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## Prospect of solar power-driven irrigation system in North Eastern states of India

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ABSTRACT

North East India has an abundant supply of renewable energy that can effectively meet the area's demand for electricity. The surplus energy also has a substantial impact on the region's ability to meet the demand of other states. Insignificant consumption occurs when fuel-powered electric motors and generators are used in typical irrigation systems. Adopting a solar photovoltaic water pumping system (SPVWPS) to meet the irrigation demand of crops offers a sustainable way to increase the effectiveness of water use in agricultural fields. By the end of 2022, a total of 787 solar pump units were installed in North East India. Therefore, this review paper examines the prospects of solar energy for irrigation in the Northeast India with the intention of assisting academics, researchers, and national policymakers by providing an understanding of the region's status of renewable energy used for irrigation. Brief outline of the technology is presented and goes into detail on the prospects for SPVWPS development and the current state in North East India. As compared to diesel-powered water pumps, SPVWPS are shown to be more cheap, eco-friendly, reliable, with fewer maintenance and a longer life duration with a payback period of 4-6 years. The work also discusses the recent Indian subsidies granted and the most recent scheme available for installation purposes.

### 1. Introduction

With growing environmental worries about agriculture's rising carbon footprint, non-conventional energy, particularly solar, has gotten a lot of attention from policymakers recently (Bassi, 2018). It has become a global problem to provide electricity to ensure irrigation access in a sustainable and resource-efficient manner, especially in response to climate change (Susanto *et al*., 2023). The main source of income for about 70% of rural households in India is still agriculture, and irrigation is usually necessary for farming to be successful. The country's 62 % of net total irrigated land is watered by deep tube wells or other, progressively shallower types of wells (Ballaji *et al*., 2022). These wells rely on electric or diesel pumps for a significant portion of their operations.

Solar energy is increasingly being employed in agriculture (Singh *et al*., 2021), and the energy generated from this sustainable source may be used on the farm or in the local power grid, giving the farmer an extra source of revenue (Roblin, 2022). The recent decline in the price of solar panels throughout the world, as well as the recent diesel price shocks, has spurred practitioners, enabling decision-makers to consider solar power as a practical energy source in isolated rural areas which are not currently supplied by rural electrification, for both home and agricultural purposes. In India, replacing merely five million diesel irrigation pumps with solar irrigation pumps may save 26 million tons of $CO_2$. With a 19 % utilization rate, replacing conventional pumps with 3-HP solar pumps will not meet the current energy use by farm consumers. This would need either the installation of an extra 25 million 3-HP solar pumps or the replacement of the current fleet with 5.5-HP solar pumps (Garg, 2022). Despite the abundance of renewable energy (RE) sources in Northeast (NE) India, relatively little research has been done on the region's energy resources. It ranks poorly for both electricity production and consumption. NE region residents use about 300 units of energy per person year on average, compared to 914 units per person annually nationwide (Central Electricity Authority – Executive Summary May, 2016). Only 53% of the rural population in NE India's villages has access to electricity on average; this is a very low percentage (Garg, 2022). Existing energy generation capacity is not enough to meet the demand in the remote parts of the State. Unless positive steps are taken to energize the region, socio-economic development of the region will always be

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dormant (Foster *et al*., 2017). While the Indian government has initiated several schemes to increase the usage of green energy-driven irrigation pumps, acceptance has been slow since the demand for environmentally friendly irrigation systems significantly surpasses the capacity of the pumps that are currently in use. Rather than a reliable and developed technology, the main obstacles to generating big commercial sales of solar water pumping systems are related to financial and market access issues (Central Energy Authority, 2022). Despite the fact that North East Region (NER) has enormous solar power potential for irrigation, the state's development in this sector has not been commensurate with the opportunities. To live a sustainable life, it is more crucial than ever to choose clean and green energy in light of increasing concern about global warming and increasing $CO_2$ footprints. Consequently, a solar photovoltaic-water-pumping system (SPVWPS) enables farmers to produce energy and become self-sufficient in their energy requirements. Therefore, the following section of the article briefly describes the solar energy prospects in NER, solar energy initiatives, plans and policies by the government for uplifting the usage of solar energy-based irrigation system.

