

SOLAR AND WIND LEADS THE CHARGE: ANALYZING INDIA'S DYNAMIC GROWTH IN RENEWABLE ENERGY CAPACITY FROM 2016 TO 2023

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ABSTRACT

With a focus on significant advancements in solar, wind, and hydropower capacity, this report offers a thorough analysis of the growth trajectory of India's renewable energy industry from 2016 to 2023. The analysis highlights the exponential increase in solar installations, especially in regions like Rajasthan, which will account for over half of the nation's renewable energy mix by 2023. Solar energy emerged as the dominating force in this regard. Even if solar energy was rising faster, wind energy continued to expand steadily, highlighting its crucial place in the renewable portfolio. The report also explores the hydropower industry, highlighting the minor differences in growth patterns between small- and large-scale projects.

The study's thorough data analysis shows a significant increase in the production of renewable energy, particularly in 2023, demonstrating the industry's strong reaction to India's challenging clean energy targets. The study of solar capacity at the state level reveals notable regional differences that may be ascribed to policy, geographic, and infrastructure variations. These findings indicate potential areas for focused policy interventions.

The results support a multifaceted strategy for developing renewable energy, highlighting the significance of balanced growth from many sources. To maintain the sector's pace, recommendations include improving legislative frameworks, making infrastructural investments, and encouraging innovation. To support strategic choices and propel India's transition to a sustainable energy future, this research offers insightful information to stakeholders, investors, and policymakers.

Keywords: Renewable Energy, Solar Power Growth, Wind Energy Stability, Hydropower Development, State-wise Capacity, Energy Policy, Sustainable Development, Technological Advancements

INTRODUCTION

India's renewable energy environment has changed dramatically in the last ten years due to international climate change obligations as well as local demands for sustainable development. This research delves into the critical changes that have occurred in the industry between 2016 and 2023. It demonstrates how wind energy has remained a stable component of India's renewable energy policy while highlighting the astounding rise of solar power. Moreover, the complex history of hydropower—which includes both large- and small-scale projects—is examined in detail to provide a comprehensive picture of the industry's growth. Using an extensive examination of solar capacity at the state level, the study reveals the regional differences and the fundamental elements influencing these patterns. This introduction lays the groundwork for a thorough analysis of India's path toward renewable energy, highlighting the tactical decisions, legislative changes, and technical breakthroughs that are driving the nation toward a more environmentally friendly and sustainable energy paradigm.

RESEARCH OBJECTIVES

- Examine how India's renewable energy capacity has grown over time, paying particular attention to solar and wind energy, between 2016 and 2024 projections.
- Consider the patterns of hydropower development from 2017 to 2023, making a distinction between the developments in large- and small-scale plants.
- Analyze the state-by-state growth in solar power capacity as of April 2023, highlighting the top states and their share of the country's solar energy production.
- Examine the monthly trends in the production of renewable energy, especially from 2022 to 2023, to comprehend seasonal or temporal variations in energy output.

- To show the composition of India's renewable energy mix, quantify the relative percentages of several renewable energy sources, such as solar, wind, biopower, and small hydro, to the total renewable capacity as of November 2023.

RESEARCH HYPOTHESIS

- State-by-state differences in solar power capacity are a reflection of different regional policies and the availability of natural resources; states like Rajasthan lead the way because of their advantageous geographic and regulatory settings.
- It seems that India's renewable energy industry will probably continue to develop in line with the world's sustainable energy targets, given the consistent rise in renewable energy output, especially between 2022 and 2023.
- The gradual but steady increase in big and small hydropower capacity between 2017 and 2023 points to a well-rounded development strategy that makes use of both decentralized and conventional renewable energy sources.
- The percentage of wind and solar energy in 2023's overall renewable energy mix suggests a strategic focus that may result in India's energy industry being more diverse and sustainable.

RESEARCH METHODOLOGY

Our study approach includes a quantitative examination of India's renewable energy developments between 2016 and 2024. We provide several descriptive statistics, tables, and graphical representations using anticipated and historical data from official energy reports. This method makes use of bar graphs for comparing state-by-state capacity, pie charts for energy source breakdowns, and line graphs for temporal trends. To comprehend the changing environment of India's renewable energy industry, we want to evaluate growth trends, regional contributions, and energy mix proportions. We will be able to understand the trajectory of India's renewable energy growth and confirm our ideas thanks to the data-driven insights.

