Chapter 19

Non-Conventional Energy Sources for Integrated Farming System in Irrigation and Water Management

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ABSTRACT

India and the rest of the globe are dealing with the depressing prospect of an altered climate as a result of the ongoing increase in the use of fossil fuels. The diesel and electric water pumps used for irrigation in India are a significant consumer of fossil fuel-based energy. Using diesel and electric water pumps results in an annual increase in CO2 emissions of up to 45 million tonnes, or between 8 and 12 percent of all greenhouse gas emissions. The Indian government initiated a solar pumping initiative for agriculture and drinking water in 2014–2015 with an ambitious objective of installing 0.1 million Solar Photovoltaic Water Pumps (SPVWP) through 2020–2021 due to its established benefits globally. The government's initiatives and systems of support for the expansion of SPVWP in India were thoroughly examined in this study. Updates on solar water pumping technology, performance analysis, optimal sizing, the deterioration of PV generators used to power the pumps, economic and *environmental considerations, and developments in PV material science and efficiency are the main topics of the study. This article provides an update on the development and application of solar water pumping technology. Areas for potential follow-up research are also noted. A model to describe the motor-pumps subsystems utilised in PV pumping installations is also included in this paper. For various total heads, the model explicitly describes the water flow output (Q) as a function of the electrical power input (P) to the motor-pump. A method to calculate the amount of carbon dioxide (CO_2) emissions saved by using water pumping facilities powered by a solar array instead of diesel fuelled generators is provided based on the motor-pump subsystem model.*

Introduction

India's GDP (Gross Domestic Product) growth is significantly influenced by the agriculture sector. According to the World Bank's Employment in Agriculture report, the agriculture industry directly employs around 70 per cent of the entire population, which has led to an ongoing increase in energy consumption in recent years. According to Central Statistics Office data for energy statistics 2016, the agriculture sector had the highest growth rate in power consumption among all sectors, using 18 per cent of the total power generated in 2014–2015 (Ministry of statistics and programme implementation, Central Statistics Office, Energy Statistics, 2016). This is mostly due to the ongoing rise in the use of fossil-based water pumps for irrigation, including both electric and diesel ones (International Energy Agency and India Energy Outlook, 2015, Reddy, 1999). There are an estimated 21 million irrigation pumps in India, 9 million of which run on diesel and 12 million on electricity, and they are primarily responsible for the agricultural sector's high energy consumption (Narale and Rathore, 2015). Furthermore, groundwater is the primary source of irrigation in India. As a result, according to the World Bank's 2012 report (World Bank, Water Paper. Managing the Invisible: Understanding and Improving Groundwater Governance, 2012) India is the world's largest irrigation groundwater user.

Because millions of water pumps require energy in the form of diesel or electricity, India's agriculture sector consumes 85 million tonnes of coal each year. Furthermore, diesel-powered pump sets consume 4 billion litres of diesel (Shakti Foundation, Feasibility Analysis for Solar Agriculture Water Pumps in India, 2014). Fuel-powered groundwater pumping accounts for 8 per cent –12 per cent of total greenhouse gas emissions (Shah, 2009). The combustion of fossil fuels increases CO2 emissions, which is a major contributor to the current climate change crisis. The reliance on fossil-based energy must be reduced in order to progress toward sustainable development. Replacing an estimated 21 million pump sets used in agriculture with energy-efficient pump sets would result in 131.96 billion kWh of annual energy savings. This would also result in a 45 million tonnes CO2 reduction in annual greenhouse gas emissions (Press information bureau, Ministry of Power).

Aside from that, particularly in India, fossil fuel-based water pumping has several limitations, including a lack of power grid availability, a continuous increase in the price of diesel, and increased maintenance costs. Access to electricity as an energy source for agricultural use is a major issue in India, forcing farmers to rely on fossil fuel-based pumping systems. Furthermore, more than 60 per cent of India's electricity is generated using fossil fuels. Furthermore, according to International Energy Agency data (IEA, 2016), approximately 244 million people in India still do not have access to electricity (International Energy Agency and World Energy Outlook, 2016). Considering all of these factors, as well as the critical need for energy in the agricultural sector, a solar photovoltaic water pumping (SPVWP) system may be a suitable and sustainable replacement for fossil fuel-powered water pumps.