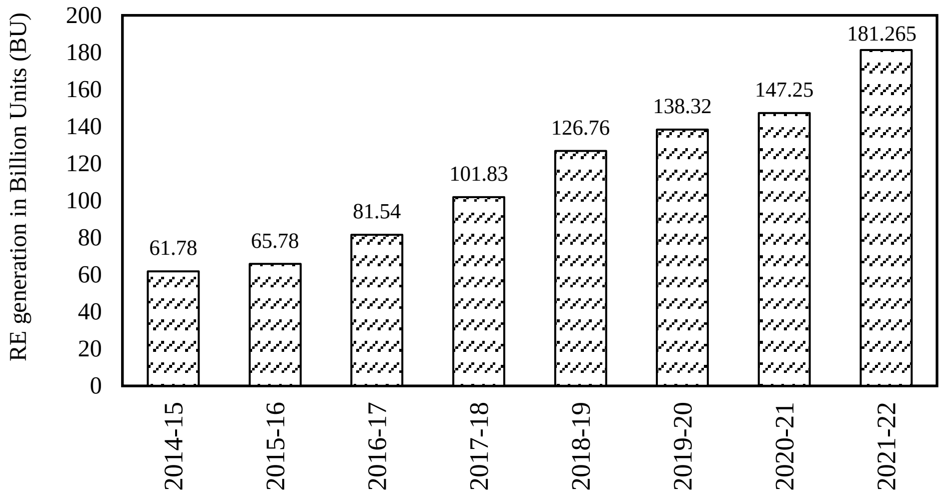


**Figure 1.** Power generation from RE sources excluding large hydro in BU (as of April 2022) (CEA energy 2022)

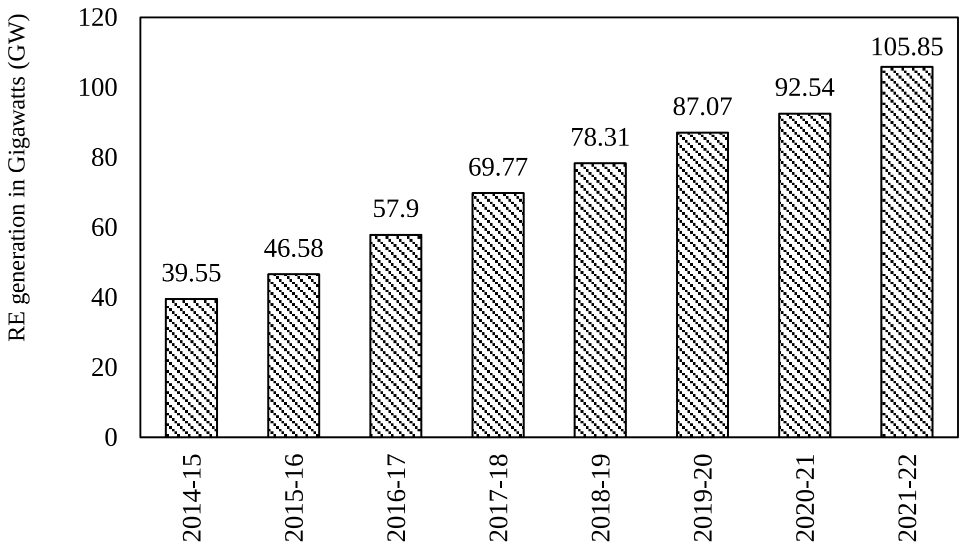


**Figure 2.** Installed capacity of RE sources excluding large hydro in GW (as of January 2022) (MNRE report 2020-21)

## 2. Energy Status in the Country

India has one of the greatest rates of global renewable energy growth. India is the fourth-largest producer of renewable energy, fourth in the world for wind power, and fifth for solar power. The requirement for power has increased significantly over the past several years as a result of the growth of the industrial and agricultural sectors (Jadhav *et al*., 2022). India's total primary fuel consumption in 2019 was 34.06 exajoules (EJ) of which just 0.04 % came from renewable sources, according to the Statistical Review of World Energy, 2020 (Statistical Review of World Energy, 2020). The Global Trends in Renewable Energy Investment 2020 research states that between 2014 and 2019, India's RE projects and programs garnered US$ 64.2 billion in investment. (4.7 lakh crore rupees). India's decadal fuel consumption from 2009 to 2019 increase was found to be 58%. Also, the primary energy consumption per capita in India increased from 17.7 Gigajoules (GJ) per capita to 24.9 GJ per capita in 2019. Based on gross generation from sources such as wind, waste, geothermal, solar, and biomass, excluding cross-border power supply, renewables consumption and renewables power generation in 2019 was 1.21 EJ and 134.9 Terawatt-hours (TWh), respectively. Globally, India accounted for a 4.8% share of RE production in 2019 as given in the report prepared by the Statistical Review of World Energy, 2020. Also, in 2019, solar energy generation increased to 46.3 TWh by 27.3% from 36.3 TWh in 2018. Based on the gross output, the electricity generation in India in 2019 was found to be 1558.7 TWh out of the global electricity generation of 27004.7 TWh, constituting a share of 4.8 %.

Each day, India receives an average of 6.5 kWh/m$^2$ of solar radiation (Kishore *et al*., 2017). According to MNRE, in January 2022, India had 152.36 GW of existing RE capacity or 38.56 % of the nation's total generation capacity. In April 2022, the production of RE rose to 13.54 billion units (BU), up from 11.64 BU in April 2021 and as of April 2022, the RE generation in the country is 181.265 BU. Figure 1 and Figure 2 gives the rise of generation RE and installed capacity over the past years without considering the energy from large hydro.