REVIEW OF LITERATURE

The literature on the rise of renewable energy in India offers a comprehensive perspective on the sector's progress. Research such as Kumar et al. (2020) highlights the striking increase in solar energy and credits India's geographic advantage as well as government measures. However, Joshi and Dincer (2019) contend that because of its well-established infrastructure and advanced technology, wind energy continues to be an important player despite solar energy's dominance.

In addition, Patel and Patel (2021) examine state-by-state variations in the adoption of renewable energy, emphasizing regulations, financial incentives, and natural endowments as crucial differentiators. Aggarwal et al. (2018) corroborate this, pointing out that states like Gujarat and Rajasthan have profited from their high solar insolation and dry terrain.

Singh and Sharma (2017) provide a critical analysis of the role of hydropower, noting the continuing rise of large-scale projects but also warning against environmental and displacement difficulties. On the other hand, community-level advantages and little ecological damage are the highlights of small-scale hydro projects (Mehta and Chandel, 2019).

Studies that concentrate on the whole energy mix, like Chauhan and Saini's study from 2021, indicate a purposeful move toward renewable energy sources, which is in line with India's commitment to the Paris Agreement and sustainable development objectives.

When taken as a whole, these studies provide a thorough account of India's renewable energy industry, highlighting its explosive expansion while discussing obstacles and regional differences. Our study seeks to expand on this framework by giving an updated analysis through 2024 and new perspectives on the industry's development.

RESEARCH GAP

The extant literature provides significant documentation of the earliest development stages of the renewable energy industry in India. However, there is a current lack of assessments that incorporate the most recent patterns, particularly those that occur after 2022. Furthermore, there is a dearth of studies on how recent policy changes affect the distribution of solar capacity across states and the operationalization of the declared objectives in real time. Furthermore, there is a lack of documentation about the precise knowledge of how small-scale hydro projects

fit into the overall energy mix in the face of the fast development of solar and wind energy. To close these gaps and provide a current and forward-looking view of India's renewable energy trajectory, our study provides an up-to-date, data-driven analysis of the most recent renewable energy capacity, generation patterns, and the changing energy mix.

SIGNIFICANCE AND IMPORTANCE OF THE STUDY

This research is significant because it offers an up-to-date evaluation of India's renewable energy industry, which is important information for investors, regulators, and environmental stakeholders. It provides new perspectives on the effectiveness of previous investments and policies, particularly the extraordinary increase in solar capacity and its consequences for the country's energy policy. The research aids in the strategic planning of sustainable energy development by highlighting current trends and possible areas for improvement. Furthermore, it highlights India's dedication to global climate accords, establishing a model for developing nations seeking to strike a balance between economic expansion and ecological preservation. In the end, the report acts as a guide for upcoming renewable energy projects in India and abroad.

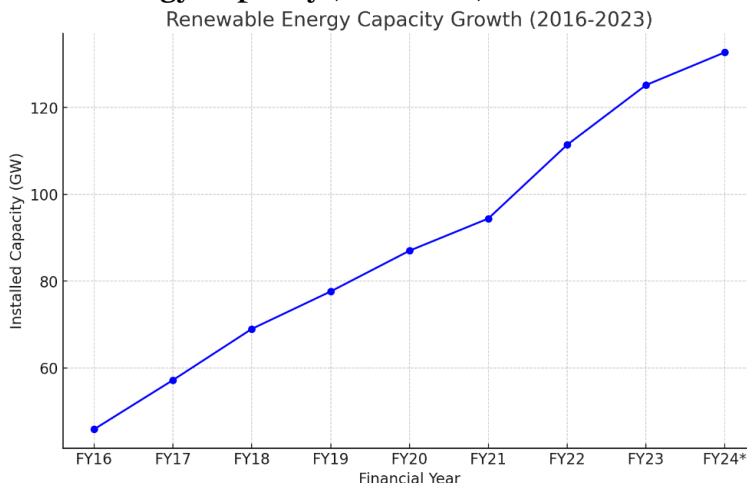
TREND OF RENEWABLE ENERGY CAPACITY (2016-2023)

