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A REVIEW OF SOLAR ENERGY: POTENTIAL, STATUS, PROVISIONS AND INCENTIVES IN RAJASTHAN

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ABSTRACT

Rajasthan boasts abundant sunlight and vast land resources, making it a key player in the country's solar energy landscape. This review paper explores the potential, current status, targets, and challenges associated with solar energy development in Rajasthan. It begins by assessing Rajasthan's solar energy potential, considering its geographical location, solar irradiance, and land availability. It delves into the state's existing solar projects and their contribution to the national grid, highlighting the progress made in recent years. Furthermore, the review discusses the ambitious targets set by the Rajasthan government in terms of solar energy generation and explores the policies and initiatives put in place to facilitate the achievement of these objectives. It provides insights into the state's role in India's commitment to renewable energy and climate change mitigation. In the final sections, the challenges hindering the full realization of Rajasthan's solar energy potential are outlined, including issues related to grid integration, land acquisition, and environmental considerations. Through a comprehensive examination of Rajasthan's solar energy landscape, this review paper aims to inform policymakers about the opportunities and obstacles in harnessing solar power in this region, ultimately contributing to a more sustainable and greener energy future for both Rajasthan and India as a whole.

Keywords: solar potential, solar photovoltaic, solar hotspot, desert, renewable energy.

I. INTRODUCTION

The sun produces large amounts of energy that reaches the earth. The Earth absorbs more energy in one hour than humans consume in a year. The total amount of solar energy reaching the world in a year is twice the sum of all coal, oil, natural gas, and uranium resources. In spring and autumn, the sun hits the earth's surface at different angles, from 0 degrees at the pole (no sunlight) to 90 degrees at the equator. At noon, the earth's surface receives the most energy. As you move away from the equator, the sun's rays have to travel longer in space. Along the way, some of the light travels into space or is scattered into the air, causing energy loss. On average, about 50% of solar energy reaches the earth through the atmosphere. The tilt of the Earth's rotation axis also causes changes in the amount of sunlight received. The Arctic receives very little sunlight in winter, while Antarctica receives very little sunlight in summer. Therefore, the amount of solar energy reaching each location varies depending on latitude, time of year, time of day, and weather conditions in the region. Solar energy is also attractive because climate change from carbon dioxide is often an energy problem, so sustainability requires the creation of renewable energy sources that do not release carbon dioxide into the atmosphere. Solar energy is abundant and can provide solutions to fossil fuel emissions and global climate change. The world receives solar energy at the rate of approximately 1,20,000 TW (1 TW = 1012W or 1MW). This is significantly greater than the current global annual electricity consumption of approximately 15 TW and all future needs. Driven by the increasing demand for energy, more than 100 countries, including India, have created policies and programs to use solar energy. But success so far has been mixed. This review provides an overview and analysis of the progress in developing solar energy in the Thar Desert of Rajasthan, one of India's best solar energy areas. We review not only performance but also focus. As we look to the future, we identify several important factors influencing practice and research, including different information that needs to be carefully considered by expert physicians and scientists. It is important to understand the groundwork of solar development early as this information will be important elsewhere in India and elsewhere. Rajasthan is the largest state of India and accounts for approximately 10.4% of India's territory. Despite the recent discovery of large hydrocarbon reserves of more than 3.6 x 109 barrels of oil and gas equivalent in the Balmer Basin, the availability of fossil fuels (e.g. coal) is still limited. The only two lakes containing bamboo, Chambal and Mahi, have almost exhausted their water resources. In summary, Rajasthan also faces two unique challenges in terms of energy resources: first, there are not many water projects due to a lack of major water resources; Secondly,

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coal has to be transported from other states, and transportation alone accounts for 10%. power generation. 50% of the price. Rajasthan has approximately 2,08,110 square kilometers of desert land, accounting for 60% of the total area of the state. Interestingly, Rajasthan receives 6.0–7.0 kWh/m2 of solar energy. This region experiences about 325 days of sunshine per year due to low rainfall, whereas in the west of the Thar Desert, it only rains for 10.4-20.5 days per year, which can be just as long. It is 345-355 days.

II. METHODOLOGY

Solar Potential In Rajasthan- Rajasthan has been proactively exploring its vast solar potential. Despite its aggressive strides, it's crucial to discuss aspects of its solar journey that could be enhanced for sustainable development.

