

The Evolution and Future Prospects of Solar Energy in India

Malusare Sejal*, Maind Aditi, Navghane Vaishnavi, Nale Tejas

Abstract

India has made great strides in incorporating solar energy into its renewable energy framework thanks to its plentiful solar resources. This case study examines the nation's advancements in solar energy development, the challenges it still faces, and its prospects for growth. India has aggressively pushed solar efforts to satisfy expanding energy demands responsibly and lessen reliance on fossil fuels, thanks to the country's high levels of sun irradiation in most locations. The report examines significant investments and inventions that have fueled solar growth, as well as important policy frameworks including the Jawaharlal Nehru National Solar Mission. It showcases historical initiatives like the Rewa Ultra Mega Solar Project and Bhadla Solar Park, which have raised the bar for affordable, utility-scale solar power globally. The study also looks at how solar energy has helped achieve more general objectives like job creation, rural development, and meeting climate action targets. However, a few obstacles prevent industry from reaching its full potential. These include problems with land availability, transmission infrastructure constraints, long-term funding challenges, and state-by-state regulatory disparities. Furthermore, controlling the unpredictability of solar energy production and guaranteeing dependable storage options continue to be significant technical obstacles. According to the report, India has made significant strides, but much more can be done. It will be crucial to address these issues by investing in grid infrastructure and energy storage, changing policies, and facilitating better financial access. Furthermore, localized solar systems can improve energy stability and accessibility, particularly in rural and isolated areas. For other countries looking to implement large-scale solar electricity, India's experience offers important insights. India has the potential to advance its position as a global leader in solar energy development and make a significant contribution to a sustainable energy future with sustained dedication, innovation, and governmental support.

Keywords: Solar energy, sustainable energy, climate change, photovoltaic technology, solar rooftop

INTRODUCTION

As nations look to lessen their reliance on fossil fuels and cut greenhouse gas emissions, solar energy has become a key factor in the global shift toward renewable energy, which is speeding up. Solar energy is unique among renewable energy sources because of its abundance, scalability, and falling costs. To promote the widespread and decentralized use of solar energy, the government has started several programs, including the National Solar Mission. Because of this, solar energy is increasingly playing a crucial role in India's long-term energy policy, fostering both environmental sustainability and economic growth [1–3].

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Due to the country's high levels of solar insolation and the pressing need to satisfy its

growing energy demand in a sustainable way, solar energy has become increasingly important in India in recent years. With more than 300 sunny days annually, India is well situated to capture solar energy, making it one of the most promising places in the world for solar energy production [4].

The need for energy keeps rising due to a fast-expanding population and increased industrialization, placing strain on conventional energy sources, which are frequently polluting and have a finite supply. India is dedicated to lowering carbon emissions and fostering green growth, and solar energy provides a clean and renewable substitute.

Energy Demand in India

With a fast-increasing energy demand, India is currently the world's third-largest energy user. Continued industrialization, rising urbanization, and the expansion of the middle class are the main drivers of this rise. Furthermore, a sizable section of the rural populace still does not have access to reasonably priced and dependable electricity, which exacerbates the nation's energy demands. As India's economy grows, maintaining a steady and sustainable energy supply has taken on national importance. The increasing demand puts strain on systems that rely on fossil fuels, underscoring the pressing need to diversify energy sources and make investments in clean, renewable alternatives like solar power.

Solar Energy's Role in India's Energy Mix

For a nation like India, which experiences high levels of solar radiation for most of the year, solar power is a clean, sustainable, and renewable energy source with enormous potential. As part of the larger National Action Plan on Climate Change (NAPCC), the Indian government started the National Solar Mission (NSM) in 2010 to exploit this plentiful resource. The mission seeks to lessen reliance on fossil fuels and encourage the use of solar energy for power generation. Additionally, it aims to increase solar infrastructure, lower the cost of solar electricity, and position India as a world leader in solar energy innovation and development.