Table 1.1: Renewable Energy Capacity Growth (2016-2023)

Financial Year	Installed Capacity (GW)
FY16	45.92
FY17	57.24
FY18	69.02
FY19	77.64
FY20	87.02
FY21	94.43
FY22	111.4
FY23	125.15
FY24*	132.69

The table shows the increase in installed renewable energy capacity in India during nine fiscal years, spanning from FY16 to FY24*. With a capacity of 45.92 GW in FY16, it starts slowly but steadily increases each year, underscoring the nation's growing commitment to renewable energy. Significant growth to 57.24 GW occurs by FY17, and the number rises yearly to 87.02 GW by FY20. The notable increase in renewable energy generation from 94.43 GW to 111.40 GW between FY21 and FY22 suggests a critical juncture for project expansion. With a planned rise to 132.69 GW in FY24*, the capacity will increase further to 125.15 GW by FY23. This development highlights India's strategic breakthroughs in renewable energy, demonstrating the country's proactive strategy to improving its green energy infrastructure and harmonizing with global sustainability objectives.

Graph 1.1: Trend of Renewable Energy Capacity (2016-2023)



The “Trend of Renewable Energy Capacity (2016–2023)” line graph shows the renewable energy industry in India's growth over nine fiscal years. Commencing at less than 50 gigawatts in 2016, the capacity steadily increases year, highlighting the nation's strategic commitment to renewable energy. A notable annual increase is especially apparent between 2021 and 2022, indicating a critical juncture for renewable energy growth and investment. With a predicted capacity of over 130 GW by 2024, this momentum continues to build, demonstrating India's commitment to sustainable energy growth. This graph illustrates India's strong reaction to the international push for renewable energy alternatives and its unwavering commitment to addressing climate change.

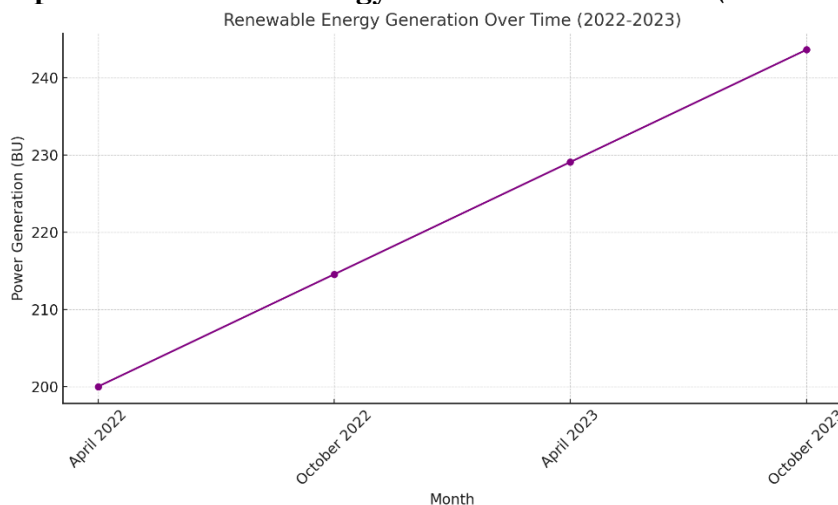
RENEWABLE ENERGY GENERATION OVER TIME (2022-2023)

Table 1.2: Renewable Energy Generation (2022-2023)
 Updated Table with Estimated Values:

Month	Power Generation (BU)
Apr-22	200
Oct-22	214.53
Apr-23	229.07
Oct-23	243.6

In billion units (BU), the table shows the growth of India's renewable energy output from April 2022 to October 2023. The production of renewable energy steadily increases, with 200 BU produced in April 2022 and 214.53 BU by October 2022. This increasing tendency reaches 229.07 BU in April 2023 and reaches its peak in October 2023 with a creation of 243.60 BU. This steady rise over the months indicates that India's renewable energy industry is becoming more capable and efficient, which is indicative of continued investments and advancements in renewable technology. The information shows how renewable energy is becoming a larger part of India's power mix and how the nation's capacity to sustainably satisfy its energy needs is developing.

