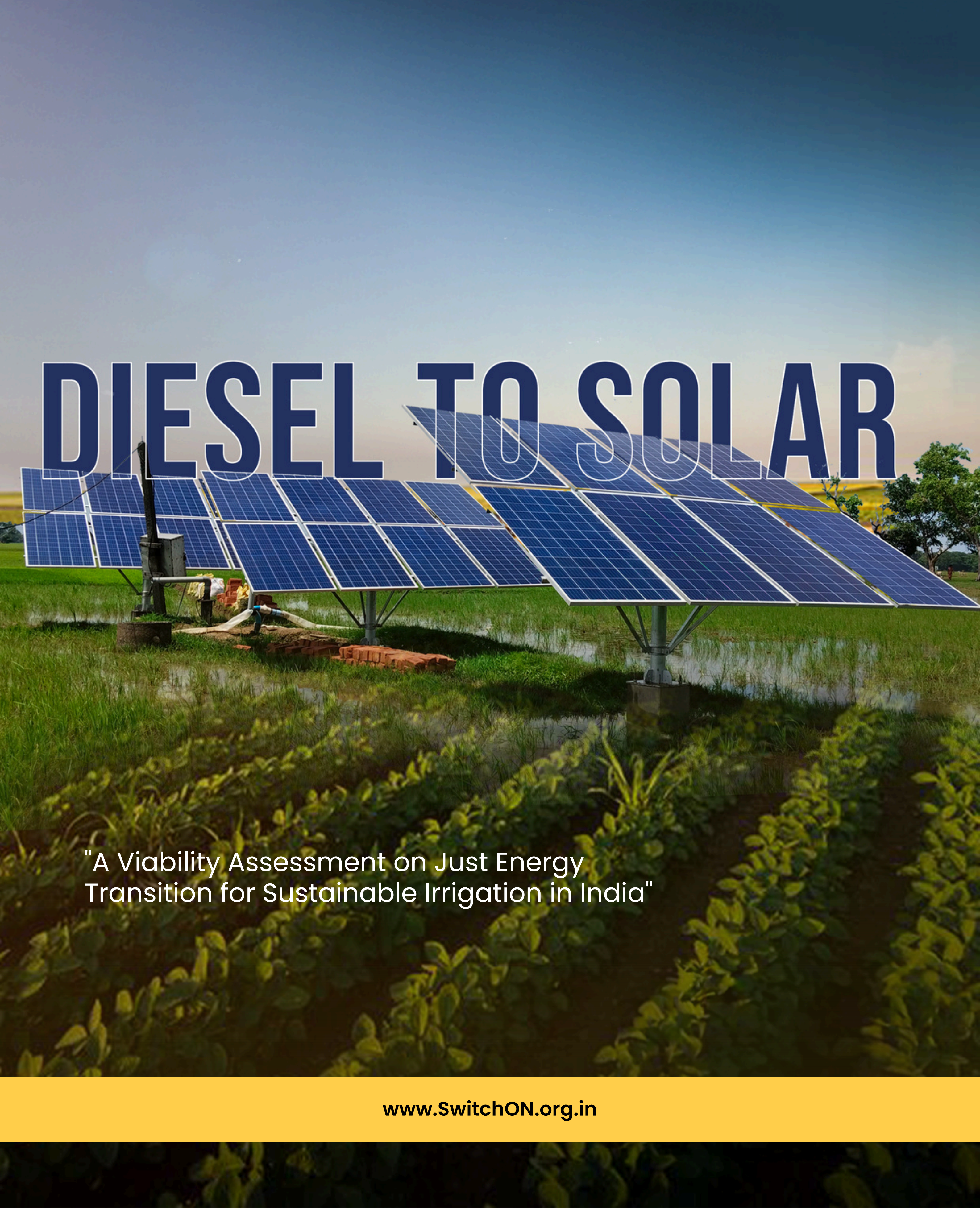

SWITCH ON FOUNDATION

DIESEL TO SOLAR

"A Viability Assessment on Just Energy Transition for Sustainable Irrigation in India"

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Founded in 2008, the Environment Conservation Society (ECS), also known as SwitchON Foundation, is a nonprofit organization dedicated to fostering equitable and sustainable development in India. Our vision is to build a sustainable and equitable India, focusing on Clean Energy, Clean Air, **Sustainable Mobility**, Climate Smart Agriculture, Conservation and Integrated Management of Natural Resources, Just Transition, Skilling, and Sustainable Cities. Our mission is to promote sustainable livelihoods and address environmental challenges through innovative business models and technologies, aiming to create opportunities for 10 million people at the bottom of the pyramid by 2030.