India has set a goal of producing 175 GW of RE by 2022 and 500 GW by 2030 (Giri *et al*., 2020). India's electricity demand is expected to expand to 817 GW by 2030, according to the Central Electricity Authority (CEA). Electricity consumption is expected to rise from 4,926 TWh in 2012 to 15,280 TWh in 2040 as the economy expands. In the past 7.5 years, India's installed RE production has grown by 286 % to more than 151.4 GW (including large hydro), accounting for nearly 39% of the nation's total capacity (as of December 31, 2021), with 300 GW (more than 60%) anticipated from solar power. In 2014, the percentage of installed RE capacity was only 8%, but this increased to 20% by 2021. As of January 2021, RE consumption increased from 61.2 Billion Units (BU) in 2014-2015 to 119.12 BU in 2020-21 (MNRE report, 2020-21). RE is now humanity's primary source of energy, as the electricity demand has skyrocketed (Sahoo, 2016; Thakur *et al*., 2022).

## 3. Status of solar pump usage in India

Solar pumps and solar irrigation are not new to India, as the first program to install solar pumps was initiated in 1993 by the MNRE (Rathore *et al*., 2018). Also, more than 10,000 times more energy is produced by solar radiation that reaches the surface of the planet in a single year (Sen *et al*., 2016). In 2010-2011, Jawaharlal Nehru National Solar Mission (JNNSM) previously called "Solar India," was launched in the country as global awareness and action regarding climate change increased. In the first phase of JNNSM, grid-connected power plants remained the focal point, but in the second phase, decentralized solar energy capacity development was a major focus. By 2021–2022, the JNNSM has raised the target for Grid Connected Solar Power Projects to 100,000 MW. The 100 GW proposal is broken down into two sections: a) 60 GW of grid-connected massive ground-mounted solar power plants, with a capacity of at least 1 MW. b) 40 GW of rooftop solar power plants. Purohit and Purohit (2018) used several solar radiation datasets and the observed data from 39 solar PV power plants spread throughout the nation to evaluate yearly energy production forecasts. For the projects in Batch-I and Batch-II, the mutual deviation of the techno-economic performance of the PV projects operating under Phase-I of NSM ranged from 14% to 27% and 12% to 31%, respectively. Before Pradhan Mantri Kisan Urja Surakhahsa evam Uttahan Mahabhiyan (PM-KUSUM) which was announced in the 2018-19 union budget, rooftop solar panels were the only way to add decentralized grid-connected solar power, but the concept of grid-connected solar pumps was introduced. The PM-KUSUM project proposed to deploy 17.50 lakh standalone solar farm pumps and solarize 10 lakh agriculture pumps that were linked to the grid. Between 2010 and 2020, the number of solar irrigation pumps in India increased to over 250,000 and the scheme has set an ambitious goal of installing more than 3.5 million solar irrigation pumps over the coming years. The components of PM-KUSUM combined would support the deployment of 30.80 GW of solar capacity. India installed 7.4 GW of solar power capacity in FY22, rising 335 % from 1.73 GW the previous year. MNRE's solar park development program also has a target capacity of achieving 40 GW by 2022, intending to simplify the setup of projects under a plug-and-play approach for solar project developers. The majority of solar pumps in India are currently supported by significant government subsidies (between 60 and 90% of the capital cost, translating to a financial outlay of INR 1,00,000 to 2,50,000 per farmer depending on the size of the pump) (Raymond and Jain, 2022).

### 3.1 Deployment of Solar Energy and Solar-based Irrigation Pumps in North East India

North Eastern region of India is blessed with abundant natural resources enough to produce RE to meet the energy demand. Solar is the most powerful energy source, with a total capacity of 62,300 MW in NER. Solar irrigation systems are the most advanced irrigation techniques available for addressing a variety of water loss issues as well as other concerns like labor and power needs (Tamoor *et al*., 2021). Water supply for domestic use can also be achieved sustainably and environmentally friendly using PV water pumping technology (Allouhi *et al*., 2019; Sontake and Kalamkar, 2016). However, the North-Eastern region of the country has not yet made effective use of its solar energy potential. Kalita *et al* (2016) conducted a thorough analysis of the viability of setting up a megawatt-level grid-connected solar photovoltaic (SPV) power plant in each of the state capitals of NE India. The study demonstrated that NER of India has great prospects for building up solar power-producing technology, making it possible to commercially collect the energy. Assam has only 117.94 MW of installed capacity from ground-mounted solar plants, although possessing the largest solar energy resource of 13,760 MW. As of April 2022, Assam generated 90.94 MU of solar energy constituting 80 % of the total solar energy production of the region. This was followed by Manipur with 8.57 MU of solar energy, constituting only 8 % of the region's solar energy generation. Arunachal Pradesh and Mizoram have been found to generate 2.14 and 3.78 MU from their 8650 MW and 9090 MW reserves, respectively. Despite the availability of huge solar potential, it is one of the most underutilized resources, with just 0.0086 % being harvested. The solar potential of Tripura, Manipur, Sikkim, Nagaland, and Meghalaya is 2080 MW, 10,630 MW, 4940 MW, 7290 MW, and 5860 MW, respectively. The solar generation from Meghalaya and Nagaland is negligible as collected from the latest data given by CEA. This means that if this resource is fully used, the amount of power produced will be proportional to the territory's need. Figure 3 and Figure 4 show the comparison of state-wise solar energy potential and ground-mounted solar energy generation in the NE region. Among the states of the NE region, Assam holds the highest amount of ground-mounted solar installed capacity, constituting 68 % of the total installed ground-mounted solar power plant, which is followed by Tripura contributing to 9 % of the total capacity. In the recent year 2021-2022, the total solar energy generation in the NE region is seen to follow an upward trend. The solar energy generation in January 2021 was 3.64 MU which increased to 9.19 MU in January 2022 with a difference of 5.55 MU.