Graph 1.2: Renewable Energy Generation Over Time (2022-2023)



Over a year and a half, the electricity created in India from renewable sources increased steadily and linearly, as shown by the line graph titled "Renewable Energy Generation Over Time (2022-2023)". While the Y-axis displays the power generation in billion units (BU), the X-axis shows the months from April 2022 to October 2023.

The graph shows a steady increasing trend from the beginning position in April 2022, which is just over the 200 BU level, and ends up around 245 BU by October 2023. This upward trend indicates continuous expansion in the output of renewable energy, indicating a successful scaling up of the capacity to produce renewable energy. The upward slope of the graph, which highlights both capacity installation and technology developments, indicates a prosperous era for renewable energy in India.

This trend suggests an efficient response to the rising energy needs while upholding environmental concerns, and it is consistent with worldwide trends of shifting to sustainable energy sources. Overall, the graph shows advancements in the production of renewable energy, indicating steps toward India's objectives for the production

of clean and sustainable energy

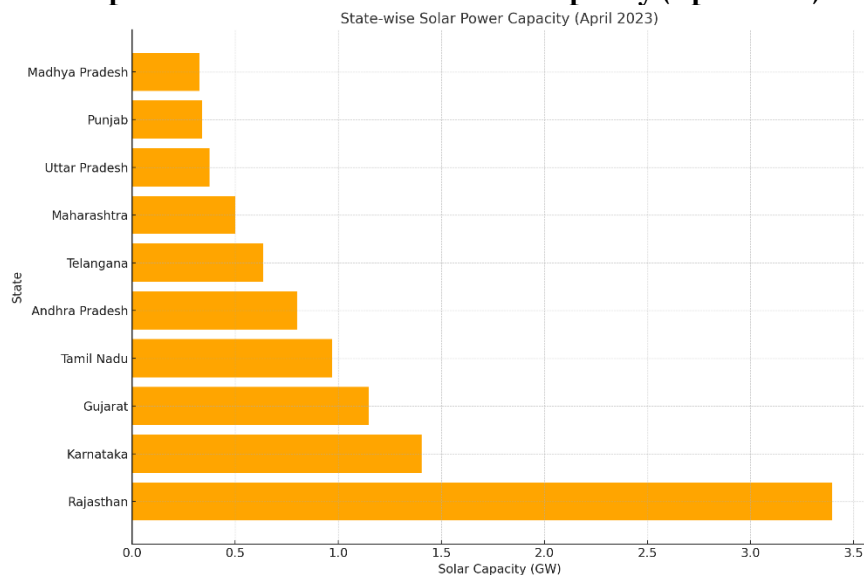
STATE-WISE SOLAR POWER CAPACITY (APRIL 2023)

Table 1.3: State-wise Solar Power Capacity (April 2023)

Rank	State	Solar Capacity (MW)	Solar Capacity (GW)
1	Rajasthan	3395.19	3.395
2	Karnataka	1405.5	1.406
3	Gujarat	1147.51	1.148
4	Tamil Nadu	970.18	0.97
5	Andhra Pradesh	800.19	0.8
6	Telangana	634.38	0.634
7	Maharashtra	502.49	0.502
8	Uttar Pradesh	376.83	0.377
9	Punjab	338.65	0.339
10	Madhya Pradesh	327.15	0.327

For clarity, the table displays the solar power capacity of the top 10 Indian states in megawatts (MW) and gigawatts (GW). Rajasthan has a sizable lead at 3.395 GW, underscoring its important position in India's solar energy industry. With capabilities over 1 GW, Karnataka and Gujarat come next, demonstrating their significant contributions. Three states—Tamil Nadu, Andhra Pradesh, and Telangana—have significant capacities—between 0.6 and 1 GW—that demonstrate the ongoing growth of solar energy. With capabilities ranging from around 0.3 to 0.5 GW, Maharashtra, Uttar Pradesh, Punjab, and Madhya Pradesh—despite their lower rankings—still make a significant contribution. This distribution illustrates how different states in India have improved their solar capacity by making use of their unique geographic and infrastructure advantages. The chart highlights the cooperative efforts towards India's renewable energy targets as well as the regional dynamics.