Key Solar Installation- Rajasthan boasts various solar initiatives, ranging from the Solar Thermal Power Project in Nokha Jaisalmer to the Solar Domestic Lighting Project in Barli Jodhpur.

Water Efficiency and Land Concerns- A crucial aspect that needs more in-depth study is the water efficiency of solar installations in Rajasthan's arid regions. As Rajasthan becomes a solar hotspot, land disputes, especially concerning common lands, have surfaced. Effective and swift conflict resolution mechanisms will be pivotal in sustaining solar momentum.

Smart Grid Integration- As Rajasthan diversifies its energy sources, the need for an integrated and automated smart grid is evident. A grid that seamlessly accepts power from diverse sources and offers enhanced services would bolster energy efficiency and conservation efforts in the state.

Rural Electrification- Hybrid systems combining PV-solar and wind energy have shown promise for remote regions in Rajasthan. Despite their potential, they haven't been the central focus. Harnessing this potential could bring transformative changes for underprivileged households.

Ultra-large Solar Farms- Research indicates that ultra-large-scale solar farms could fulfill a significant portion of energy needs without utilizing much of Rajasthan's land. The state should consider this as a prospect.

Solar Insights in Rajasthan- Rajasthan's proactive stance in tapping into solar energy sets a benchmark. The establishment of regulatory bodies and the state's collaboration with various organizations has fast-tracked its solar journey. Challenges persist, particularly concerning maintenance in desert regions and water concerns. Furthermore, land disputes need prompt resolution. The focus, however, is clear: advancements like smart grids and large-scale solar farms could redefine Rajasthan's solar landscape.

Sr. No.	State/UT	Cumulative Solar Capacity till 30-06-2023 (MW)
1	Andaman & Nicobar	29.91
2	Andhra Pradesh	4552.12
3	Arunachal Pradesh	11.75
4	Assam	155.70
5	Bihar	203.18
6	Chandigarh	63.59
7	Chhattisgarh	962.51
8	Dadra & Nagar Haveli	5.46
9	Daman & Diu	41.01
10	Delhi	227.73
11	Goa	33.74
12	Gujarat	10133.66
13	Haryana	1106.49
14	Himachal Pradesh	106.55

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15	Jammu & Kashmir	53.29
16	Jharkhand	119.34
17	Karnataka	9050.59
18	Kerala	802.16
19	Ladakh	7.80
20	Lakshadweep	3.27
21	Madhya Pradesh	3021.57
22	Maharashtra	4870.64
23	Manipur	12.43
24	Meghalaya	4.15
25	Mizoram	30.43
26	Nagaland	3.04
27	Odisha	458.88
28	Puducherry	43.26

https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1947140

Civil Engineering Aspects in Solar Panel Installation:

Step1: Determine the Foundation Depth- In a desert environment, where shifting sands and high winds are common, a deep and stable foundation is crucial for the support of solar panels. The foundation depth can vary depending on specific site conditions, but as a guideline, consider a minimum foundation depth of 2 meters (approximately 6.56 feet). A deeper foundation provides stability in sandy soils and helps prevent shifting or settling, which can affect the alignment and efficiency of the solar panels. The depth of 2 meters helps ensure that the foundation reaches below the potentially loose and shifting surface layers of desert sands.

Material and Strength: Use reinforced concrete with a minimum compressive strength of 25 Megapascals (MPa) or higher for the foundation. Reinforce the foundation with steel rebars to enhance its load-bearing capacity and resistance to wind forces. It's important to conduct a site-specific geotechnical analysis to determine the precise foundation depth and design parameters based on soil conditions, wind loads, and other environmental factors. Additionally, local building codes and standards should be followed to ensure structural safety and compliance

Step 2: Determine Optimal Tilt Angle- To maximize the energy capture of solar panels in a desert area, you need to calculate the optimal tilt angle. This angle depends on the latitude of the location and the desired energy output. Here's how to calculate it:

1. Find the latitude of the desert location. For example, let's assume the latitude is 30 degrees.

2. Determine the season with the lowest sun angle, which is typically winter. In this case, we'll assume it's 45 degrees.