Recently, under the Solar Park Scheme implemented by the government, Solar Parks has been approved to be set up in Arunachal Pradesh, Manipur, Meghalaya, and Mizoram with a capacity of 20 MW in each state. Due to slow progress, the 70 MW Amguri Solar Park in Assam and the 23 MW Solar Park in Nagaland were canceled. At the request of the State Government, the capacity of the Solar Park in Arunachal Pradesh was reduced from 30 MW to 20 MW. Also, during the Financial year 2020-21, under the Grid-connected Rooftop Solar program (Phase-II), a total capacity of 77.8 MW has been distributed to the electricity departments of various NE states achieving a total capacity of 84.3 MW to the selected NE states (Table 1). In the Phase-I of the program, the overall installed capacity of the eight NE states was 43.11 (as of 31-12-2020).

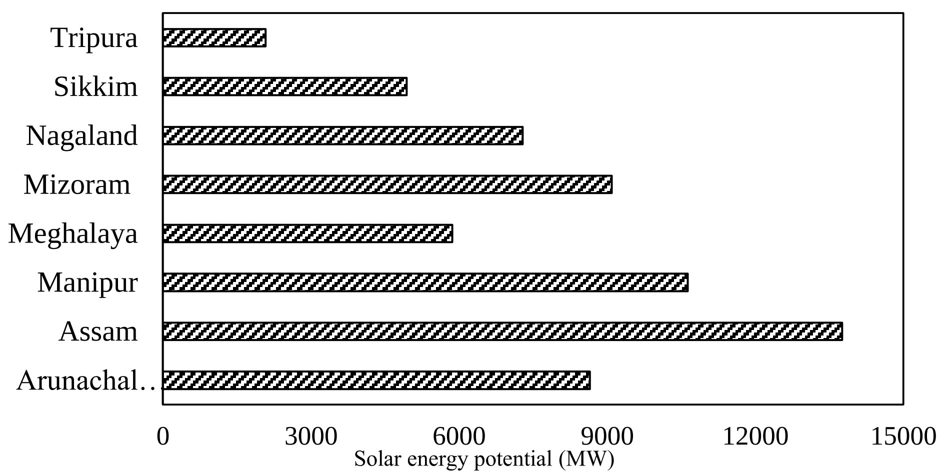


**Figure 3.** State-wise solar power potential of NER of India (MNRE report 2020-21)

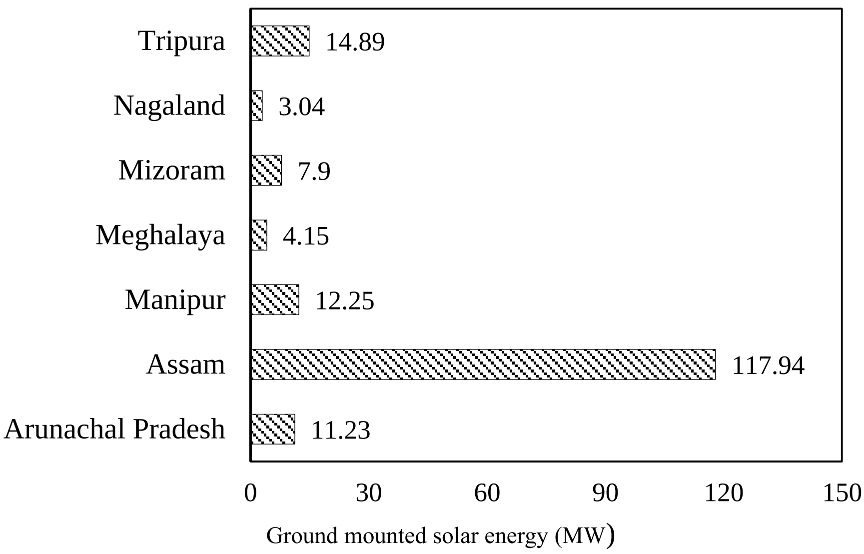


**Figure 4.** Ground-mounted solar installed capacity from NER as of April 2022 (CEA energy 2022, MNRE report 2020-21)

The PM-KUSUM Scheme offers subsidies for freestanding solar water pumps, grid-connected solar power plants up to 2 Megawatts, and the solarization of current grid-connected agricultural pumps. 1700, 1300, and 100 units of standalone solar pumps were given to Meghalaya, Tripura, and Manipur, respectively, under the PM-KUSUM Scheme in the NER for FY 2019-20. The slow uptake of solar pumps over the past few years, however, highlights the need for research into potential alternative strategies to promote solar pumps as well as a better understanding of the factors that influence how farmers choose among the irrigation options that are available to them (Raymond and Jain, 2018). As of December 31, 2020, Table 2 lists the installed solar pump units and solar power plants in the NER. Capital subsidies for SPVS (Solar photovoltaic system) and provisions for state energy utilities to purchase surplus power generated by farmers connected to SPVS are two of the most important policy interventions to promote the technology. The benchmark cost of a standalone solar pump unit with and without Universal Solar Pump Controller (USPC) for the NE region is presented in Table 3. To its credit, the government is pushing the farmers to construct standalone, photovoltaic off-grid water pumps so that they can not only satisfy their water demand but also generate additional revenue by selling surplus power to distribution firms.

