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Techno-economic Evaluation of Solar Photovoltaic Water Pumping based Micro-irrigation System in Vegetable Cultivation: A Case Study

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ABSTRACT: Techno-economic assessment of a standalone solar photovoltaic water pumping based drip irrigation system has been evaluated for okra cultivation in 1 acre of land in warm and humid climatic condition of the state of Odisha, India in rabi and summer seasons during 2018-19. This activity has been taken up with a view to study the feasibility of creating secured irrigation facility at the individual level through a pumping system powered by sustainable and eco-friendly solar PV electricity for cultivating highly remunerative vegetables in order to improve the livelihood of small and marginal farmers. Micro-irrigation method through drip system has been integrated with the solar PV device to achieve judicious utilization of water. Monthly income of Rs. 10,000/- throughout the year may be possible by adopting remunerative hybrid okra cultivation in 1 acre of land both during rabi and summer seasons and payback period was calculated to be only 2 years.

Keywords: Solar photovoltaic system, Solar PV water pump, Micro-irrigation, Water use efficiency, Drip irrigation, Vegetable cultivation

INTRODUCTION

Pumping of water to the agricultural land for irrigation purposes is mostly performed by the electric and diesel fuel based power sources in the state of Odisha (Anon., 2019). The use of these two fossil fuels in operating the pumping systems is not only polluting the environment due to the emission of greenhouse gases directly and indirectly but also becoming more expensive for the rising price of the fuels. In the remote areas, the grid electricity is either unavailable or very much erratic in supply. Likewise, the easy availability of diesel fuel nearer to the agricultural farm as well as its transportation from the far distance pose major constraints in the use of diesel pump for the small and marginal farmers. Looking into those hindrances, solar photovoltaic (PV) water pumping system is considered to be a viable option and promising alternative for irrigating land in the remote and rural areas. Moreover, solar PV pumping system is environment-friendly, reliable and require low maintenance and having no fuel cost (Foster and Cota 2014). The technology is almost similar to any other conventional water pumping system except that the source of power is from the solar energy. The incident solar radiation and the size of PV panel are the key parameters for the solar PV pumping system to quantify the flow rate of the pumped water (Chandel *et al*., 2017). The system therefore requires proper design to achieve cost savings on long-term basis compared to the conventional systems. In addition, the cost of the system can be reduced if storage tank for the pumped water is used in place of using batteries for the storage of electricity, mostly using during off-sunshine hours (Rohit *et al.,* 2013). Directly coupled PV panel to the DC solar pump is therefore nowadays gaining importance looking into the affordability of the users, user friendliness, less complexities for the system (Mokeddem *et al*., 2011). Hence, there is the wide scope to popularize solar PV system due to declining in the price of panel owing to the increase in the mass production and improvement in its efficiency because of the continuing research and development in the recent years (Reca *et al.,* 2016). Also being a tropical country, India is endowed with the abundant availability of solar radiation. The ranges of solar radiation in the country are between 4.5 to 7 .0 kWh/m^2/day with bright sunshine hours from 5 to 9 h/day and of about 300 clear days in a year (Gopal *et al.,* 2013). The use of solar PV system is therefore a sustainable approach for harnessing energy to power water pumping systems particularly in the off-grid rural areas for creating irrigation facilities at the individual level. Such system is easy to install and operate, durable, reliable, non-polluting and not requiring long pipelines because of its establishment at the site of use (Chandel *et al.,* 2015). Moreover, more the amount of water to pump, more is the consumption of power. The power consumption can be reduced by following the judicious use of water particularly in the agricultural sector. One such option to enhance water use efficiency in the crop cultivation is the use of micro-irrigation, which has been proved to be a viable approach mostly in the vegetable cultivation (Ghosal *et al.*, 2020), looking into the present day's concerns of energy crisis and water scarcity particularly in agricultural sector. Hence, the aim of the present study is to evaluate the techno-economic assessment of irrigating vegetable crop through the use of directly coupled solar PV water pumping based micro-irrigation system of small capacity (1 hp DC solar pump) in warm and humid climatic condition of the state of Odisha, India (20.29°N latitude and 85.82°E longitude). No study has been undertaken till date in warm and humid climates of the state Odisha to provide appropriate researchable data to practitioners, agriculturists and finally for the knowledge of the farmers about the use and benefits of solar PV water pump. The findings of the study would provide the right information for the majority of small and marginal farmers of the state whether to adopt the practice or not, from the technical feasibility, user friendliness and livelihood improvements points of view.

