

Solar Energy Challenges and Future Role in India: A Review

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Abstract- India, a rapidly developing country with an ever-increasing energy demand, faces significant challenges in meeting its power needs sustainably. Solar energy, a clean and abundant renewable source, presents a viable solution. This research paper explores the current status, technological advancements, government initiatives, and future prospects of solar energy in India. It also examines the socio-economic and environmental impacts of adopting solar power on a large scale.

Keywords:- India solar energy, renewable energy India, solar power capacity India, solar parks India, Bhadla Solar Park, floating solar projects India, agrivoltaics India, rooftop solar installations solar energy policy India.

I. INTRODUCTION

Energy is the cornerstone of development, and as India progresses, its energy demand continues to grow. Traditional sources like coal and oil are not only limited but also environmentally damaging. Solar energy, with India's geographical advantage of abundant sunlight, emerges as a crucial alternative. With over 300 sunny days annually, India is well-positioned to harness solar power effectively. India, a country blessed with abundant sunlight throughout the year, holds immense potential for solar energy generation. With over 300 sunny days annually and vast stretches of arid land, India is geographically well-suited to harness solar power as a reliable and sustainable energy source. As the nation's population and energy demands continue to grow, the need for clean, renewable, and affordable energy has become more urgent than ever. To address this, India has made significant strides in promoting solar energy as a key component of its renewable energy strategy.

The launch of the National Solar Mission in 2010 marked a turning point, setting ambitious goals for solar capacity installation and encouraging technological innovation, investment, and international collaboration. Solar energy not only

helps reduce dependence on fossil fuels but also contributes to mitigating climate change, enhancing energy security, and supporting rural development. As the country aims to achieve net-zero carbon emissions by 2070, solar power is expected to play a central role in transforming India into a global leader in clean energy.

II. CURRENT STATUS OF SOLAR ENERGY IN INDIA

As of March 31, 2025, India has made significant strides in solar energy development, achieving a cumulative installed solar capacity of approximately 105.65 GW. This capacity comprises:

- **Ground-Mounted Solar Plants:** 81.01 GW
- **Grid-Connected Rooftop Solar:** 17.02 GW
- **Hybrid Projects (Solar Component):** 2.87 GW
- **Off-Grid Solar Installations:** 4.74 GW

This marks a substantial increase from 70.10 GW in June 2023, reflecting India's rapid expansion in solar energy infrastructure. India's commitment to renewable energy is further evidenced by its ambitious target of achieving 500 GW of non-fossil fuel-based power capacity by 2030, with solar energy expected to contribute around 250 GW to this goal. However, the sector faces challenges. In

2024, despite issuing 73 GW of utility-scale renewable energy tenders, approximately 8.5 GW remained undersubscribed due to complex tender structures and delays in interstate transmission readiness. Additionally, about 38.3 GW of capacity was cancelled between 2020 and 2024 due to various issues, including tender design and technical challenges. Despite these hurdles, India's solar energy sector continues to grow, driven by supportive government policies, technological advancements, and increasing investments. The country's focus on expanding solar parks, enhancing domestic manufacturing through initiatives like the Production Linked Incentive (PLI) scheme, and integrating energy storage systems positions it well to meet its renewable energy targets and contribute to global sustainability efforts.

India ranks among the top countries in solar power generation. As of early 2025:

- **Total installed solar capacity:** Over 75 GW.
- Contribution to total renewable energy: ~35%.
- **Leading states:** Rajasthan, Gujarat, Karnataka, Tamil Nadu, and Telangana.
- **Major projects:** Rewa Solar Project (MP), Bhadla Solar Park (Rajasthan), and Pavagada Solar Park (Karnataka).

III. GOVERNMENT INITIATIVES AND POLICIES FOR SOLAR ENERGY IN INDIA

India's transition to renewable energy, particularly solar power, has been strongly driven by proactive government initiatives and supportive policy frameworks. Recognizing the potential of solar energy to address energy security and climate goals, the Indian government has implemented various programs and schemes that have significantly accelerated the growth of the solar sector.

1. National Solar Mission (NSM)

Launched in 2010 as part of the National Action Plan on Climate Change (NAPCC), the Jawaharlal Nehru National Solar Mission set ambitious targets to make India a global leader in solar energy.

- Target: 100 GW of solar power by 2022 (now revised to ~280 GW by 2030).
- Focus on grid-connected and off-grid solar, manufacturing, and research.

2. Production Linked Incentive (PLI) Scheme

To reduce reliance on imports and boost domestic manufacturing of solar modules:

- Offers financial incentives to companies manufacturing high-efficiency solar PV modules.
- Aims to build a domestic manufacturing capacity of 40 GW.
- Reduces dependency on China for solar components.

3. PM-KUSUM Scheme

Launched in 2019, this scheme empowers farmers by promoting:

- Installation of solar pumps for irrigation.
- Grid-connected renewable energy plants on barren agricultural lands.
- Solarization of existing agricultural pumps.

4. Rooftop Solar Programme

To encourage the use of solar panels on residential and commercial rooftops:

- Provides up to 40% subsidy for households installing rooftop solar.
- Simplified net metering policies across several states.
- Target: 40 GW of rooftop solar capacity.