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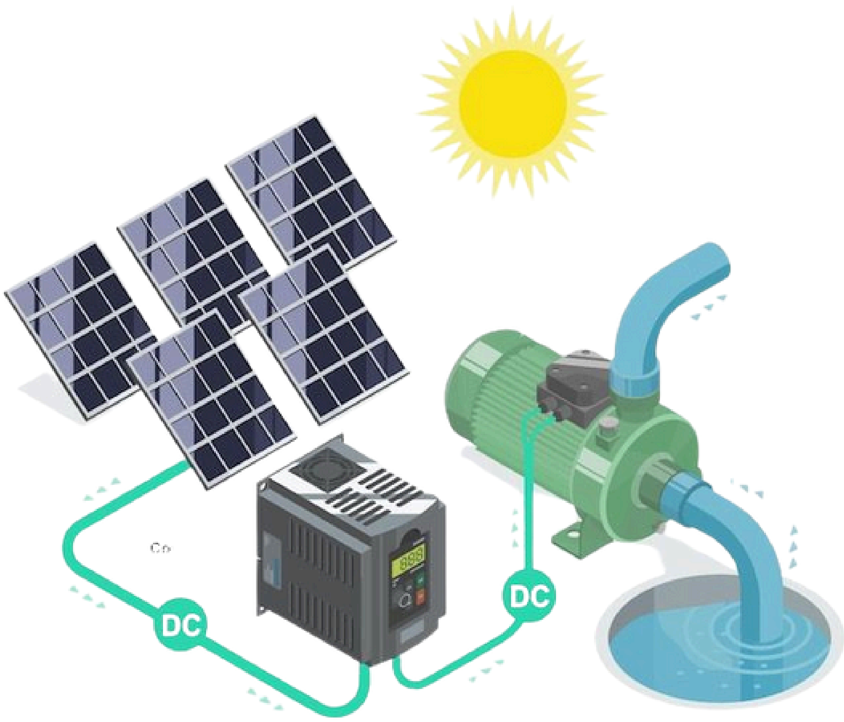
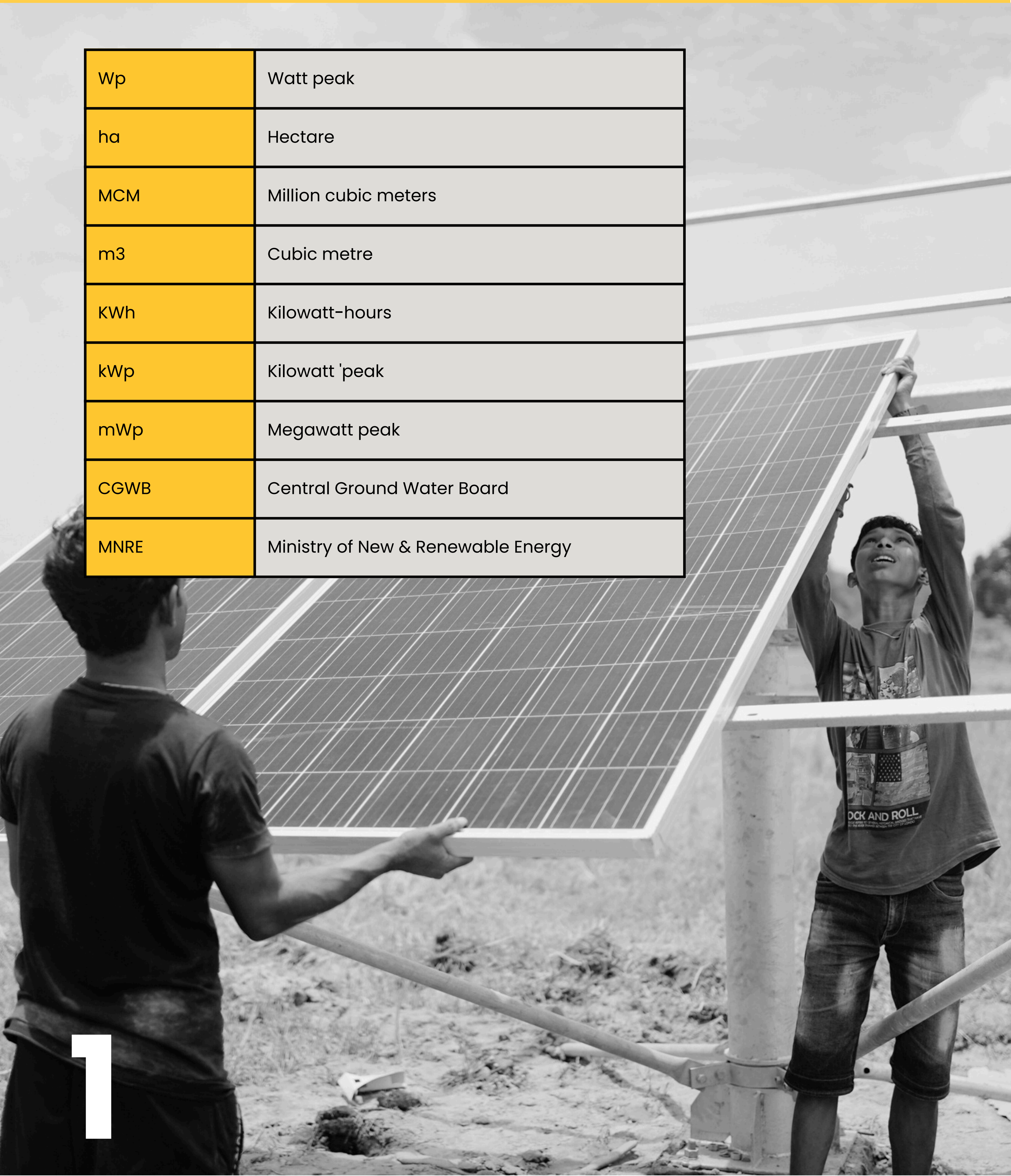