**Table 1.** Allocated capacity under Grid-connected Rooftop Solar Program (Phase-II) (MNRE report 2020-21)

| State | FY 2019-20 (MW) | FY 2020-21 (MW) | Total allocated capacity (MW) |
|---|---|---|---|
| **Assam** | -- | 2.0 | 2.0 |
| **Manipur** | 0 | 1.0 | 1.0 |
| **Meghalaya** | 0 | 70.0 | 70.0 |
| **Mizoram** | 0.5 | 1.0 | 1.5 |
| **Nagaland** | 1.0 | 3.8 | 4.8 |
| **Sikkim** | 5.0 | 0.0 | 5 |
| **Total** | **6.5** | **77.8** | **84.3** |

**Table 2.** Installed solar pump units and solar power plant (as of December 31, 2021) (MNRE report 2021-22)

| States | Solar pump units | Solar power plant (KW) |
|---|---|---|
| Arunachal Pradesh | 22 | 963.2 |
| Assam | 45 | 1605.0 |
| Manipur | 54 | 1580.5 |
| Meghalaya | 54 | 2004.0 |
| Mizoram | 37 | 3894.6 |
| Nagaland | 3 | 1506.0 |
| Sikkim | 0 | 850.0 |
| Tripura | 572 | 867.0 |
| Total | 787 | 13,270.3 |

**Table 3.** Benchmark cost of standalone solar pump for NER as per MNRE specification (2021-2022)

| Pump Capacity | USPC | Benchmark Cost (Rs. /pump) without GST |
|---|---|---|
| 1 HP | Without USPC | 105509 |
| 2 HP | Without USPC | 134802 |
| 3 HP | Without USPC | 181175 |
| | With USPC | 217447 |
| 5 HP | Without USPC | 255647 |
| | With USPC | 306795 |
| 7.5 HP | Without USPC | 355371 |
| | With USPC | 408631 |
| 10 HP | Without USPC | 444536 |
| | With USPC | 511202 |

## 4. Solar energy technology based pumping system for irrigation

Solar energy system can be divided into two categories: those that convert solar energy into DC electricity and those that convert solar energy into heat. Both varieties have a wide range of uses in agricultural contexts, simplifying tasks and raising output. The first is solar power, sometimes known as photovoltaic (or PV). Solar cells called photovoltaics use light to create direct current (DC) power. When light energy reaches the cell, it causes the atoms in the material to lose their electrons. Power lines connected to the material's positive and negative sides can trap the electrons as a DC. Because the energy produced is largely in DC and the pumps are primarily accessible in AC, the inverter must convert the output energy to AC. A water pump can be positioned on the land or submerged in water (submersible pump). To benefit from gravity flow, it moves water up to a tank that is positioned at a specific height using a pump from the reservoir. The pump’s head is the height between the tank and the level of the water reservoir. When choosing pump to pump water from the reservoir into the tank, the head is a crucial consideration. Different configurations of solar irrigation water pumping system can be formed by various AC/ DC couples with or without storage backup. The angle of incident, cell temperature, and dust buildup on PV module surfaces, PV module deterioration, and motor-pump efficiency has the greatest effects on the performance of PVWPS systems (Hadwan and Alkholidi, 2018).

The complete solar pumping system is made up of panels, a support structure with tracking capabilities, electrical control components, cables, pipelines, and the actual pump.

i. **Solar modules or panels:** Solar panels are the key components that drive the solar pump. Many solar panels are connected in arrays to provide DC; connections are established utilizing series or parallel configurations to get the required voltage and power for the pump. PV cells present in the PV modules convert the sunlight irradiance directly into electricity (Verma *et al*., 2020).

ii. **Solar pump:** Centrifugal or submersible pumps are the most common type of pumps used in the SPVWPS. They are connected to the solar array by using the DC power generated in the solar panels. For solar pumps to operate well, accessories including filters, float valves, and switches are installed. Solar pumps are made of low lead marine grade bronze and stainless steel, and they are rust and maintenance-free so they may operate in a tough environment for a very long time (Sawant and Jadhav, 2020). Any of the following pumps are used by the SPVWPS in India: a) Surface mounted pumps b) Submersible pumps c) Floating motor pumps d) Any other pump set with ministry clearance (Rathore *et al*., 2018).