EXPERIMENTAL SITE

The field experiment was conducted in the campus of State Level Farm Machinery Training and Testing Centre (SLFMTC), Baramunda, Bhubaneswar, Odisha during January 2108 to May 2018. This site is located at 20.29 ^{0} N latitude and 85. 82°E longitude and at an elevation of 25.9 m above mean sea level. The field of 1-acre(0.4 ha) area was developed by installing solar water pump 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. Okra (Hybrid variety-SARTAJ) 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).

Sizing of Solar Photovoltaic Powered Drip Irrigation System

(i) Water Requirement for Okra Crop

W_r = (Crop area × PE × P_c × K_c × W_a)/E_u

W_r = Peak water requirement (m^3/day); crop area (m^2); PE = Pan Evaporation rate (mm/day); P_c = Pan Coefficient (0.7 to 0.9); K_c = Crop Coefficient (0.8 to 1); W_a = wetted area (%) (80 % for drip irrigation); E_u = Emission uniformity of drip irrigation (approx. 0.8). Net crop area is 3600 m^2 (1 acre, 4000 m^2 -10 % of gross area for covering peripheral bunds). Putting the values of crop area = 3600 m^2; PE = 8 mm/day; P_c = 0.85; K_c = 0.9; W_a = 0.8 and E_u = 0.8, W_r = 22.03 m^3/day (22030 lit/day). Taking irrigation interval to be 2 days, W_r = 22030/2 = 11015 lit/day = 11.01 m^3/day ≈ 11 m^3/day.

(ii) Sizing of PV panel for above water requirement

$E = (\rho\, g\, H\, V)/(3.6 \times 10^6)$

E = Hydraulic energy required (kWh/day);

ρ = density of water (1000 kg/m^3);

g = Gravitational acceleration (9.81 m/s^2);

H =Total dynamic head (TDH) is sum of static head (m) and frictional losses in the suction and delivery pipe (m) → 45 (static head) + 5 % (45) for frictional losses = 47.25 m.

V = volume of water to be pumped (11 m^3/day in this case). Putting all values,

E = 1.416 kWh/day = 1416 Wh/day

Assuming peak sun shine hours in a day = 5 hours, the total wattage of PV module = 1416/5 = 283.2 watt

Assumptions:

(i) Operating factor = 0.75-0.85 (PV panel mostly does not operate at peak rated power)

(ii) Pump efficiency = 70-80 % (can be taken 75 %)

(iii) Motor efficiency = 75-85 % (can be taken 80 %)

(iv) Mismatch factor = 0.75-0.85 (PV panel does not operate at maximum power point)

Considering system losses, wattage requirement = (Total PV panel wattage)/(pump efficiency × mismatch factor) = (283.2)/ (0.75 × 0.8) = 472 watt

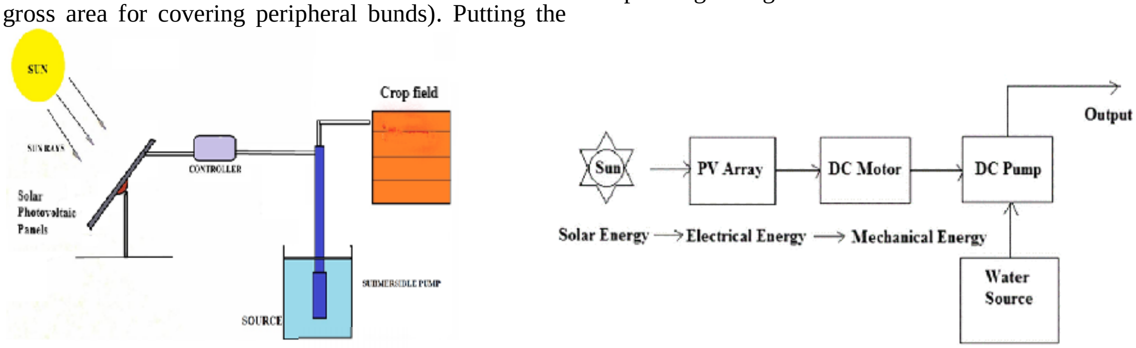
Considering operating factor for PV panel = (Total PV panel wattage after losses)/operating factor × motor efficiency) = (472)/(0.8 × 0.8) = 737.5 watt

