	1 1	2 1	1200 600	-	-	1800
2.	Planking	Wooden planker (manual)	1	2	31.25/hour	-	-	62.50
3.	Seed (Hybrid)							500
4.	Planting (manual)		1	16	31.25/hour			500
5.	Fertilizer	FYM Gromer Potash	Once Twice Twice			1 tractor load 100 kg 100 kg	4000 2500 2500	4000 2500 2500
6.	Interculture	Manual	Thrice	40	31.25/hour			3750
7.	Plant protection	Knapsack sprayer	Thrice	2	31.25/hour	Pesticides	4000	4187
8.	Irrigation	Solar PV powered sprinkler system	45 (2 days interval)	1	Rs. 49/hour			2205
9.	Harvesting	manual	Twice/week	120/ month				3750
10.	Miscellaneous							4000
Total Cost								**29,754 ≈ 30,000**

Without assured irrigation, production of tomatoes = 40 quintals/acre @ Rs. 20/kg = Rs. 80,000
With assured irrigation, production of tomatoes with 15 % increase in yield = 46 quintals/acre @ Rs. 25/kg = Rs. 1, 15, 000
Net gain = Rs. 1, 15,000 –Rs. 30,000 = Rs. 85,000 (in Rabi season)
Net gain = Rs. 1, 15,000 –Rs. 30,000 = Rs. 85,000 (in Summer season)
Considering tomato cultivation in both the seasons in a year with assured irrigation, total gain = Rs. 1, 70,000/annum
Monthly income from tomato cultivation with assured irrigation = Rs. 14,167 ≈ Rs. 15,000 per month
Simple payback period = (Initial investment cost) / (Net annual gain) = 2,20,000/1, 70,000 = 1.29 ≈ 1 year.

Table 4: Estimated techno-economic environmental assessment of the study.

Sr. No.	Parameters	Unit	Calculated values
1.	Capital cost of set-up	Rs.	2,20,000
2.	Life of set-up	year	22
3.	Hourly cost of operation of solar PV water pump (1 hp capacity)	Rs.	82
4.	Hourly cost of operation of diesel pump (1 hp capacity)		144
5.	Hourly cost of operation of electric pump (1 hp capacity)		50
6.	Cost of cultivations of tomato (1 acre) for 2 seasons /year	Rs.	60,000
7.	Annual income from cultivation of tomato for 2 seasons/yr.	Rs.	1,70,000
8.	Payback period	year	1.0
9.	Expected monthly income of the user after completion of payback period	Rs.	15,000
10.	Mitigation of total CO_2 emission per year by replacing diesel and electric pump sets in Odisha	kg	70×10^7
11.	Saving of electrical energy per year by replacing electric pump set in Odisha	kWh	22×10^7
12.	Saving diesel fuel per year by replacing diesel pump set in Odisha	litre	11×10^7

CONCLUSIONS

Solar PV water pumping system is gaining importance nowadays for operating it from a reliable source of energy and can be used anywhere in rural, remote and urban locations. Looking into the scarcity of water in the agricultural sector, integration of micro-irrigation system is another added advantage for sustainable cultivation of remunerative vegetable crops in a small scale for raising income level of the majority of small and marginal farmers at their individual level. This approach is also one appropriate initiative to supplement the target of harnessing 100 GW power from solar energy in India by 2025 (Anon, 2018). Hence, sustainable energy source along with adoption of possible water management practices may be achieved with the help of solar photovoltaic micro-irrigation system in order to solve the problem of inadequate availability of two critical inputs such as energy and water for assured irrigation in agricultural sector. Micro-irrigation method through drip system may also be an added advantage if integrated with the solar PV device to achieve judicious utilization of water. The findings of the present study would definitely give an insight to the farming community of the state to go for adopting the technology to strengthen their agricultural production system with secured availability of energy and water. The solar PV water pumps have been considered to be the viable option especially for providing micro-irrigation facilities to the vegetable cultivation in warm and humid climate conditions because of the growing concerns of energy crisis and water shortage in the agricultural sector. The following conclusions may be drawn from the study.

(i) Monthly income of Rs. 15000/- throughout the year may be possible by adopting vegetable cultivation (tomato) in 1 acre of land both during rabi and summer seasons.

(ii) The small and marginal farmers of the state may be attracted to adopt off-grid solar photo voltaic powered water pumping system as the hourly operating cost is Rs. 82/hour, not much higher than the electric pump set, which is Rs. 50/ hour and Rs. 144/hour for diesel pump set.

(iii) Pay- back period of the setup is only 1 year, due to which, it may be easily accepted by the small and marginal farmers of the state inspite of its high initial cost.

(iv) Total annual CO_2 emissions can be mitigated by 70 $\times$ 10^7 kg with the replacement of existing diesel and electric pump sets in the state of Odisha by the adoption of a reliable off-grid solar photovoltaic powered system in the irrigation sector.

(v) Total annual electrical energy consumption from the existing 2.00 lakhs electric pump sets can be saved in the tune of 22×10^7 kWh (saving around 22 crore units of electricity and costing about Rs. 110 crores/annum)

(vi) Total annual diesel consumption from 3.00 lakhs diesel pump sets can be saved in the tune of 11×10^7 litres of diesel (saving around Rs. 1100 crores/annum)

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Conflicts of Interest. The results furnished in this paper are from our own research and there are no any conflicts from other research scholars or scientists.

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