iii. **Motor:** Several types of AC motors and DC motors are used in SPWPS. The right motor should be chosen based on the system's size, efficiency, cost, power input, availability, and maintenance status. The use of an inverter increases energy and cost and, to some extent, reduces system efficiency (Verma *et al*., 2020).

iv. **Support structure and tracking system**: The mounting solar panels are kept steady by the support framework, which also protects them from theft and environmental risks. To guarantee required water production, a manual tracking device is mounted to the support structure. By allowing the panels to face the sun as it moves across the sky, tracking boosts water output.

v. **Electrical connections:** The system consists of junction boxes, connectors, switches, and a set of connections that are the appropriate size**.** In the case of lightning or a circuit breaker, safety is ensured by the provision of an earthing kit. If A.C. pumps are utilized, the SPVWP's three main electronic components are the Maximum Power Point Tracker (MPPT), Inverter, and Controller.

## 5. Solar photovoltaic irrigation water pumping system: technical, economic, and environmental feasibility

SPVWPS improves farmers' quality of life by providing reliable and cheaper power for irrigation. It also helps to address issues related to gender, education, and health. Solar pumping systems are technically possible in places where the average daily sunlight is between 4 $kWh/m^2/day$ and 5 $kWh/m^2/day$, based on the solar radiation required for the operation of a solar irrigation system (Diop *et al.*, 2020). In India, SPVWPS with capacities of 3 HP and 5 HP are typically employed for irrigation purposes. Big capacity pumps tend to cause declination of groundwater level. The feasibility of SPVWPS can be examined using the efficiency of the PV array, subsystem, and overall system, including the performance factor (the ratio of field performance to theoretical performance) (Santra, 2021). The comparison between SPV, diesel-powered, and electric-powered pumps for pumping irrigation water is presented in Table 4.

**Table 4.** Comparison between PV and other available water pumping system (Rathore *et al*., 2018) (Mantri *et al*., 2020)

| | SPV-Pump | Diesel Pump | Electrical Water Pump |
|---|---|---|---|
| **Advantage** | • Minimum maintenance cost<br>• Low environmental issues<br>• Low maintenance and<br>• No fuel is needed<br>• Easy to install<br>• Easy to operate<br>• Can be used as an anchor load for charging batteries, solar lamps and etc. | • Moderate initial cost<br>• Can be operated at any time of the day and night<br>• Easy availability of sales and services<br>• High life cycle cost | • Easy to install<br>• Can be portable<br>• Easy availability of sales and services<br>• Moderate initial cost |

| | | | |
|---|---|---|---|
| **Disadvantage** | • Solar radiation required<br>• High initial cost<br>• Low life cycle cost in remote areas | • High maintenance and operating cost<br>• Generate air and noise pollution<br>• Constant supervision required<br>• Lack of maintenance shortens life span<br>• Continuous fuel supply required | • High operating cost<br>• Poor and interrupted power supply extends downtime<br>• Access to the electricity grid is necessary. |

In Rajasthan, India, (Santra, 2021), assessed the potential of 1 HP solar PV pumps to lift and irrigate using a pressurized irrigation system and found that mini-sprinklers, micro-sprinklers, and drippers could be successfully operated by the SPVWPS of either the DC or AC type with good irrigation uniformity. A solar PV pumping system of 1 HP was found to be marginally less expensive than an equivalent AC pumping system but had a significantly smaller carbon footprint compared to other energy-efficient pump systems. According to a life cycle cost estimate, a 1 HP solar pumping system would cost about Rs.19,90,875.00 ($25,000) less per year than a comparable AC pump for the same output. Mantri *et al.* (2020) assessed the techno-economic performance (array area, PV array output for a given location and tilt) of grid-connected SPVWPS with off-grid systems in Andhra Pradesh, India. The 1.2 HP off-grid SPVWPS used 4.29 kWh of electricity per day to successfully irrigate 1.3 acres with a flow rate of 20.62 $m^3$. In 2020, (Gautam and Singh, 2020) conducted a cost analysis of pearl millet produced under the SPVWPS. The total cost of growing pearl millet was estimated to be INR 30,779.63, with a net return, including irrigation fees, of INR 4,347.89 per hectare. Yadav *et al.* (2020) examined the impact and efficiency of SPVWPS on livelihood, social, and economic aspects in Maharashtra, India, and discovered that when SPVWPS was used, the area of study produced 7 quintals more wheat and 13 quintals more cotton per acre. Additionally, when SPVWPS was combined with a drip irrigation system, chili producers noticed a noticeable increase in chili production of between 15 and 25 %.