Power rating of motor = 737.5/746 = 0.98 hp ≈ 1 hp

Determination of designed sizing of PV panel

In order to meet the other losses in the wiring, interconnections and MPPT inbuilt controller, the designed sizing of PV panel should further be higher than the wattage calculated above. The designedsizing was determined to be 885 Wh/day (737.5 × 1.2) based on the factor of safety to be 1.2 (Chel and Tiwari 2011). Hence, number of 300W_p solar PV panel required for the designed size of PV array = 885/300 = 2.95 ≈ 3panels

The MPPT charge controller capacity can be determined based on the PV array size and the system operating voltage.



Charge controller capacity (A)

$$= \frac{\text{PV array size } (W_p)}{\text{system operating voltage (V)}} = \frac{885}{100} = 8.85 \text{ A}$$

Fig. 1. Layout of solar PV water pumping system.

Specification of solar panel (Waaree Solar-300)

Parameters	Value
Dimensions of panel	2.0 m × 1.0 m × 0.05 m
No. of cells in a panel	72
W_{peak} of panel (Watt peak)	300 watt
I_{sc} (Short circuit current)	8.89 A
V_{OC} (Open circuit voltage)	45.0 V
I_{max} (Current at maximum power)	8.22 A
V_{max} (Voltage at maximum power)	36.5 V
Maximum system voltage	100 V
No. of panels in the system	3 (all in series connection)
Panel efficiency	16.00 %

All these electrical measurements were carried out at standard test condition of 25°C cell temperature, 1.5AM (Air mass ratio) and 1000W/m^2 solar intensity

Cost of Experimental Solar Photovoltaic Powered Drip Irrigation System

(i) Solar PV panel (3× 300W_p) = 900 watt @ Rs. 50 per W_p= Rs. 45,000

(ii) MPPT based charge controller (8.85 A) = Rs. 5000

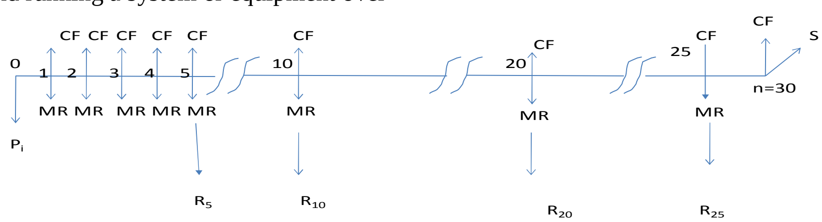
(iii) 1.0 hp submersible DC solar water pump = Rs. 60,000

(iv) Drip irrigation set up for 1-acre land = Rs. 1,10,000

(v) Pipes, fittings, wiring etc. = Rs. 10,000

Total = Rs. 2,30,000

Lifecycle Cost (LCC) of the system: The LCC of the system is the cost of using it during its lifetime. The cost of owning and running a system or equipment over its lifetime can be divided into three components i.e. (i) Capital cost (initial investment, P_i) (ii) Maintenance, operation and repair cost (P_{mor}) and (iii) Replacement cost (cost incurred if any component of the system or equipment needs replacement before the life of the system is over, P_r). The useful lives of solar PV system, solar pump and drip set up are respectively considered to be 30, 10 and 5 years. The annual cash flow is obtained from the profit gained from the cultivation of okra crop during rabi and summer period in a year. The break-up costs of solar pumping based micro-irrigation system are presented above. The line diagram of various cash flows at different intervals of time during the useful life of the system is shown in cash flow diagram.



Cash flow diagram

Capital cost *(P_i)*

Capital cost is the total cost involved for all the components in making the set-up. The capital cost in the present study is Rs.2,30,000.