ABBREVIATION

Wp	Watt peak
ha	Hectare
MCM	Million cubic meters
m3	Cubic metre
KWh	Kilowatt-hours
kWp	Kilowatt 'peak
mWp	Megawatt peak
CGWB	Central Ground Water Board
MNRE	Ministry of New & Renewable Energy



EXECUTIVE SUMMARY:

India’s extensive solar resources present a significant opportunity for solar pump-based irrigation, with over 300 sunny days annually across the country. By 2019, India had installed 181,521 solar water pumps, with Chhattisgarh and Rajasthan leading the adoption, having installed 119,282 and 107,500 pumps respectively. This study evaluates the effectiveness of these systems across India, focusing on geographical distribution, government initiatives, agricultural impact, and economic viability.

The study, based on secondary data from government reports and research publications (2018-2024), utilized a qualitative approach to analyze the impacts of solar water pumps on rural irrigation. India’s solar water pump installations have seen notable growth, particularly in Rajasthan, which experienced a 123% increase from 2019 to 2023. Chhattisgarh also showed significant growth, with nearly doubling the number of pumps. Rajasthan's photovoltaic power potential of 5.0 kWh/m^2 highlights its capacity for solar energy utilization.

Government schemes such as the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM KUSUM) and the Jawaharlal Nehru National Solar Mission (JNNSM) have been instrumental in promoting solar pump adoption. PM KUSUM offers subsidies of at least 30%, with additional bank financing options, while JNNSM provides a 30% subsidy for off-grid solar power systems. States like Rajasthan benefit from a combined subsidy of up to 86%, and Maharashtra offers a substantial 95% subsidy through its Saur Krushi Pump Scheme.

The adoption of solar pumps has substantially impacted agriculture by increasing cropping intensity and expanding cultivated areas. For instance, in Chhattisgarh, the installation of solar pumps led to a rise in cropping intensity from 121.63% to 181.60%, with farmers diversifying into seasonal and summer crops. Rajasthan saw similar improvements, with increased cropping intensity and expanded gross cropped areas.

Environmentally, solar pumps contribute to significant reductions in carbon emissions and diesel consumption, addressing climate change and pollution concerns. Economic analyses demonstrate that while solar pumps require a high initial investment, they are more cost-effective in the long term compared to diesel pumps. Solar pumps offer substantial savings on fuel and maintenance costs, with cumulative savings estimated at ₹117,738 over 20 years versus a diesel pump's total cost, which is 4.5 to 5 times higher. Additionally, solar pumps lead to environmental benefits, including a reduction in CO2 emissions and improved water conservation.

Despite these benefits, the high initial cost of solar water pumps remains a significant barrier to widespread adoption. Challenges include limited operational skills, availability of spare parts, and the shortage of skilled technicians. Addressing these issues through innovative financing and enhanced support mechanisms is crucial for maximizing the potential of solar irrigation technology in transforming rural agriculture in India.

1. INTRODUCTION:

India, with its abundant solar resources, experiences over 300 sunny days annually, making it an ideal candidate for solar pump-based irrigation. As of 2019, the country had 181,521 solar water pumps, and by 2024, Chhattisgarh and Rajasthan led with 119,282 and 107,500 pumps respectively. Solar pumps enhance agricultural productivity and farmer income, significantly increasing cropping intensity. Despite high initial investments, they also reduce crop production costs and offer long-term economic benefits.

Government initiatives like PM KUSUM and JNNSM have been pivotal in promoting solar pump adoption through substantial subsidies. However, widespread adoption faces challenges due to high initial costs, farmers' lack of operational skills, limited spare parts availability, and a shortage of skilled technicians. This study explores the geographical distribution, government initiatives, agricultural impact, and economic viability of solar pump-based irrigation in India, highlighting both the benefits and challenges of this sustainable technology in transforming rural irrigation practices.

2. METHODOLOGY

2.1 Study Design

This study is based on a secondary research process that utilizes data from government reports and research publications issued between 2018 and 2024. The primary focus was on the irrigation techniques operated by solar water pumps used in rural areas across India.

2.2 Research Approach

An inductive research logic was adopted, using secondary data to acquire insights. The research process was guided by a qualitative research approach, empowered by an in-depth evaluation of the observed data.