3. Calculate the optimal tilt angle using the latitude and sun angle. The formula is:

Optimal Tilt Angle = Latitude + (0.9 * (90 degrees - Sun Angle))

Optimal Tilt Angle = 30 degrees + (0.9 * (90 degrees - 45 degrees))

Optimal Tilt Angle = 30 degrees + 0.9 * 45 degrees

Optimal Tilt Angle = 30 degrees + 40.5 degrees

Optimal Tilt Angle = 70.5 degrees

So, for a desert location at 30 degrees latitude, the optimal tilt angle for the solar panels to capture the most sunlight during the winter would be approximately 70.5 degrees. This step is crucial for ensuring that the solar

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panels are positioned at the right angle to maximize energy production, considering the specific geographical location and seasonal variations in the sun's position in the sky.

III. MODELING AND ANALYSIS

Current Solar Status and Projects in Rajasthan:

Rajasthan boasts the highest solar power generation potential of any state in India, recently surpassing Karnataka as the leading state in solar installations. As of August 2023, operational solar power projects in Rajasthan produced an impressive 17.8 GW of solar energy. The state has ambitious plans to install a total of 30,000 MW of solar energy capacity by 2025.One of Rajasthan's standout achievements is the Bhadla Solar Park in Jodhpur, which covers 14,000 acres and boasts an installed capacity of 2,245 MW, making it the largest fully operational solar park in the world. Rajasthan is also home to India's sole solar thermal power plant with a tower.

The national government has disclosed plans for a massive 25,000 MW ultra-mega renewable energy facility. In the initial phase of this project, 10,000 MW of solar generating capacity will be installed throughout the state over the next three years. This substantial commitment has attracted significant investments in major solar power projects notable developments include Coal India and ONGC's announcement to develop over 1 GW of solar projects in October 2022. In a significant development, in January 2023, the Indian President laid the foundation for yet another impressive 1 GW solar project in Bikaner, Rajasthan. This project underscores the continued commitment to expanding solar energy generation in the region and further solidifies Rajasthan's position as a key player in India's renewable energy landscape. The central government has also given the green light to nine solar park projects in the state, with a combined capacity exceeding 7 GW. Rajasthan is undeniably at the forefront of India's solar energy revolution.

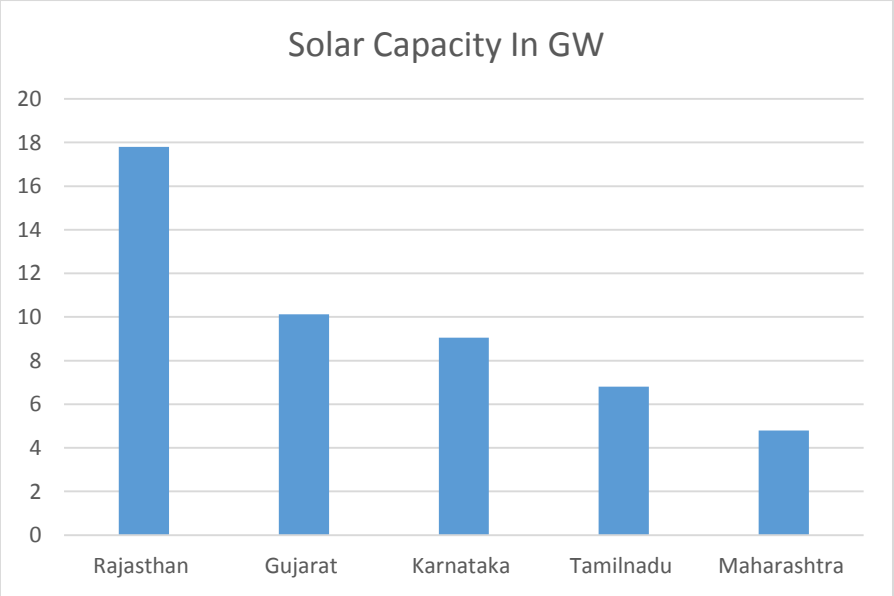

Fig 1: State-wise installed capacity of solar energy in MW till March 2023

Under the 'Development of Solar Parks and Ultra Mega Solar Power Projects' scheme, the Indian government has given the green light to 57 solar parks with a combined capacity of 39,385 MW across 13 different states. Within this impressive initiative, Rajasthan is set to host 9 solar parks, contributing to an aggregate capacity of 7,036 MW. These ambitious projects are part of the larger effort to harness solar energy and advance India's renewable energy sector. The following are the approved solar project:

- Bhadla-II Solar Park (680 MW),
- Bhadla-III Solar Park (1000 MW),
- Phalodi-Pokhran Solar Park (750 MW),
- Fatehgarh Phase-1B Solar Park (421 MW),
- Nokha Solar Park (925 MW),
- Pugal Solar Park Phase-I (1000 MW),

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- Pugal Solar Park Phase-II (450 MW)
- RVUN Solar Park (1310 MW).