An Overview of Solar Photovoltaic Water Pumping Technology in India

In India, the Ministry of Renewable Energy Resources (MNRE) is in charge of the expansion and development of SPVWP for irrigation and drinking water across the country. According to the MNRE guidelines for SPVWP systems released in 2015 (Ministry of New and Renewable Energy and Solar Photovoltaic Water Pumping System, 2015), the PV module capacity of the SPVWP system must be in the range of 900 Watt to 9 KWP and must operate under daily average solar irradiation of 7.15 KWh/m^2 on the surface of the PV array (*i.e.* coplanar with the PV modules). Table 19.1 contains the detailed technical specifications of the SPVWP system released by MNRE and followed throughout the country, while Figure 19.1 depicts a typical SPVWP system installation (Climate Technology Centre and Network. UNFCC Technology Mechanism).

Table 19.1: Technical Specification of DC and AC Solar Photovoltaic Water Pumping system in India (Ministry of New and Renewable Energy and Solar Photovoltaic Water Pumping System, 2015)

Sl. No.	*Description*	*PV Array (W_p)*	*Motor Capacity*	*Shut Off Dynamic Head (Meters)*	*Water Output (L/day)*
1	Model-I* (DC)	900	1 HP	12	90,000
2	Model-II* (DC)	1800	2 HP	12	180,000
3	Model-III* (DC)	2700	3 HP	25	135,000
4	Model-I (DC)	1200	1 HP submersible with controller	45	42,000
5	Model–II (DC)	1800	2 HP submersible with controller	45	63,000
6	Model-V (DC)	3000	3 HP submersible with controller	100	42,000
7	Model-VIII (DC)	4800	5 HP submersible with controller	150	45,600

Sl. No.	Description	PV Array (W_p)	Motor Capacity	Shut Off Dynamic Head (Meters)	Water Output (L/day)
8	Model-IX (DC)	6750	7.5 HP submersible with controller	70	141,750
9	Model-XIII (DC)	9000	10 HP submersible with controller	100	126,000
10	Model-I* (AC)	900	1 HP submersible with controller	12	81,000
11	Model-II* (AC)	1800	2 HP submersible with controller	15	162,000
12	Model-III* (AC)	2700	3 HP submersible with controller	15	243,000
13	Model-V* (AC)	4800	5 HP submersible with controller	15	432,000
14	Model –I (AC)	1200	1 HP submersible with controller	45	38,400
15	Model – II (AC)	1800	2 HP submersible with controller	45	57,600
16	Model – V (AC)	3000	3 HP submersible with controller	100	39,000
17	Model – VIII (AC)	4800	5 HP submersible with controller	150	40,800
18	Model – IX (AC)	6750	7.5 HP submersible with controller	70	128,250
19	Model-XIII (AC)	9000	10 HP submersible with controller	100	117,000

* SPVWP models for shallow well (surface).

A brief detail of SPVWP system components are given below:

I. **Solar Panels**: The SPVWP should be run with a PV array capacity ranging from 200 WP to 10000 WP (Ministry of New and Renewable energy and Solar Photovoltaic Water Pumping System, 2015). To achieve the desired power, the solar panels will be connected in series and parallel.

II. **Pump:** The SPVWP system in India uses any of the following pumps:

a) Surface mounted pumps
b) Submersible pumps
c) Floating motor pumps
d) Any other pump set after approval from the ministry