2.3 Data Collection and Analysis

All secondary data were collected from relevant government reports and research documents. These data were systematically analyzed to visualize the impacts and implications of solar water pump usage in rural irrigation practices across various regions of India. The qualitative nature of the research approaches helps to contextualize the major study outcomes from the secondary sources.

3. GEOGRAPHICAL DISTRIBUTION OF INSTALLED SOLAR PUMP

India has abundant solar resources, experiencing over 300 clear sunny days annually. The country's solar radiation ranges from 4 to 6 kWh/m² daily (ICID, 2019). At this present time, farmers are highly aware of the increasing cost of diesel and the limited access. With the help of government subsidy schemes and awareness campaigns solar water pump adaptation rates rapidly increase. As per the data from the Government of India Ministry of New and Renewable Energy, the country's number of solar water pumps was 1,81,521 by 2019 (sansad, 2019). According to reports published by MNRE in 2019, the state of Chhattisgarh has 61,970 solar water pumps (table 1).

Table 1. India's Leading States for Solar Pumps and Power Potential in 2019 and 2023

Sl no.	State name	No. of solar water pump in 2019	No. of solar water pumps in 2023	Growth rate (%)	Photovoltaic power potential (kWh/kWp)
1	Chhattisgarh	61,970	119,282	92%	4.4
2	Rajasthan	48,175	107,502	123%	5.0
3	Andhra Pradesh	34,045	34,035	-0.02%	4.4
4	Uttar Pradesh	20,546	41,423	101%	4.2
5	Madhya Pradesh	17,813	25,047	40.6%	4.4

(Source: Yashodha, Sanjay, & Mukherji, 2021, Statista, 2024, Global Solar Atlas, 2023)

The table highlights the growth of solar water pumps in various Indian states from 2019 to 2023, with Rajasthan showing a notable increase from 48,175 to 107,502 pumps (refer to figure 1). This significant growth underscores Rajasthan's massive solar potential, supported by its high photovoltaic power potential of 5.0 kWh, the highest among the listed states (Global Solar Atlas, 2023) (refer to Annexure 2). Chhattisgarh also saw considerable growth, with the number of solar pumps nearly doubling, indicating a strong push towards solar energy. The state of Gujarat also has massive potential for expanding the use of solar pumps for its photovoltaic power potential. Rajasthan experienced the highest growth rate in solar water pump installations from 2019 to 2023, with a remarkable increase of 123%, followed by Uttar Pradesh at 101% and Chhattisgarh at 92%. In contrast, Andhra Pradesh saw a slight decline of 0.02% in the same period (refer to table 1).

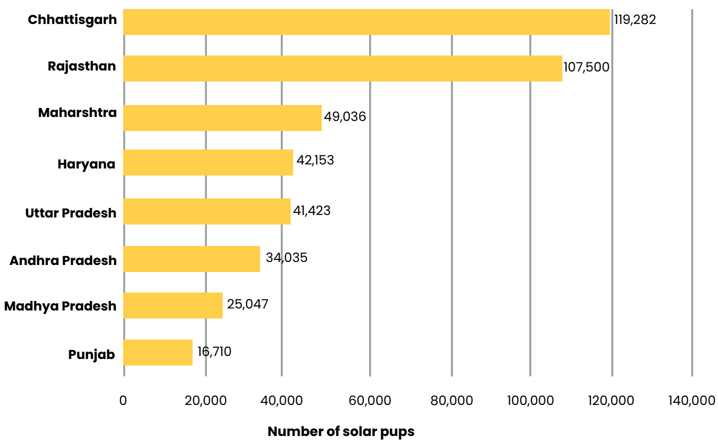


Figure 1: State-wise number of Solar pumps (Source: Statista, 2024)

The Press Information Bureau stated in their report Union Minister for Power and New and Renewable Energy announced that over 295,000 standalone off-grid solar water pumps have been installed across India under Component B of the PM-KUSUM scheme for farmers (pib, 2024).

4. GOVERNMENT INITIATIVES

All government schemes aim to de-dieselize the farm sector, providing water and energy security to the farmers. In addition, these schemes also ensure the increasing income rate of farmers.

PM Kusum: The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM) Yojana was launched in March 2019 and comprises three main components: A, B, and C. Under this scheme, the State Government offers a subsidy of at least 30%, with the farmer responsible for the remaining 40%. Farmers can also avail bank finance, allowing them to pay only 10% of the initial cost, with the remaining 30% covered by a loan (MNRE, 2024).

JNNSM: The Jawaharlal Nehru National Solar Mission (JNNSM), or the National Solar Mission, is an initiative of the Government of India and State Governments to promote solar power in India which was inaugurated in January 2010. The Ministry, under the Off-grid and Decentralized Solar Applications scheme of Jawaharlal Nehru National Solar Mission (JNNSM), provides a subsidy of 30% of the project cost ranging from Rs. 30/- to Rs. 63/- per watt peak for off-grid SPV power plants having module capacity upto 100 kWp depending on their capacity and configuration in general category states.