Obstacles and issues in the realm of solar power generation within Rajasthan include:

There are various types of challenges that Rajasthan faces in Solar Energy Generation. Some of them are as follows:

1. Despite Rajasthan's 325 sunny days, the high temperatures lead to significant losses in photovoltaic energy production.
2. Project implementation is often delayed due to various challenges, including issues related to land acquisition and obtaining necessary statutory approvals. These challenges can hinder the progress of projects in the solar energy sector.
3. Solar projects in Rajasthan face significant challenges related to open access, wheeling charges, and grid availability.
4. Another challenge in the solar energy sector is the relatively higher per-unit cost of solar energy compared to conventional power sources. Additionally, the enforcement of Renewable Purchase Obligations (RPO) can pose obstacles, which can discourage private solar developers from participating in the sector. These factors impact the competitiveness and attractiveness of solar energy projects.The cleaning of solar panels in large solar farms results in the wastage of substantial amounts of water, posing an environmental concern.

IV. RESULTS AND DISCUSSION

Provisions & Incentives In Solar Projects:

1. Rooftop PV Solar Power Systems

1.1 Rooftop PV Solar Power Systems with Net Metering: The State government is actively promoting the installation of Rooftop PV Solar Power Systems with Net Metering. Their plan includes developing "Green Energy Cities" in key areas by implementing Solar Rooftop Systems in the following ways:

- Encouraging grid-connected Rooftop PV Solar Power Plants with Net Metering. DISCOMs will permit adding Solar Rooftop capacity up to 50% of the distribution transformer's capacity in the area.
- Government buildings will be equipped with Rooftop Solar Power Plants under the RESCO (Renewable Energy Service Company) mode.
- DISCOMs will create a user-friendly IT application to streamline online project approvals and monitoring.
- Subsidies and incentives, following MNRE/State Government guidelines, will be provided to Rooftop consumers.
- Promoting startups for the installation of Rooftop Solar Systems.
- A defined timeframe will be established for various activities related to Solar Rooftop Systems under Net Metering, to ensure efficient execution by DISCOMs.

1.2 Rooftop PV Solar Power Systems with Gross Metering:

Solar Rooftop Systems can also be established under the Gross Metering Scheme, following the guidelines set by the State Government and the Government of India. Under this scheme, all the power generated will be supplied to DISCOMs (Distribution Companies) at a tariff determined by RERC (Rajasthan Electricity Regulatory Commission). This scheme permits Solar Rooftop Systems with capacities of up to 1 MW.

1.3 The Urban Building Byelaws will include suitable provisions to encourage and simplify the adoption and installation of Solar Rooftop Systems. This is aimed at promoting the widespread use of such systems in urban areas.

2. Decentralized Grid-Connected Solar Power Projects:

Decentralized Grid Connected Solar Power Projects offer a valuable opportunity to meet power demand in proximity to load centers. These decentralized projects can help utilities reduce Transmission & Distribution (T&D) losses and optimize the costs associated with the transmission and distribution system.

2.1 The State is actively encouraging the establishment of decentralized solar power projects with capacities ranging from 0.5 MW to 5 MW in the vicinity of 33 kV Grid Sub-Stations. These projects are intended to supply power to DISCOMs. The selection of sub-stations for such projects will be carried out by RUVNL/DISCOMs.

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Tariffs for these projects will be determined through competitive bidding or by the guidelines of the State Government or Government of India.

2.2 The State aims to involve farmers in the solar energy sector to enhance their income sources through solar energy production and sale to DISCOMs. This will be achieved as follows:

- Farmers, either independently or through a developer, can establish decentralized power projects on their non-cultivable agricultural land.
- The State will promote the conversion of existing grid-connected agriculture pumps to solar power, following the provisions and guidelines issued by DISCOMs based on the regulations of RERC and guidelines of the Central or State Government.

2.3 The State Government will introduce schemes and programs to encourage decentralized solar generation within the state.