Maintenance, operation and repair cost (P_{mor})

Maintenance, operation and repair cost can be considered as recurring expenses because of incurring this cost annually throughout the life of the system for running it properly. For the solar PV pumping system, this recurring cost is very small, hence, it is assumed that the annual maintenance, operation and repair cost would increase at the inflation rate of 0.5 % per annum with respect to the expenses made during 1st year. The 1st year cost can be assumed to be 1 % of the total capital cost of the system (1 % of Rs. 2,30,000 = Rs. 2300). The present worth of the future recurring investments, considering the cost to incur at the end of each year, can be calculated by the following equation (Ghosal, 2021).

$$P_{(mor)rec-end} = P_i k\left[\frac{1-k^n}{1-k}\right] = P_i F_{\text{pw-rec-end}}$$

where, $F_{\text{pw-rec-end}} = k\left[\frac{1-k^n}{1-k}\right]$ and $k = \frac{1+g}{1+i}$

P_i is the initial expenses made for maintenance, operation and repair of the system during 1st year, 'g' is the inflation rate (0.5 %) and 'i' is the interest rate (10 %). $F_{\text{pw-rec-end}}$ is the present worth factor of the recurring investment made at the end of each year, 'n' is the useful life of the system (30 years) and P_i in this case = Rs. 2300. The annual maintenance, operation and repair cost is represented as 'MR' in the cash flow diagram.

$P_{mor} = \text{Rs.}\,22{,}770$

Replacement cost (P_r)

It is the cost incurred for replacement of drip set up at every 5 years interval and solar pump at every 10 years interval. The initial costs of drip set up and soar pump are respectively Rs. 1,10,000 and Rs. 60,000. The replacement cost can be considered as future one-time investment and its present worth can also be calculated by considering both inflation rate and interest rate. Thus, the present worth of the investment that needs to be made 'n' years later would be lower by the factor given by $F_{\text{PW- one time}}$.

$$F_{PW-\text{one time}} = \frac{\text{future cost}}{\text{future value}} = \frac{X(1+g)^n}{X(1+i)^n} = \left(\frac{1+g}{1+i}\right)^n$$

where X is the present cost of the product and $F_{PW-one\ time}$ can be read as 'present worth factor for future one-time investments'. Now if the present cost of a product is X, then its present worth (PW) for the actual one-time investment after 'n' years would be given as:

$$PW_{\text{replacement}} = XF_{\text{PW-one time}} = X\left(\frac{1+g}{1+i}\right)^n.$$

The inflation rate for drip set up is assumed to be 5 %. Hence, $PW_{\text{replacement (drip) after 5 years}} = 1,10,000 \left(\frac{1+0.05}{1+0.1}\right)^5$ = Rs. 86,900

$PW_{\text{replacement (drip) after 10 years}} = 1,10,000 \left(\frac{1+0.05}{1+0.1}\right)^{10}$ = Rs. 68,687

$PW_{\text{replacement (drip) after 15 years}} = 1,10,000 \left(\frac{1+0.05}{1+0.1}\right)^{15}$ = Rs. 54,277

$PW_{\text{replacement (drip) after 20 years}} = 1,10,000 \left(\frac{1+0.05}{1+0.1}\right)^{20}$ = Rs. 42,890

$PW_{\text{replacement (drip) after 25 years}} = 1,10,000 \left(\frac{1+0.05}{1+0.1}\right)^{25}$ = Rs. 33,892

The present worth of replacement cost of drip set up during the life of the system = 86,900 + 68,687 + 54,277 + 42,890 + 33,892 = Rs. 2,86,646

Similarly, replacement costs for the solar pump can be calculated as follows by assuming 'g' to be 1 %;

$PW_{\text{replacement (solar pump) after 10 years}} = 60,000 \left(\frac{1+0.01}{1+0.1}\right)^{10}$ = Rs. 26,063

$PW_{\text{replacement (solar pump) after 20 years}} = 60,000 \left(\frac{1+0.01}{1+0.1}\right)^{20}$ = Rs. 11,321

The present worth of replacement cost of solar pump during the life of the system = 26,063 + 11,321 = Rs. 37,384

The present value of total replacement cost for the drip set up and solar pump = P_r = 2,86,646 + 37,384 = Rs. 3,24,030.

Salvage value (P_s)

It is the expected value of the system at the end of its useful life. If 'S' is the salvage value at the end of the useful life, then its value in terms of present worth is

$$(P_s) = S \times \left[\frac{1}{(1+i)^n}\right]$$

Salvage value may be assumed to be 10 % of capital cost (P_i), then P_s = 1318.