Table 2: Subsidy rate of solar water pump in different states in India

Sl No.	Name of the state	Name of the schemes	Subsidy %
1	Rajasthan	Jawaharlal Nehru National Solar Mission (JNNSM) + Rashtriya Krishi Vikas Yojana (RKVY) and Ministry of New and Renewable Energy (MNRE)	30% + 56% = 86%
2	Gujarat	The government of Gujarat	30%
3	Maharashtra	Saur Krushi Pump Scheme 2024	95%
4	Tamil Nadu	State 40% + Union government and MNRE 30% • An additional 20% subsidy will be provided for small and marginal farmers belonging to the SC/ST category.	70% & 90% for SC/ST farmers category

Government initiatives like the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM KUSUM) and the Jawaharlal Nehru National Solar Mission (JNNSM) aim to reduce the reliance on diesel in the farm sector, enhance water and energy security, and increase farmers' income. Under PM KUSUM, farmers receive a subsidy of at least 30%, with options for bank finance. JNNSM provides a 30% subsidy for off-grid solar power plants. Chhattisgarh and Rajasthan lead in solar water pump installations, benefiting from substantial subsidies. For instance, Rajasthan offers an 86% subsidy through combined schemes, while Maharashtra provides a 95% subsidy under the Saur Krushi Pump Scheme.

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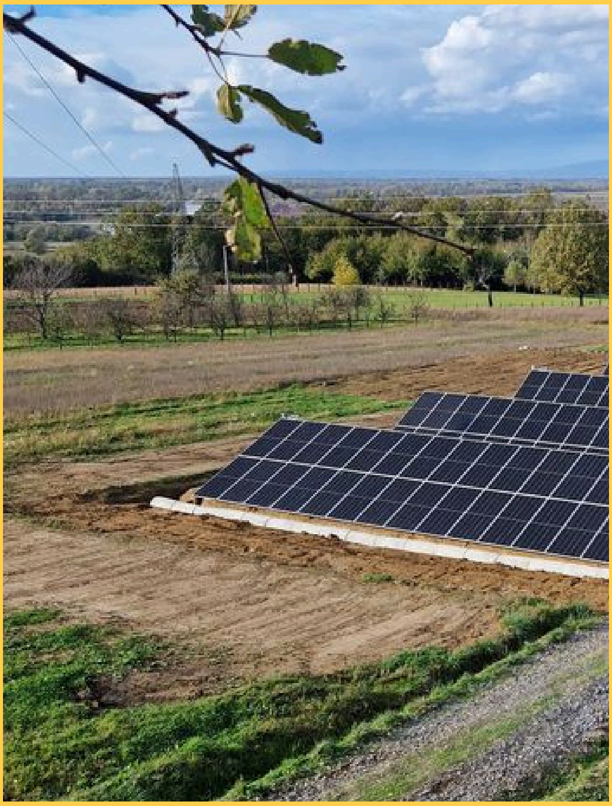
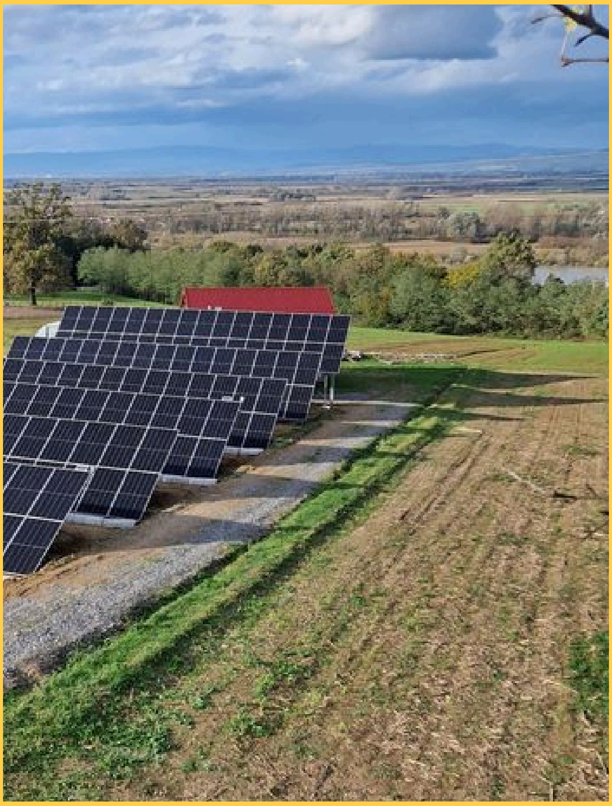
5. IMPACT ON AGRICULTURE





The agriculture sector is the largest employer and contributes about 16% to the country's GDP (statista, 2024). The installation of sustainable technology enhances crop intensity and positively impacts farmers' cropping patterns. It also positively affected farmers' income patterns by reducing their production costs. A research report on Raipur district in Chhattisgarh shows that after installing solar water pumps, farmers changed their cropping patterns. They expanded their total cultivated area and started growing crops like peas in the Rabi season and coriander in the summer season. Additionally, the total cropped area increased from 3.63 hectares to 5.43 hectares, and cropping intensity rose from 121.63% to 181.60% (Chandrakala *et al.* 2023).