For various pressure heads, Tiwari and Kalamkar (2022) examined the performance of the SPVWPS with a helical rotor pump (4 bar, 6 bar, 13 bar, 8 bar, and 10 bar) in Nagpur which receives the sun's total energy at the irradiance range of 400 to 800 $W/m^2$. The influence of radiation fluctuation on pump performance revealed that the total head of 10 bar, which is recommended for helical rotor submersible pumps, provided the best system efficiency. Kishore *et al.* (2017) examined the performance of 16 SPVWPS in Bihar for a year (2013) in the Nalanda District of Bihar. Farmers were able to cultivate paddy throughout the region using solar pumps to water the soil even though approximately 40% of other land remained left fallow due to serious drought. A 9–10% rise in rice and wheat yields as well as a bigger gain in farmers' net income was both brought about by the availability of solar pumps for irrigation. Research on the potential for solar energy in eastern India's groundwater pumping was performed by Rahman and Bhatt (2014). The research revealed that between 9:30 am to 2:30 pm, the network's nominal power fluctuated between 1.8 and 2.5 kW. Additionally, they demonstrated that in this region, solar energy of 3000-watt peak (Wp) can operate a 3 HP pump for 5 hours. They concluded that in the eastern region of India, a 1000 Wp network is necessary for operating a 1 hp subsurface pump. Maurya *et al.* (2015) concluded that discharge of 1.3 $m^3$/hr to 2.6 $m^3$/hr of water may be moved by a 50 W photovoltaic solar panel powering a 12 Volt pump. Solar pumps can compete with diesel pumps using conventional energy sources by delivering water up to 500 m below the water table at a discharge rate of 500 $m^3$/day. Kumar *et al.* (2015) designed an SPVWPS of 4 and 5.5 kW by using PVsyst 7.1.1 and used the system in two distinct agricultural fields that use drip irrigation and flood irrigation in Tamil Nadu, India. The case study's findings indicate that with the usage of SPVWPS and a 25 year project lifespan, a farmer might profit by at least 250% on their investment. Using SPVWPS, Pande *et al.* (2003) created a drip irrigation system for arid areas. They took into account important design elements such as the required water volume, the pump's size, the variation in the pumping head induced by changes in solar radiation during the day, and pressure correction in the atomizers. According to their findings, an SPVWPS can deliver discharge between 3.4 and 3.8 L/hr with a 900 W PV array and an 800 W mono-block DC pump at pressures between 70 and 100 kPa at each dripper during the day. The different models of SPVWPS suggested by MNRE are given in Table 5. SPVWPS was recommended for orchards in arid areas using water harvesting tanks with lower suction heads. The SPVWPS has been considered to be more economical, eco-friendly, and reliable, with less maintenance and a longer life span in comparison to diesel-powered water pumps and electric pumps. Compared to diesel and wind-powered water pumping systems, solar-powered water pumping systems were found to be more cost-effective at low pumping capacities (Aliyu *et al.*, 2018). SPVWPS preserves the environment by decreasing carbon emissions and increasing the carbon sink. Table 5 represents the different models along with the specification for surface and submersible solar pumps available in India.

**Table 4.** Technical Specifications of Shallow Well (Surface) and Deep well (submersible) Solar Pumping Systems with AC and DC Motor Pump Set as per MNRE

| | Description | PV Array ($W_p$) | Motor Pump-set capacity (HP) | Shut Off Dynamic Head (m) | Water output (L/Day) | | Total Head (m) |
|---|---|---|---|---|---|---|---|
| | | | | | DC | AC | |
| Shallow Well (Surface) | Model-I | 900 | 1 | 12 | 99000 | 89100 | 10 |
| | Model-II | 1800 | 2 | 12 | 198000 | 178200 | 10 |
| | Model-III | 2700 | 3 | 12 | 297000 | 267300 | 10 |
| | Model-IV | 2700 | 3 | 25 | 148500 | 132300 | 20 |
| | Model-V | 4800 | 5 | 12 | 528000 | 475200 | 10 |
| | Model-VI | 4800 | 5 | 25 | 264000 | 235200 | 20 |
| | Model-VII | 4800 | 5 | 45 | 182400 | 168000 | 30 |
| | Model-VIII | 6750 | 7.5 | 12 | 742500 | 641025 | 10 |
| | Model-IX | 6750 | 7.5 | 25 | 371250 | 330750 | 20 |
| | Model-X | 6750 | 7.5 | 45 | 256500 | 236250 | 30 |
| | Model-XI | 9000 | 10 | 12 | 990000 | 890000 | 10 |
| | Model-XII | 9000 | 10 | 25 | 495000 | 441000 | 20 |
| | Model-XIII | 9000 | 10 | 45 | 342000 | 324000 | 30 |
| Deep well (submersible) | Model-I | 1200 | 1 | 45 | 45600 | 42000 | 30 |
| | Model-II | 1800 | 2 | 45 | 68400 | 63000 | 30 |
| | Model-III | 3000 | 3 | 45 | 114000 | 105000 | 30 |
| | Model-IV | 3000 | 3 | 70 | 69000 | 63000 | 50 |
| | Model-V | 3000 | 5 | 100 | 45000 | 42000 | 70 |
| | Model-VI | 4800 | 5 | 70 | 110400 | 100800 | 50 |
| | Model-VII | 4800 | 5 | 100 | 72000 | 67200 | 70 |
| | Model-VIII | 4800 | 7.5 | 150 | 50400 | 43200 | 100 |
| | Model-IX | 6750 | 7.5 | 70 | 155250 | 141750 | 50 |
| | Model-X | 6750 | 7.5 | 100 | 101250 | 94500 | 70 |
| | Model-XI | 9000 | 10 | 150 | 70875 | 60750 | 100 |
| | Model-XII | 9000 | 10 | 70 | 207000 | 189000 | 50 |
| | Model-XIII | 9000 | 10 | 100 | 135000 | 126000 | 70 |