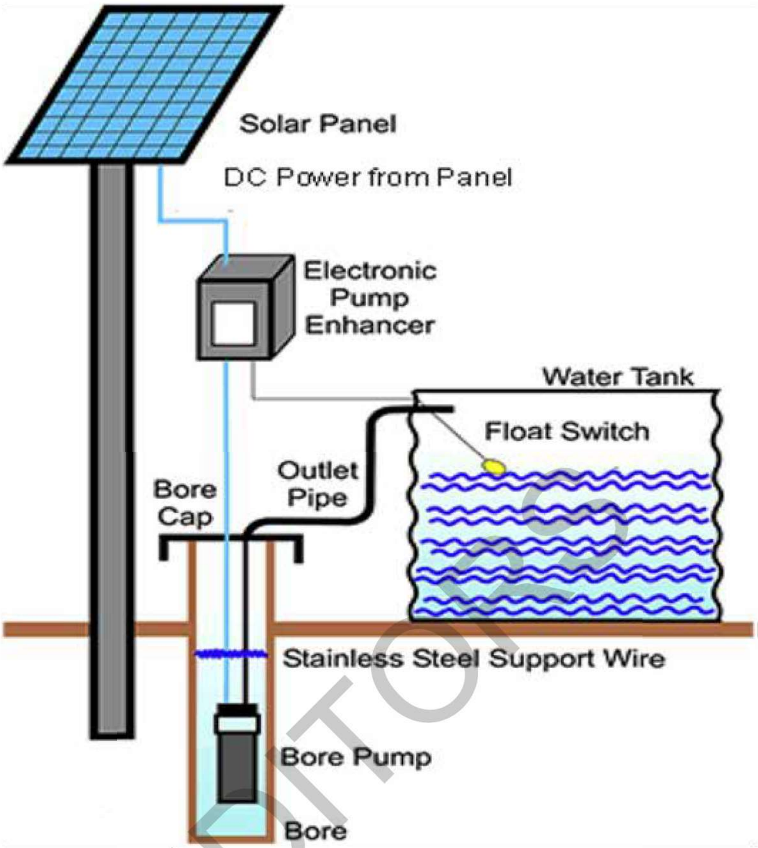

Figure 19.1: A Typical Solar Water Pump Installation (Climate Technology Centre and Network. UNFCC Technology Mechanism).

III. Electric motor: Following are the two types of motors available in India:

a) Inverters are required to convert DC to AC for AC motors. Solar pumping systems make use of variable-frequency inverters, which optimise current by matching it between the panel and the pump.

b) Permanent magnet DC motors are generally more efficient. They can be equipped with or without carbon brushes. The carbon brushes in DC motors should be replaced every two years. As a result, brushless DC motors are becoming increasingly popular in solar water pump systems.

IV. Electronics: Major electronic components used in SPVWP are Maximum Power Point Tracker (MPPT), Inverter (if A.C pumps are used) and a Controller.

Availability of Solar Irradiation

The performance of solar water pumps is determined by the availability of solar irradiation at the location where the pump is installed (Sontake and Kalamkar, 2016). An increase in solar irradiation increases the flow rate and efficiency of SPVWP (Hamrouni *et al*. 2008). India's geographical extent is between 8°4' and 37°6' north latitude and 68°7' to 97°25' east longitude, and it is the world's seventh largest country, with a landmass of 2.9 million km^2. India's solar profile is very rich. India's geographical location ensures that it receives maximum solar irradiation all year. Many regions in India receive solar insolation of more than 5 KWh/m^2/day and account for nearly 58 percent of the country's land area, or approximately 1.89 million km^2 (Ramachandra *et al.* 2011).

Table 19.2: State-Wise Estimated Solar Energy Potential in the Country (National Institute of Solar Energy, Annual Report 2017-18)

Sl.No.	*State/UT*	*Solar Potential (GW_p) #*
1	Andhra Pradesh	38.44
2	Arunachal Pradesh	8.65
3	Assam	13.76
4	Bihar	11.20
5	Chhattisgarh	18.27
6	Delhi	2.05
7	Goa	0.88
8	Gujarat	35.77
9	Haryana	4.56
10	Himachal Pradesh	33.84
11	Jammu and Kashmir	111.05
12	Jharkhand	18.18
13	Karnataka	24.70
14	Kerala	6.11
15	Madhya Pradesh	61.66
16	Maharashtra	64.32
17	Manipur	10.63
18	Meghalaya	5.86
19	Mizoram	9.09
20	Nagaland	7.29
21	Odisha	25.78
22	Punjab	2.81
23	Rajasthan	142.31
24	Sikkim	4.94

Sl.No.	State/UT	Solar Potential (GW_p) #
25	Tamil Nadu	17.67
26	Telangana	20.41
27	Tripura	2.08
28	Uttar Pradesh	22.83
29	Uttarakhand	16.80
30	West Bengal	6.26
31	UTs	0.79
	Total	**748.98**

The time period and water requirement of major crops in India is shown in Table 19.3 (Bhave, 1994).

Table 19.3. Comparative Chart of Water Requirement and Availability of Solar Radiation (Bhave, 1994)

Field Crop Season	*Time Period (Month)*	*Water Requirement (mm)*	*Average Solar Radiation Availability (KWh/m²/day)*	*Water Source*
Kharif (Major crop is Rice)	July-October	900-2500	Maximum (>5)	Rain, Tube well
Rabi (Major crop is Wheat)	November-March	450-650	Normal (>4)	Canals, Tube wells
Zaid (Major crop is sugarcane)	March-June	1500-2500	Maximum (>5)	Tube wells

The period when the major crops that require a lot of water are grown coincides with the period when India receives the most solar irradiation, which is from March to November. As a result, Indian farmers can use solar water pumps to replace existing fossil-fueled water pumps for irrigation.