LITERATURE REVIEW

Government regulations, technological developments, and growing environmental concerns have all influenced India's solar energy development. India's first solar power projects started in the 1970s, mostly concentrating on small-scale uses including rural electricity and solar lights. Despite early excitement, solar energy adoption was sluggish because of high costs and little awareness, claim Bhandari and Wiser [5]. Due to the pressing demand for cleaner, renewable energy sources, solar energy did not receive much attention until the early 2000s. The establishment of the National Solar Mission (NSM) in 2010 as a component of the National Action Plan on Climate Change (NAPCC) marked a significant turning point in India's solar energy growth. This mission sought to establish India as a global leader in solar power generation and set high goals for solar energy capacity. The NSM had a key role in lowering costs through extensive installations and promoting public-private collaborations [6]. India's solar power generation capacity increased dramatically between 2010 and 2020, reaching over 36 GW by the end of the decade, according to a report published by the International Renewable Energy Agency (IRENA) in 2019. Additionally, a study highlighted how solar energy has been crucial to rural electrification in India in addition to enhancing energy security. According to their research, solar technology, in particular, decentralized solar systems, has proven essential for supplying electricity to isolated locations where the grid is unstable or unavailable [7]. There are still difficulties in spite of these developments. The adoption of solar energy may be slowed down by India's ongoing infrastructure, and financial and regulatory challenges. Furthermore, even though solar energy is now more reasonably priced, obtaining reliable power generation still requires effective energy storage technologies.

In conclusion, India's solar energy development has advanced significantly, especially since the NSM was introduced and the nation's dedication to renewable energy has grown. But there are still obstacles to overcome, like grid connectivity, funding, and storage, and doing so will be essential to ensuring that India reaches its solar energy goals in the upcoming years.

Historical Context and Development of Solar Energy in India

- *Early Developments:* For a nation like India, which experiences high levels of solar radiation for most of the year, solar power is a clean, sustainable, and renewable energy source with enormous potential. As part of the larger National Action Plan on Climate Change (NAPCC), the Indian government started the National Solar Mission (NSM) in 2010 to exploit this plentiful resource [8].
- *Ambitious Targets:* The mission seeks to lessen reliance on fossil fuels and encourage the use of solar energy for power generation. Additionally, it aims to increase solar infrastructure, lower the cost of solar electricity, and position India as a world leader in solar energy innovation and development. India first experimented with solar technologies in the 1970s, marking the beginning of its path into solar energy [9]. Early initiatives concentrated on small-scale initiatives and studies to see whether solar energy might be exploited. Nevertheless, the influence of these early initiatives was little, and solar energy continued to play a minor role in India's energy policy for many years. Innovation occurred in the 21st century, when the nation was confronted with rising energy use, pressing environmental issues, and the possibility that solar energy could help create a more sustainable future.

KEY GOVERNMENT POLICIES AND INITIATIVES

- *National Solar Mission (NSM):* The NSM, as a cornerstone of India's renewable energy policies, sought to create a large-scale, viable solar power industry. It focused on:
 - Setting ambitious capacity targets (initially 20 GW, later revised to 100 GW).
 - Reducing the cost of solar power through policy support, technology advancements, and large-scale installations.
- *Financial Incentives and Support:* India has introduced various financial incentives such as tax credits, subsidies, and financial support for solar projects. This includes incentives for rooftop solar installations and incentives for manufacturers of solar panels.
- *State-Level Initiatives:* In addition to national policies, individual states like Rajasthan, Gujarat, and Karnataka have introduced their own solar energy policies, often offering additional incentives such as land allocation, lower taxes, and reduced power tariffs.

SOLAR ENERGY PROJECTS IN INDIA: A CASE STUDY OF KEY SOLAR PARKS

Rewa Ultra Mega Solar Park (Madhya Pradesh)

- *Overview:* Rewa Solar Park, inaugurated in 2018, is one of the largest solar parks in India, with a capacity of 750 MW, has been crucial in illustrating and demonstrating the feasibility of large-scale solar projects in India.
- *Impact:* The park has set new records in terms of power purchasing agreements (PPAs), with costs down to ₹2.97/kWh, a historic low. The Rewa Solar Park's achievement has demonstrated that solar power can be cost-competitive even in regions traditionally dominated by coal [10].

Pavagada Solar Park (Karnataka)

- *Overview:* Pavagada has a 2050 MW overall capacity, making it one of the biggest solar parks globally. It reflects India's growing capacity for solar energy, contributing substantially to the Karnataka state's renewable energy portfolio.
- *Challenges and Achievements:* Pavagada faced challenges related to land acquisition, but the park overcame these hurdles through collaboration with local farmers, where land was leased for solar projects, enabling both farmers and investors to benefit.