The utilization of SPVWPS is popular globally for its various advantages over other water pumping systems. Gutierrez *et al.* (2021) in Chile, developed an SPVWPS driven by a standard alternating current surface pump and a variable frequency inverter, and assessed the performance ratio (PR) to check the hydraulic efficiency of the photovoltaic pumping system. On days with solar irradiation exceeding 7.3 peak sun hours (PSH) and days with PSH less than 3, the designed system could pump a flow of more than 45 m3/day for more than 5 hours at pressures over 4.7 bar for the former and 8 m3 of water at a pressure above 4.1 bar for the latter. This type of PV system can be used to pump water for irrigation or storage systems and is a viable option for small farmers in remote places where a power grid is not available or those who wish to integrate PV energy with the existing traditional water pumping system. Based on the geographic and meteorological position of Isfahan city, Iran, Chahartaghi and Nikzad (2021) developed the ideal size of an SPVWPS depending on the net irrigation water requirement of a potato crop in a 1 ha plot of land. The optimal PV array size and number with a power rating of 9.6 kW of the polycrystalline kind were examined (16 series PV modules in 2 parallel string format). The electricity output of the recommended SPVWPS ranged from 3.99% to 6.81% and increased with irradiation levels while falling with ambient temperature. The proposed method is expected to cut annual carbon dioxide emissions by around 4.8 tonnes, which is equivalent to 11.1 barrels of crude oil. Carrêlo *et al.* (2020) compared the economic viability of five SPVWPS in the Mediterranean region, between 40 and 360 kWp. Switching from fossil fuel to solar-powered pumps helps preserve the environment. By lowering $CO_2$ emissions (25.3 million tonnes and 2.5 million tonnes from the replacement of 1 million diesel pumps and 1 million electric pumps, respectively), switching from fossil fuel to solar-powered pumps helps preserve the environment. Nikzad *et al.* (2019) designed and developed an SPVWPS in Iran to replace the conventional pumping system to irrigate a 1 ha rice field using the flooding (basin) irrigation method by estimating the PV array's ideal capacity with a 1.2 kW output power, a portrait installation, and a 6 × 2 lay-up (6 series modules in 2 parallel strings). If the proposed off-grid PVWPS is only used during the irrigation period at an ideal PV array tilt angle of 15°, it might reduce the wasteful use of 3570 $m^3$ of fossil fuels as well as 2754 L of water in Iran's thermal energy plants during the length of the project. At the USDA-ARS research facility in Bushland, Texas, Vick and Clark (2007) examined the performance of four solar PV-powered diaphragm pumps. These pumps were put through several simulated pumping heads of testing. Two pumps were tested at various pumping heads of 20, 30, 50, and 70 m with 100 W of PV power and 50 m and 70 m with 160 W of PV powers, with flow rates varying from 2 to 8 L/min. The other two pumps were utilized for shallow pumping heads and moderate flow (9–15 L/min) (10–30 m). They concluded that the diaphragm pumps provided 1650 and 3650 L/day at 70 m and 30 m, respectively, pumping heads. Ghoneim (2006) reported on the outcomes of performance tuning of a photovoltaic water pumping system for the environment in Kuwait. To maximize system efficiency, a direct coupled SPVWPS was built using a PV array, centrifugal pump, DC motor, storage tank, and maximum power point tracker. In a distant location in Kuwait, 300 people's domestic requirements will be met by the pumped water. Analysis showed that for the year, a deep well should be pumped daily with a volume of 12 $m^3$, assuming a daily water consumption rate of 40 L/person. Posorski (1996) studied the technical maturity and cost-effectiveness of SPVWPS through a pilot project in Germany and found that for community drinking water delivery systems, SPVWPS systems can effectively replace water pumping systems powered by diesel engines. Economically, a solar PV pump set is best for distributing electricity for irrigation, but these pumps are vulnerable to theft and need a certain level of technical expertise for optimal operation and maintenance. Additionally, if SPVWPS are not properly controlled and monitored, there is a risk of excessive groundwater withdrawal and inefficient water use since low energy prices might result in unmanageable water demand. The SPV pump may be a dependable source for irrigation by instilling a feeling of social responsibility in users.

## 6. Conclusion

The current the study presents the prospect of using SPVWPS in the Northeast region of India. Due to the rising industrialization, automation, and urbanization, the region has an increasing need for energy. By producing power from RE sources, particularly solar energy, this energy constraint may be reduced and the agricultural productivity can be increased. The Indian government has tried to develop policies for growth and SPVWP development, but the utilization of SPVWPS is still stagnant in the NE region. More work and resources must be put into this area to support research and development efforts so that solar energy can be used to provide the appropriate amount of power required to perform agricultural activities. The NE region should also take the required actions to encourage individuals to use solar PV systems as their main source of energy for irrigation related activities.

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