Economics of SPVWP Systems

The Indian market is extremely cost-conscious. As a result, in order to successfully introduce any new technology into this market, the long-term cost (capital cost and operation and maintenance) must be as low as possible. Because SPVWP systems must compete with well-established fossil-based water pumping technology, they must be economically and financially appealing to the end user. In this regard, various dominating factors such as annual increases in the cost of diesel and fossil-based electricity, frequent power outages, and the inability of electric water pumps to connect to the power grid are making solar water pumps more economically appealing.

Table 19.4: Shuba *et al*. (2010) Shows a Comparison of the Cost of Water Pumping Incurred by using different Water Pumping Sources of 5 HP Pump Capacity for Irrigation in India

Factors	*SPVWP*	*Diesel Powered Pumps*	*Grid Connected Pumps*
Capital cost (INR)	5,00,000 (system cost)	50,000 (Pump cost)	1,50,000 (initial connection cost) and 50, 000 (Pump cost)
Fuel consumption	Nill	1.23 L/hour	4.5 KWh/hour
Fuel price	Nill	58 Rupees/Liter	6 Rupees/KWh
Fluctuation in fuel price	Nill	Increasing	Increasing
Discount rate	10 per cent	10 per cent	10 per cent
Hours of operation per year (6h/day for 200 days)	1200	1200	1200
Net present value (NPV)Over 25 years (INR)	5,16,300	9,27,400	5,60,000
Cost of pumping per hours (INR)	17.2	18.7	30.9

In comparison to diesel and electric pumps, the SPVWP is clearly more cost effective. As a result, it can serve as a better replacement option for fossil-fueled water pumps in India.

Policies and Status of SPVWP in India

In India, the Ministry of New and Renewable Energy (MNRE) is in charge of the growth and development of solar water pumping, and it was in 1993 that the MNRE launched a programme to install 50,000 solar PV water pumping systems across the country. This programme is being carried out with the assistance of several organisations, including the Indian Renewable Energy Development Agency (IREDA) and state nodal agencies (SNAs). Between 1990 and 2000, the high cost of PV silicon solar cells resulted in low penetration of SPVWP across the country. As a result, only 13,964 SPVWP were installed until 2014, compared to the targeted 50,000. (Ministry of New and Renewable Energy, 2014). Despite the fact that the government provided a variety of financial incentives such as subsidies, low-interest rates, and soft loans through IREDA and SNAs, SPVWP growth lagged far behind the stated target.

The Indian government launched the Solar Pumping Program for Irrigation and Drinking Water in 2014. The program's goal was to install 0.1 million pumps in 2014–2015, and it is expected that by 2020–21, at least 1 million SPVWP would be installed across the country (Ministry of New and Renewable Energy, 2014). To promote this programme and ensure its proper implementation on the ground, the MNRE will provide financial assistance through SNAs and the National Bank for Agriculture and Rural Development (NABARD) in accordance with the schemes listed in Table 19.5 (Press information bureau. Ministry of New and Renewable Energy, Government of India Pattern of Central Financial Assistance (CFA) for Off-grid Solar PV Pumps (2015).

Table 19.5: Subsidy Pattern for SPVWP Program in India

Sl.No.	*SPVWP System*	*Capacity*	*Maximum Subsidy in INR (per HP)*
1	DC Pumps	Upto 2 HP	57,600
		>2 HP to 5 HP	54,000
2	AC Pumps	Upto 2 HP	50,400
		>2 HP to 5 HP	43,200
3	DC/AC pumps	>5 HP to 10 HP	194,400

Source: Chandel *et al*. (2017).

The release of the subsidy is conditional on all of SPVWP's systems and sub-systems confirming the minimum technical requirements as laid out by MNRE guidelines from time to time. Beneficiaries must spend 20 per cent of the total system cost of SPVWP, plus bank loans at standard interest rates, over a 10-year repayment period (Ministry of New and Renewable Energy, 2014).

Key Barriers in the Growth of SPVWP in India

It has been more than two decades since the Government of India launched a programme to promote and develop SPVWP throughout the country. Unfortunately, the SPVWP market has not grown in line with expectations, with only 25,000 SPVWP installations by 2016. To improve the SPVWP scenario, the MNRE announced in 2014 a target of installing 1 million SPVWP by 2021. However, the solar pump market in India continues to struggle. Policies for the growth and development of renewable energy face a difficult implementation bottleneck (Beck and Martinot, 2004). Economic and financial barriers, policy and regulatory practises, a lack of education, and technological barriers are all examples of bottlenecks. These barriers become even more critical in countries such as India, where the entire solar PV market must contend with them (Rathore *et al*. 2017).