Rajasthan, with its average solar insolation of 6–7 kWh/m²/day and about 325 sunny days per year, is the most promising region in the country for harnessing solar energy. In the Jaipur and Sikar regions, the average cropping intensity has increased by 2-10%, while in Bikaner, it has increased by 2-9% after installing solar water pump. The gross cropped area has expanded by approximately 12-53% in Jaipur and by 10-116% in Bikaner (Gupta, 2019).

6. ENVIRONMENT AND ECONOMIC VIABILITY

Solar energy helps prevent environmental pollution by reducing carbon emissions by substituting fossil fuel-based pumps. While diesel pumps emit CO_2 gas that contribute to climate change and pose health risks, solar pumps avoid these issues (Kanna *et al.*, 2020). It significantly lowers electricity and diesel consumption, linked to high carbon emissions. Fuel-based irrigation pump energy use in the US produced 12.6 million metric tonnes of CO_2 in 2018 (Driscoll *et al.*, 2024). A study on greenhouse gas emissions from on-farm irrigation pumps in Egypt found that diesel pumps emit approximately 1.35 kg of CO_2 per kilowatt-hour (kWh) of electricity generated (El-Gafy *et al.*, 2016). Another study in Morocco estimated that diesel pumps emit around 14,977 kg of CO_2 per year, highlighting the environmental and economic benefits of switching to solar water pumps (Hilali *et al.*, 2022).

In contrast to solar water pumps, diesel water pumps are cheaper initially but become expensive to operate and maintain (refer to Table 2). The switch from diesel to solar pumps is particularly beneficial due to the high cost of diesel (Gupta, 2019). Solar water pumps, although they have a high initial cost, least minimal operational and maintenance expenses.

A recent study by the International Copper Association-India (ICA) and the International Institute of Energy Conservation (IIEC) in Haryana and Chhattisgarh found that solar pumps reduce farmers' daily workload, improve farm productivity, and increase average income. In Chhattisgarh, 36% of farmers and in Haryana, 14% of farmers reported a 50% increase in annual income. Additionally, 82% of farmers confirmed a 25% increase in earnings after installing solar water pumps (Karmakar, 2023).

Table 3: Cost comparison of a Diesel pump and Solar water pump

Costing	Year 1 (in USD)	Year 10 (in USD)	Year 20 (in USD)
Solar water pump			
Capital Cost	46644	0	0
Servicing cost	0	574	673
Maintainance cost	0	32,163	37684
Cumulative total cost	46644	79381	117738
Diesel Pump			
Servicing cost	500	2,873	3,501
Maintainance cost	0	8620	6386
Fuel and delivery cost	6980	74,338	2,58,509
Total cost	7480	136240	553441

(Source: Kanna *et al.*, 2020)

Table 2, based on the cost comparison over 20 years shows that solar water pumps have significant economic potential for marginal farmers. The cumulative total cost of a solar water pump is ₹117,738, and a diesel pump's total cost is approximately 4.5 to 5x.

According to a state-level case study of Rajasthan and an average capacity of 3000 Wp (watt peak) across 4000 pumps, the system saves 12 MWp of electric power, equivalent to 3,600 kWh per pump annually. Switching to solar pumps saves INR 21,176 (US$ 253) annually on electricity costs, plus INR 42,352 (US$ 506) by avoiding diesel use. This results in significant financial and environmental benefits, with a total diesel savings of 2.4 million liters per year.

The foreign exchange saved due to reduced crude oil imports is INR 5,35,73,440 ($0.64 million) annually, and the government saves INR 2,67,86,720 ($0.32 million) in diesel subsidies each year, amounting to $4.8 million over 15 years (refer to Annexure 1).

Environmentally, the shift to solar pumps reduces CO_2 emissions by 3480 kg annually, as diesel pumps emit 0.29 kg of CO_2 per kWh of electricity produced. Additionally, solar pumps conserve 48 million cubic meters of water annually due to efficient drip irrigation systems, which save 2000 m^3 of water per hectare. This water efficiency and the increased area irrigated (24,000 ha) led to a boost in agricultural production, adding an additional INR 2,677,248,256 ($32 million) in value (refer to Annexure 1).

Overall, the use of solar water pumps demonstrates significant economic savings and environmental benefits, reinforcing their viability as a sustainable alternative to diesel pumps in the region.