Hence the overall life cycle cost of the proposed set-up in terms of present value is expressed as $P_{net} = P_i + P_{mor} + P_r - P_s$ = 2,30,000 + 22,770 + 3, 24,030 – 1318 = Rs. 5,75,482

Annualized uniform cost (C_A)

Annualized uniform cost is defined as the product of net present value of the system and Capital Recovery Factor (CRF) and can be written as

$$C_A = P_{net} \times \left[\frac{(i \times (1+i)^n}{((1+i)^n - 1)}\right] = \text{Rs. } 61,000$$

Cost of cultivation of Okra in 1Acre (0.4 ha) Land (Anonymous 2017).

Sr.No.	Name of operation	Implements used	No. of operation	Man-h	Operation cost (Rs.)	Input	Rate of input (Rs.)	Total cost (Rs.)
1.	Tillage	Tractor drawn rotavator (hired)	1 1	2 1	1200 600	—	—	1800
2.	Planking	Wooden planker (manual)	1	3	50.00/h for human labour	—	—	150
3.	Lay out of land	Manual	1	60 (10 man-days)	50.00/h	—	—	3000
4.	Seed (Hybrid)	—	—	—	—	2.5 kg	3000/kg	7500
5.	Sowing (manual)	Using pegs and rope	1	24 (4 man-days)	50.00/h	—	—	1200
6.	Manure application	FYM	3			8 tractor load	1200/ tractor load	9600
7.	Interculture	Manual	3	6 (12 man days)	50.00/h			10,800
8.	Plant protection	Solar sprayer	3	3	50.00/h	Pesticides	1000	1450
9.	Irrigation	Solar PV powered pump for drip system	70 times throughout cropping period	1	50.00/h for human labour			3500
10.	Harvesting	manual	5 times/week Total 6 weeks	6	50.00/h			9000
11.	Miscellaneous							2000
Total cost								**50,000**

Income:

Yield per acre for summer okra = 4.0 ton, price per kg = Rs. 40

Yield per acre for winter okra = 3.0 ton, price per kg = Rs. 40

Income from cultivating okra per acre only during winter and summer period without affecting the usual kharif rice is Rs. 2,80,000.

The productivity data for okra during summer and winter period are almost same as the yield from the irrigated land by electric pump set with the drip system (Anonymous 2018).

Expenses

The cost of cultivating okra in one season is Rs. 50,000 and for 2 seasons/year, it is Rs. 1,00,000

Annualized uniform cost for solar pumping based drip irrigation system is Rs. 61,000

Total expenses/year = Rs. 1,61,000

Gain

Rs. 2,80,000-Rs.1,61,000 = Rs. 1,19,000/year. This amount accounts for the net cash inflow (CF), which is assumed to be same for each year in cash flow diagram.

Payback period = (Initial investment cost)/(Net annual gain) = 2,30,000/1, 19,000 = 1.93 years≈ 2.0 years.

Estimated techno-economic parameters of the study.

Sr. No.	Parameters	Unit	Calculated values
1.	Capital cost of set-up	Rs.	2,30,000
2.	Life of set-up	year	30
3.	Net present value (considering the costs for initial investment, repair and maintenance, replacement of equipment and revenues from salvage value during life of set-up)	Rs.	5,75,482
4.	Annualized uniform cost for solar PV pump based drip system	Rs.	61,000
5.	Cost of cultivations of okra (1 acre) for 2 seasons /year	Rs.	1,00,000
6.	Annual income from cultivation of okra for 2 seasons/yr.	Rs.	2,80,000
7.	Cash inflow/year (from cultivation of okra, 2 times/year)	Rs.	1,19,000
8.	Payback period	year	2.0
9.	Expected monthly income of the user after completion of payback period	Rs.	10,000

CONCLUSION

Agricultural production depends on the availability of two important input materials i.e. water and energy. There is at present the crisis of these two materials worldwide particularly in the agricultural sector. However, it is the dire need of time to increase the crop production in order to feed the fast rising of the population. Hence, sustainable approaches are necessary to achieve energy and food security. One of the promising approaches is the use of solar photovoltaic water pumping unit not only for its cost-effective application but also usage at the individual level in remote off-grid areas, especially in the developing countries (Sontake and Kalamkar 2016). Continuous research and developments in recent years have established the fact of the economic viability of the photovoltaic water pumping system in the domestic, industrial and agricultural sectors compared to the conventional ones, mostly in the tropical belts of the world (Kelley *et al.,* 2010). This paper therefore focusses on the techno-economic evaluation of a standalone small capacity solar PV water pumping based drip irrigation system in vegetable cultivations with the aim of providing a broad outlook for the researchers, engineers, manufacturers, and policy makers in its popularization in a wide scale. The conclusions of the present study are as follows,