3. Off-Grid Solar Applications:

3.1 The State is actively encouraging and providing incentives for off-grid solar applications, including hybrid systems, in line with the guidelines issued by MNRE. These systems cater to various electrical and thermal energy needs for both domestic and commercial purposes.

3.2 The State is also promoting the establishment of solar power plants by individuals to sell power directly to consumers through their distribution system or local solar grid.

3.3 In remote villages and hamlets (Dhanis), the State is promoting the deployment of stand-alone solar systems to supply electricity to households.

3.4 The State is actively encouraging the installation of Solar PV Pumps for pressure irrigation systems to enhance agricultural practices and reduce reliance on traditional power sources.

4. Utility Grid Power Projects:

4.1 Solar Power Projects in Rajasthan for sale of power to DISCOMs of Rajasthan:

The State is committed to promoting the establishment of solar power projects to sell power to the DISCOMs (Distribution Companies) of Rajasthan. The tariff for these projects will be determined through a competitive bidding process. This initiative serves two primary purposes:

- Meeting the Renewable Purchase Obligation (RPO) targets set by RERC (Rajasthan Electricity Regulatory Commission).
- DISCOMs and RUVNL (Rajasthan Urja Vikas Nigam Limited) have the option to procure solar power beyond the RPO limit and can leverage the benefits of Renewable Energy Certificates (RECs) as per the

regulations of CERC (Central Electricity Regulatory Commission) and guidelines issued by NLDC (National Load Despatch Centre).

4.2 Solar Power Projects sanctioned under guidelines/schemes of MNRE:

The State is actively encouraging the establishment of Solar Power Projects following the guidelines and schemes provided by MNRE (Ministry of New and Renewable Energy) or through competitive bidding processes initiated by other State Utilities and Entities.

4.3 Grid-connected Solar Power Projects for Third-Party Sale:

The State will promote the setting up of solar power projects for third-party sale within outside the State as under:

- Solar Power Projects within premises of consumers of Rajasthan (Under RESCO Mode);
- Solar Power Projects set up for the sale of power within the State through open access;
- Solar Power Projects are set up for the sale of power outside the State through open access/power exchange.

TARGET IN RAJASTHAN FOR SOLAR ENERGY DEVELOPMENT

Since Rajasthan has a huge potential in solar energy generation, it aims to generate maximum power from solar energy.

The mission is divided into two parts; the first part is for the National Solar Mission and the second part is for the National Solar Policy.

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Sr. No.	Particulars	Capacity
1	Solar	65000 MW
2	Wind and hybrid	15000 MW
3	Hydro, Pump Storage Plant(PSP), Battery Energy Storage System	10000 MW

V. CONCLUSION

This review paper has provided a comprehensive overview of solar energy in the State of Rajasthan, India. Rajasthan, with its abundant sunlight and vast land resources, has emerged as a key player in India's solar energy landscape. The state has made significant strides in harnessing solar energy, with impressive growth in its solar capacity over the years.

We have studied solar energy: potential status, targets, and challenges in Rajasthan. We have discussed the potential of solar energy in Rajasthan, emphasizing the region's favorable climatic conditions and vast untapped solar resources. The state has set ambitious targets for the expansion of its solar energy capacity, reflecting a commitment to a sustainable and renewable energy future. These targets align with India's national goals for increasing the share of renewable energy in its energy mix, contributing to both environmental protection and energy security.

However, we have also highlighted the numerous challenges that Rajasthan faces in its pursuit of solar energy growth. These challenges include land acquisition, infrastructure development, grid integration, and the need for effective policy frameworks and financial incentives. The intermittent nature of solar power generation and its impact on grid stability are issues that must be addressed.

To overcome these challenges and achieve its targets, Rajasthan will need a multi-pronged approach that includes further investments in solar infrastructure, technological advancements, policy reforms, and capacity building. Collaboration between government bodies, industry stakeholders, and research institutions will be critical for the successful implementation of solar energy projects.

In summary, while Rajasthan has made significant progress in the solar energy sector, there are still several hurdles to overcome. With a concerted effort, continued innovation, and a commitment to sustainable energy solutions, Rajasthan can realize its full solar energy potential, contributing to a cleaner and more sustainable future for the state and the nation as a whole. The future of solar energy in Rajasthan is bright, and it is essential to address the challenges to harness this abundant renewable resource fully.

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