7. Case studies

7.1. Name: **Sutapa Mandal**

Purba Medinipur | **Pump size: 2 HP**

Sutapa and her husband, Ujjawal Mandal, initially owned 2 bigha (1.25 acres) of land and in 2018 bought more land to make it 4 bigha (2.5 acres), which they use for growing paddy, seasonal vegetables, and fish cultivation, especially tilapia. She is also selling water to other local farmers and earning INR 2000/bigha as an additional income. Another aspect of livelihood expansion can be seen in the form of poultry (duck) farming, which is being farmed in and around the ponds. The solar pump has enabled Sutapa and her family to be self-sufficient for consumption, earn additional income, and prevent the migration of further generations.

7.2. Name: **Pori Giri**

Purba Medinipur | **Pump size: 2 HP**

Pori Giri, along with her family, manages a 1-acre land cultivating a nursery alongside growing paddy. After installing a 2 HP solar pump in November 2011, with the assistance of SwitchON Foundation, their nursery and paddy production flourished. The over extracted water supply facilitated by the solar pump enabled cultivation throughout the year, leading to the growth of a diverse range of crops like apples, grapes, berries, and various flowers. This expansion resulted in a threefold increase in income and the ability to sell surplus water to local farmers. The switch from heavy diesel/electric pumps to solar ones not only simplified irrigation but also empowered Pori, instilling a sense of independence and confidence in her agricultural endeavors.

7.3. Name: **Maqsood Ala**

Sahibganj, Jharkhand | **Pump size: 5 HP**

Maqsood Ala, owning 1 acre of land in Sahibganj district, faced water scarcity due to erratic rainfall, resulting in frequent crop losses over the past 4-5 years. In December 2019, he learned about the PM Kusum scheme and applied for a 5HP DC solar pump installation. Since then, he has diversified his crops to include wheat, potatoes, and various vegetables. Maqsood conducted trials with spinach, brinjal, and tomatoes in the last season and plans to expand his crop variety in the upcoming season to fetch better market prices and economic benefits. Additionally, he actively participates in water conservation efforts by utilizing small ponds in his village for fish farming, benefiting more farmers and generating additional income.

8. Challenges related to solar water pump

- The high initial investment required for solar-assisted agricultural systems can deter farmers from adopting these technologies, as they are more expensive compared to conventional agricultural systems.

- The limited use of solar-integrated agricultural systems is also due to the farmers' lack of skills in operating and maintaining these systems, the immediate availability of spare parts, and the shortage of skilled technicians for maintenance (Thakur *et al.*, 2022).

- According to the CGWB 2022, scanty groundwater recharge and overexploitation are key reasons for groundwater depletion. Vijendra Singh, a 57-year-old farmer from Murot village in Jhunjhunu district, installed solar pumps on his farm in 2016, but the declining groundwater levels have rendered the solar pumps inoperable (Pandey, 2023).

9. Conclusion

The implementation of solar water pumps under initiatives like PM Kusum and JNNSM has showcased remarkable benefits in agricultural practices across India. Case studies such as those of Sutapa Mandal, Pori Giri, and Maqsood Ala highlight the transformative impact of solar pumps on farm productivity, income generation, and livelihood sustainability. These pumps have enabled farmers to diversify crops, increase cropping intensity, and venture into allied activities like fish farming and poultry, leading to enhanced economic resilience. Moreover, the environmental benefits of reduced carbon emissions and water conservation further underscore the significance of solar pump adoption in mitigating climate change impacts and ensuring resource sustainability. However, despite the evident advantages, the initial cost of solar water pumps remains a major limitation, inhibiting widespread adoption among marginal farmers. Therefore, concerted efforts are needed to address this barrier through innovative financing mechanisms and enhanced government support to realize the full potential of solar irrigation technology in India's agricultural landscape.