1. Standalone solar photovoltaic water pumping system with micro-irrigation unit may be an attractive option for small and marginal farmers for achieving assured irrigation particularly for vegetable cultivation.
2. Monthly income of Rs. 10,000/- throughout the year may be possible by adopting remunerative vegetable cultivation in 1 acre of land during rabi and summer seasons only.
3. The existing area under vegetable cultivation in the state may be enhanced mostly during summer season due to the assured irrigation facility through solar photo voltaic system.
4. The developed set up may also be utilized for irrigating land in rainy season in case of irregular or scanty rainfall
5. Pay- back period of the developed set up is only 2 years, due to which, it may be easily accepted by the small and marginal farmers of the state inspite of its high initial cost.

This practice has the great potential for disseminating among the farming community in the future because of low capacity, cost effectiveness, user and environment friendliness and sustainability (Meah *et al.,* 2008).

This is also one appropriate initiative to supplement the target of harnessing 100 GW power from solar energy in India by 2025 (MNRE 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. The only implication of the practice is that the system cannot be used during night time and cloudy days as no storage device is included in the system. However, day time irrigation is sufficient for the vegetable crops due to precise water applications with the drip system.

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Conflict of Interest. None.

REFERENCES

Anonymous (2019). Economic Survey of Odisha, 2019, Govt. of Odisha, India

Anonymous (2017). Agricultural Statistics, 2017, Govt. of Odisha, India

Anonymous (2018). Annual Report, 2018. Ministry of New and Renewable Energy, Govt. of India, New Delhi, India.

Anonymous (2018). Annual Report, 2018. Directorate of Research, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India.

Chandel, S. S., Naik, M. N., & Chandel, R. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. *Renewable and Sustainable Energy Reviews*, *49*, 1084-1099.

Chandel, S. S., Naik, M. N., & Chandel, R. (2017). Review of performance studies of direct coupled photovoltaic water pumping systems and case study. *Renewable and Sustainable Energy Reviews*, *76*: 163-175.

Chel, A., & Tiwari, G. N. (2011). A case study of a typical 2.32 kWP stand-alone photovoltaic (SAPV) in composite climate of New Delhi (India). *Applied Energy*, *88*(4): 1415-1426.

Foster, R., & Cota, A. (2014). Solar water pumping advances and comparative economics. *Energy Procedia*, *57*, 1431-1436.

Ghosal, M. K., Badra, S., & Sahoo, N. (2020). Studies on solar water pumping based micro-irrigation for sustainable vegetable cultivation. *International Journal of Chemical Studies*, *8*(6): 1202-1208.

Ghosal, M. K. (2021). Entrepreneurship in Renewable Energy Technologies. Book published (first edition) by Jaya Publishing House, Rohini, New Delhi, India.

Gopal, C., Mohanraj, M., Chandramohan, P., & Chandrasekar, P. (2013). Renewable energy source water pumping systems—A literature review. *Renewable and Sustainable Energy Reviews*, *25*: 351-370.

Kelley, L. C., Gilbertson, E., Sheikh, A., Eppinger, S. D., & Dubowsky, S. (2010). On the feasibility of solar-powered irrigation. *Renewable and Sustainable Energy Reviews*, *14*(9): 2669-2682.

Meah, K., Ula, S., & Barrett, S. (2008). Solar photovoltaic water pumping—opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *12*(4), 1162-1175.

Mokeddem, A., Midoun, A., Kadri, D., Hiadsi, S., & Raja, I. A. (2011). Performance of a directly-coupled PV water pumping system. *Energy conversion and management*, *52*(10): 3089-3095.

Reca, J., Torrente, C., López-Luque, R., & Martínez, J. (2016). Feasibility analysis of a standalone direct pumping photovoltaic system for irrigation in Mediterranean greenhouses. *Renewable Energy*, *85*: 1143-1154.

Rohit, K. B., Karve, G., and Khatri, M. (2013). Solar water pumping system. *Int. J. Emerg. Technol.* Adv. Eng., *3*: 225–259.

Sontake, V. C., & Kalamkar, V. R. (2016). Solar photovoltaic water pumping system-A comprehensive review. *Renewable and Sustainable Energy Reviews*, *59:* 1038-1067.

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