Discussion and Policy Recommendation

Because of the use of diesel and electric water pumps for irrigation, Indian agriculture has one of the highest carbon footprints in the world. In India, an estimated 21 million fossil fuel-powered water pumps are currently in use for irrigation. This situation is becoming more critical, as nearly 244 million Indians lack access to electricity, and air quality is deteriorating day by day due to increased use of fossil-based energy. SPVWP can provide an environmentally sustainable, dependable, and cost-effective irrigation water pumping solution in India.

Literature Survey of PV Water Pumping Systems

Table 19.6: Summary of PV Water Pumping System Performance Evaluation Studies

Sl.No.	*Reference*	*Country*	*Application*	*Research Finding*
1	Kou *et al.* (1988)	USA	Domestic	Predicted monthly water pumped by a system within 6 per cent of TRNSYS predicted based on hourly data.
2	Hadj Arab *et al.* (1991)	Spain	Domestic	Optimized a proposed PV water pumping system by studying individual requirements with a simulation program.
3	Loxsom and Veroj (1994)	Thailand	Irrigation	Algorithm was developed to estimate the water pumped as per insolation.
4	Alghuwainem *et al.* (1996)	Saudi Arabia	Irrigation	Self excited induction generator utilization avoids need for matching devices and tracking system.
5	Katan *et al.* (1996)	Australia	Domestic	System efficiency increases with MPPT and sun tracker.
6	Pande *et al.* (2003)	India	Irrigation	Reported 6 year pay-back period including subsidies on PV modules.
7	Mohanlal *et al.* (2004)	Egypt	Irrigation	System efficiency is increased upto 20 per cent by manually tracking thrice in a day.
8	Gad (2009)	Egypt	Domestic	Computer simulation program is used to simulate the performance of a proposed PV water pumping system.
9	Mokeddem *et al.* (2011)	Algeria	Irrigation	System efficiency increased by orientation and sizing of PV array and motor pump system.
10	Khan *et al.* (2012)	Bangladesh	Rural water supply	System efficiency is increased by adding DC-DC buck converter for a direct coupled PV water pumping system.

Sl.No.	*Reference*	*Country*	*Application*	*Research Finding*
11	Atlam and Kolhe (2013)	Turkey	Domestic	System performance and efficiency can be improved by matching the output characteristics.
12	Benghanem *et al.* (2013)	Saudi Arabia	Irrigation	Electronic array configuration should be included in order to match maximum power points of PV array with pumps.
13	Reddy and Reddy (2014)	India	Domestic	Configuration of the photovoltaic system can be improved with dynamic models for inverter, single phase induction motor and Neural network based maximum power point tracking.
14	Setiawan *et al.* (2014)	India	Irrigation	Two important design aspects for PV water pumping system are identified; analyzing piping system to determine the type of pump to be used and power system planning

Source: Chandel *et al.* (2015).

Table 19.7: Summary Highlights of Optimal Sizing of PV Water Pumping Systems

Sl. No.	*Reference*	*System Type*	*Optimal Sizing Technique*	*Research Finding*
1	Argaw (1994)	Direct coupled interfaced with PWM DC/AC inverter	Non-linear optimization	Optimum matching factor of 0.74 and 0.55 are found using DC/AC inverter facing
2	Wagdy *et al.* (1994)	Direct coupled and battery buffered	Switched mode	Optimization provides maximum utilization of available solar radiation to minimize cost.
3	Cuadros *et al.* (2004)	Inverter coupled with AC pump	Multi-Step optimization	Output yield of crop can be improved by photo irrigation.
4	Firatoglu and Yesilata (2004)	Direct coupled	Multi-Step optimization	System performance is found better for lower photovoltaic array area.

Sl. No.	*Reference*	*System Type*	*Optimal Sizing Technique*	*Research Finding*
5	Zvonimir *et al.* (2007)	Inverter coupled with AC pump	Hybrid simulation	Electrical power of the PV generator, obtained by the new optimization method is relatively smaller as compared to usual method.
6	Hamidat and Benyoucef (2008)	Inverter coupled with AC pump	Conventional Method	DC engine and a positive displacement pump shows best performance when compared with AC engine centrifugal pump.
7	Kaldellis *et al.* (2009)	Battery based	Two-level analysis	Energy storage capability of a properly designed PV system determined analytically and experimentally to meet the electricity and water needs.
8	Yahia *et al.* (2011)	Direct coupled	Loss of power supply probability (LPSP)	Program developed for relationship between system power reliability and system configurations.