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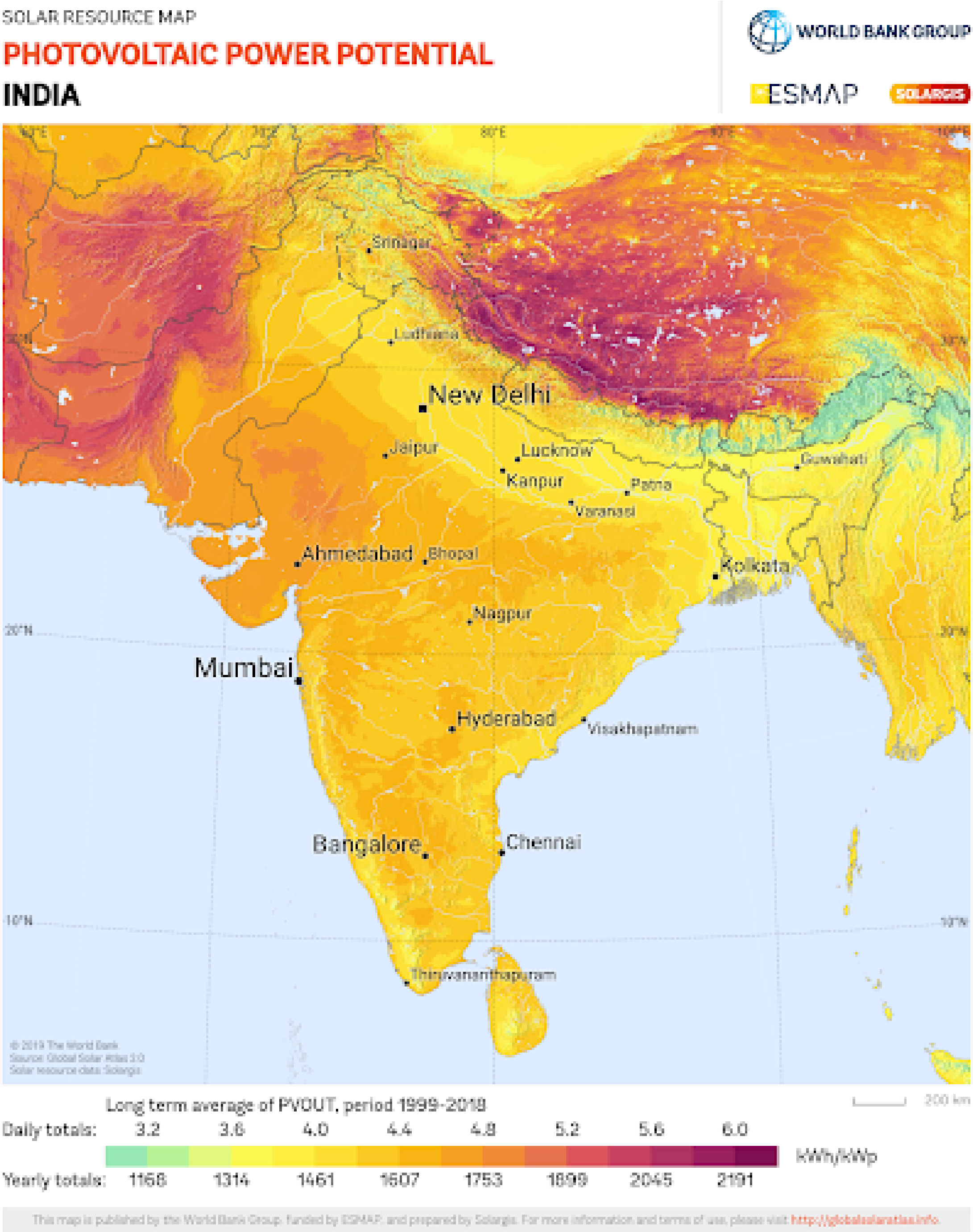
Annexures

Annexure 1: **Economic and environmental viability of solar water pump (Based on Rajasthan region, 2019)**

Sl no.	Item	Total	Unit
1	Average solar water pump capacity	3000	Wp
2	No. of pumps	4000	Number
3	Equivalent electric power saved (4000 x 3000 Wp)	12	MWp
4	Duration in hours a pump runs/day	6	hr
5	No. of units (KWh) saved per day	18	KWh
6	No. of days a pump runs in a year	200	Days
7	No. of electric units saved per pump per year 18 x 200	3600	KWh
8	Money saved by solar water pump per day 3,600x5	253	US$
9	Diesel cost saved per year (diesel generation is twice as costly than electric)	506	US$
10	Diesel saved per pump per day	3	Liter
11	Diesel saved per pump per year (3 liter x 200 days)	600	Liter
12	Diesel saved total, per year (4000 pumps x 600 litre)	2.4	Million liter
13	Foreign exchange saved per year, crude price @ US$ 0.27/Litre	0.64	US$ million
14	Diesel subsidy saved by Govt. per year	0.32	US$ million
15	Diesel subsidy saved by Govt. in 15 years	4.8	US$ million
16	Area Irrigated per pump per crop	3	ha
17	Area irrigated total, 2 crops a year (4000 pumps x 2 x 3)	24000	ha
18	Water required for surface irrigation per ha	5000	m3
19	Water saved per hectare with drip irrigation (40% of 5000)	2000	m3
20	Total water saved, 24,000 x 2,000	48	MCM
21	Additional production value due to irrigation through solar pumps	1333	US$
22	Total Additional production value due to irrigation through solar pumps	32	US$ million
23	CO_2 Emission for one 1 kWh electricity produced by Diesel	0.29	kg
24	Total CO_2 reduced, 12,000 kWh x 0.29 kg	3480	kg

(Source: ICID, 2019)

Annexure 2: **Photovoltaic Power Potential in India**



(source: Global Solar Atlas, 2023)

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SwitchON Foundation, established in 2008, is a leading non-profit organisation focusing on Environment Sustainability and Equal Opportunities. Operating in 10 Indian states. It leads initiatives in Clean Energy Access, Sustainable Agriculture, Skilling, Clean Air and Sustainable Cities. Key strengths encompass innovative project implementation, capacity building, field support, awareness and advocacy.