5. Solar Parks and Ultra Mega Solar Power Projects

To facilitate the installation of large-scale solar projects with government support:

- Target of establishing 50 solar parks with a capacity of 40 GW.
- Provides land, transmission access, and infrastructure to developers.
- Examples: Bhadla Solar Park (Rajasthan), Pavagada (Karnataka).

6. Green Energy Corridor

An initiative to develop a dedicated transmission network for renewable energy:

- Enables the smooth integration of solar and wind power into the grid.
- Funded through assistance from international agencies like KfW (Germany).
- inverters, batteries, and mounting infrastructure remains high.
- This deters small businesses, farmers, and residential users despite subsidy programs.

7. International Solar Alliance (ISA)

Launched by India and France in 2015 during COP21:

- Headquartered in Gurugram, India.
- Aims to promote solar deployment globally, especially in sun-rich tropical countries.
- Facilitates technology transfer, finance, and capacity-building.

8. Renewable Energy Investment Promotion

- FDI (Foreign Direct Investment) up to 100% is allowed under the automatic route.
- Viability Gap Funding (VGF) and solar bidding through reverse auctions.
- Encouragement of Public-Private Partnerships (PPP) for solar projects.
- Technological Developments
- Advancements in solar technology are making solar energy more efficient and affordable:
- Photovoltaic (PV) Efficiency improvements, now exceeding 22%.
- Floating Solar Plants gaining popularity due to land scarcity.
- Solar Storage Systems (like lithium-ion batteries) becoming cost-effective.
- Smart grid integration for efficient power distribution.

IV. CHALLENGES OF SOLAR ENERGY IN INDIA

Despite India's rapid progress in solar energy adoption, several challenges continue to hinder its full potential. These challenges span across policy implementation, financial viability, infrastructure, and environmental concerns. Addressing them is crucial to ensuring a sustainable and reliable solar future.

1. High Initial Capital Costs

- While solar energy is cheaper in the long run, the upfront installation cost of solar panels,

2. Land Acquisition Issues

- Large-scale solar parks require vast areas of land.
- Land acquisition is often expensive and complicated due to legal, ownership, and environmental concerns.
- It sometimes leads to displacement of local communities and land use conflicts, especially in rural and semi-arid regions.

3. Intermittency and Reliability

- Solar energy is weather-dependent and can't produce power at night or during cloudy days.
- Without adequate energy storage systems, it can't provide consistent power supply.
- This affects its integration into the national grid, especially for base-load demand.

4. Weak Grid Infrastructure

- Many parts of India lack a modern and robust electricity grid to support large-scale solar power transmission.
- Rural areas, where land for solar farms is abundant, often lack grid connectivity or have low-quality transmission lines.

5. Financial and Investment Barriers

- Developers face delays in payments from distribution companies (DISCOMs), many of which are financially stressed.
- Complex tendering processes and delays in project approvals discourage private investment.
- Limited access to low-interest financing for small-scale installations.

6. Policy and Regulatory Inconsistencies

- Differences in state-level policies, net metering rules, and incentive structures cause confusion.
- Frequent changes in import duties, solar panel quality standards, and subsidy norms disrupt planning for developers and investors.

7. Import Dependence

- India still relies heavily on imports (especially from China) for solar modules, cells, and inverters.
- This affects both costs and energy security, and hinders the growth of the domestic manufacturing ecosystem.

8. Environmental and Waste Concerns

- Solar panels have a lifespan of around 20–25 years, after which they need to be disposed of.
- India lacks a comprehensive plan for solar panel recycling, which may become an issue in the coming decades.

9. Low Rooftop Solar Adoption

- Despite incentives, adoption of rooftop solar has been slow due to:
- **Lack of awareness.**
- Complicated subsidy application processes.
- Space limitations in urban buildings.
- Concerns over maintenance.

Despite the progress, several challenges remain:

- High initial investment and financing hurdles.
- Grid integration issues and lack of infrastructure in rural areas.
- Intermittency of solar power due to weather dependence.
- Land acquisition for large solar farms.
- Socio-Economic and Environmental Impact
- Reduction in carbon emissions and air pollution.
- Creation of millions of jobs in manufacturing, installation, and maintenance.
- Empowerment of rural areas with decentralized power supply.
- Increased energy security and reduced import dependence.

V. CONCLUSION

While solar energy is a cornerstone of India's renewable energy future, overcoming these challenges is essential to ensure long-term success. This requires coordinated efforts from the government, industry stakeholders, financial institutions, and local communities. Solar energy

stands as a beacon of hope for India's sustainable future. With the right mix of policy support, technological innovation, and public participation, solar energy can transform India's energy landscape. The journey toward a greener and more energy-secure India is already underway and solar power is leading the charge. The future of solar energy in India looks promising to Project solar capacity by 2030: 280–300 GW. There will be Solar energy to power 25% of India's total electricity needs by 2040 and also boost to employment through green jobs. There will be growth in hybrid systems (solar + wind + storage) and Green hydrogen production through solar electrolysis could revolutionize energy storage and transport.

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