Source: Chandel *et al.* (2015).

Table 19.8: Techniques Used for Improving Efficiency of PV Water Pumping Systems

Sl. No.	*Reference*	*Motor-Pump Set Type*	*Type of Technique Used*	*Research Finding*
1	Ziyad and Dagher (1990)	DC	Electrical Array Reconfiguration Controller (EARC)	System improves pump performance during cloudy conditions and provides extra pumping hours.
2	Eduard (1997)	DC	Six-step-square-wave-inverter	System can be implemented by a simple micro controller
3	Odeh *et al.* (2006)	AC	TRANSYS modeling	Increasing PV array size improves water output volume and subsystem efficiency and decreases PV efficiency.
4	Abdolzadeh and Ameri (2009)	DC	Spraying water over PV modules	Spraying water over the PV modules strongly improves the system and sub-system efficiencies.

Sl. No.	*Reference*	*Motor-Pump Set Type*	*Type of Technique Used*	*Research Finding*
5	Azadeh (2010)	DC	Covering the surface of PV array by a thin film of water	Reduces system costs and provides needed power with lower array nominal power.
6	Abdolzadeh *et al.* (2011)	DC	Spraying water on PV module	Spraying water on the PV modules decreases modules temperature and increase modules' performance and pump flow rate.
7	Kim *et al.* (2011)	DC	Optimum power point tracking (OPPT) algorithm	System designed is suitable for indoor solar energy harvesting under dim lighting conditions.
8	Joao and Luis (2014)	AC	Two-inductor boost converter (TIBC) and Voltage source inverter (VSI)	Proposed solution is a viable option for more reliability.

Source: Chandel *et al.* (2015).

Table 19.9: Economic and Environmental Aspects of PV Water Pumping Systems

Sl. No.	*Reference*	*Country*	*Study Type*	*Research Finding*
1	Foster and Hanley (1998)	Mexico	Economic analysis	Economic viable PV water pumping systems gained foot hold and changing the face of water pumping in Mexico.
2	Hamidat (1999)	Algeria	Economic analysis	PV surface pumps to supply water can contribute to socio-economic development in remote Sahara regions.
3	Odeh *et al.* (2006)	Ireland	Economic viability	Mismatch between water demand and supply patterns have a major effect on economic viability of the PV pumping.
4	Kumar and Kandpal (2007)	India	Environmental and economic analysis	Capital cost of PV pump, its useful life, price of fuel substituted, and discount rate on the unit cost of CO_2. Emission mitigation are of importance for solar pumping promotion.

Sl. No.	Reference	Country	Study Type	Research Finding
5	Meah *et al.* (2008)	USA	Rural water supply	PV water pumping system reduce CO_2 emission considerably over its 25 – year life span.
6	Fedrizzi *et al.* (2009)	Brazil	Irrigation	Negligence of local specificities and technology transfer methods cause PV water pumping system failure
7	Kaldellis *et al.* (2011)	Greece	Economic and Environmental analysis	PV pumping systems are economical viable options for water consumption need of remote communities.
8	Purohit and Kandpal (2011)	India	Financial Evaluation	PV pumping systems are viable option when sufficient incentives are provided by Government.
9	Jamil *et al.* (2012)	India	Techno-economic analysis	Payback period of less than 4 years with huge saving over 16 years.
10	Foster *et al.* (2013)	USA	Rural water supply	Investment payback for PV water pumping system is averaged about 5-6 years.
11	Rezae and Gholamian (2013)	Iran	Economic analysis	Considerable savings are observed in PV water pumping system as compared to conventional system.

Source: Chandel *et al*. (2015).

Conclusions

PV water pumping technology is a dependable and cost-effective alternative to electric and diesel water pumps for crop irrigation. PV water pumping for urban, rural, and community water supplies and institutions is another potentially viable but underutilised sector. Remote, inaccessible areas with no grid electricity require special attention as well. These industries continue to rely on traditional electricity or diesel-powered pumping systems, resulting in higher recurring costs for users. Given the high installation costs of solar water pumps, particularly for large irrigation and water supply systems, governments must provide more incentives to make the technology a more appealing alternative to diesel and electrical water pumping. Factors influencing performance and efficiency improving techniques, use of highly efficient PV modules including bifacial modules, and degradation of PV generator are areas for further research in order to reduce costs, improve performance, and extend the life of pumping systems.

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