Bhadla Solar Park (Rajasthan)

- *Overview:* Bhadla Solar Park is in the Thar Desert and boasts a capacity of 2245 MW, making it the largest solar park in India. Its strategic location is among the world's most productive solar parks since it is in an area with high solar irradiation.
- *Impact:* The park's success has spurred the development of similar large-scale projects in other regions of India and has been pivotal in India meeting its renewable energy targets.

TECHNOLOGICAL ADVANCEMENTS AND INNOVATIONS

India's significant advancements in solar technology have resulted in reduced costs and increased efficiency.

Photovoltaic Technology

India primarily uses silicon-based solar panels for large-scale projects. The focus has been on improving the efficiency of these panels while reducing their cost.

Emerging Innovations

Bifacial Solar Panels

Solar panels that receive light from the front and back, increasing efficiency.

Concentrated Solar Power (CSP)

Use of mirrors and lenses to concentrate sunlight to generate heat and produce electricity.

Energy Storage Solutions

The development of battery storage devices for storing and using solar energy during non-sunny periods is a crucial area of innovation [2].

Solar Rooftop Solutions

India's focus on rooftop solar installations for homes, businesses, and industry has led to the creation of thousands of decentralized solar projects. This has the potential to increase the accessibility of solar energy and make it affordable for households, small enterprises, and local communities.

Job Creation

The solar industry in India has created millions of jobs (Figure 1).

ECONOMIC AND ENVIRONMENTAL IMPACT: ECONOMIC BENEFITS

- *Job Creation:* The solar industry in India has created millions of jobs, ranging from manufacturing and installation to maintenance, and research and development.
- *Reduction in Energy Costs:* As the cost of solar power continues to fall, it has become increasingly competitive with coal, offering a long-term solution to India's energy needs.
- *Attracting Foreign Investment:* Foreign direct investment (FDI) has been drawn to the industry, especially in the form of joint ventures, and technology and equipment imports.



Figure 1. Implementation of solar panels in rural area.

Environmental Benefits

- *Reduction in Carbon Emissions:* Solar electricity has considerably lowered India's reliance on fossil fuels, contributing to lower greenhouse gas emissions.
- *Sustainability:* Solar energy reduces air pollution and helps conserve natural resources, making it a critical part of India's commitment to the Paris Climate Agreement.

CHALLENGES IN SOLAR ENERGY IMPLEMENTATION

Despite the progress made, India faces several challenges in scaling solar energy.

- *Grid Integration:* Integrating solar power into the national grid, particularly in areas with limited infrastructure, remains a significant challenge. Grid balancing and storage technologies need to be improved.
- *Financing and Investment:* Although costs have fallen, financing large solar projects is still difficult due to high initial capital requirements and perceived risks.
- *Regulatory and Land Acquisition Issues:* Delays in land acquisition and regulatory approvals often slow down project implementation. The availability of land for large-scale solar projects is another major issue.

CONCLUSION

Over the past few years, India's solar energy industry has made great progress. The country is now among the top countries in the world market for solar energy due to the quick expansion of its solar capacity. However, there are still issues with financing, policy barriers, and grid infrastructure. Notwithstanding these obstacles, solar energy remains a vital part of India's energy policy, supporting both economic expansion and sustainable development. India's energy strategy now heavily relies on solar energy, which promotes environmental sustainability in addition to energy security. It has been crucial in creating economic opportunities, lowering greenhouse gas emissions, and lessening the country's reliance on fossil fuels. Millions of people, especially in rural regions, now have access to reasonably priced and dependable electricity thanks to the ongoing expansion of solar projects, opening up new opportunities for growth and the reduction of poverty. Notwithstanding these achievements, a number of obstacles still stand in the way of India's solar industry reaching its full potential. Due to the intermittent nature of solar energy, which threatens grid stability, integrating solar power into the current grid architecture is still a significant challenge. High initial investment costs and restricted access to cash make financing solar installations difficult, especially in distant areas. Some projects have also been dragged down by regulatory and legislative impediments, such as delays in the permitting and land acquisition processes.

However, India's dedication to solar energy is still strong, and sustained efforts to overcome these obstacles, like enhancing grid infrastructure, streamlining regulations, and boosting funding, will be essential to guaranteeing solar energy's continuous expansion as a major pillar of India's sustainable energy future.

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