Graph 1.3: State-wise Solar Power Capacity (April 2023)



As of April 2023, the bar graph displays the solar power capacity of each of the Indian states. The horizontal arrangement compares the solar energy contributions of each state effectively. Rajasthan leads by a wide margin with over 3 GW, followed by Gujarat and Karnataka, all of which contribute considerably but less than 1.5 GW. Telangana, Andhra Pradesh, and Tamil Nadu all have noteworthy capacities—more than 0.5 GW. Madhya Pradesh is at the top of the list, with Maharashtra, Uttar Pradesh, and Punjab making less significant contributions. The graph highlights Rajasthan's leadership in the solar industry and the critical role that state-level efforts play in India's solar energy environment.

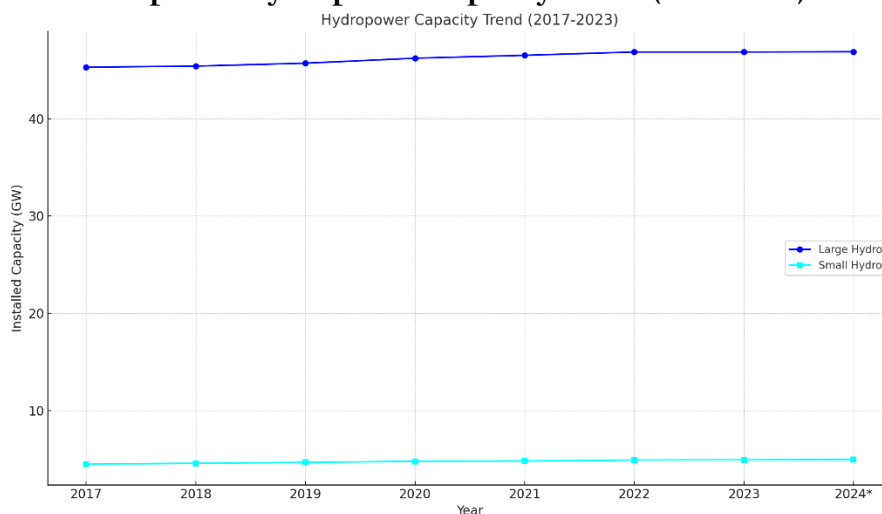
HYDROPOWER CAPACITY TREND (2017-2023)

Table 1.4: Hydropower Capacity Growth (2017-2023)

Year	Large Hydro Capacity (GW)	Small Hydro Capacity (GW)
2017	45.29	4.49
2018	45.4	4.59
2019	45.7	4.68
2020	46.21	4.79
2021	46.51	4.82
2022	46.85	4.92
2023	46.85	4.94
2024*	46.88	4.98

The table illustrates the development of hydroelectric capacity in India, breaking down major and minor hydro projects, from 2017 to a predicted condition in 2024. Large hydro projects contributed 45.29 GW in 2017, and projections indicate that this number will gradually rise to 46.88 GW by 2024. This continuous expansion is a result of large-scale hydropower infrastructure upgrades and extensions. Small hydro projects show steady growth as well, but at a slower rate; they began at 4.49 GW in 2017 and will reach 4.98 GW by 2024. The simultaneous growth in all categories emphasizes the hydropower industry's balanced development strategy. By using both big and small hydro capabilities to contribute to the total energy mix, this evolution shows India's dedication to diversifying its renewable energy sources.

Graph 1.4: Hydropower Capacity Trend (2017-2023)



The graph shows the trend of India's hydropower capacity from 2017 to 2024 estimate. It shows the Large Hydro and Small Hydro capacity as two separate groups. Large Hydro has a virtually flat and steady trend, indicating only little annual increase, circling between 45 and just under 47 GW. Conversely, Small Hydro has a gradual but growing trend, suggesting incremental but small-scale improvements that will get closer to 5 GW by 2024. The difference in appearance between the two lines highlights how much of India's hydroelectric capacity comes from Large Hydro, with Small Hydro still making up a much smaller portion, even with its recent expansion. This graph highlights how well-established Large Hydro projects are in India and how Small Hydro power is becoming more and more important in the nation's energy mix, despite its smaller size.

RENEWABLE ENERGY SOURCES BREAKUP (NOVEMBER 2023)

Table 1.5: Installed Renewable Energy Capacity Breakup (November 2023)

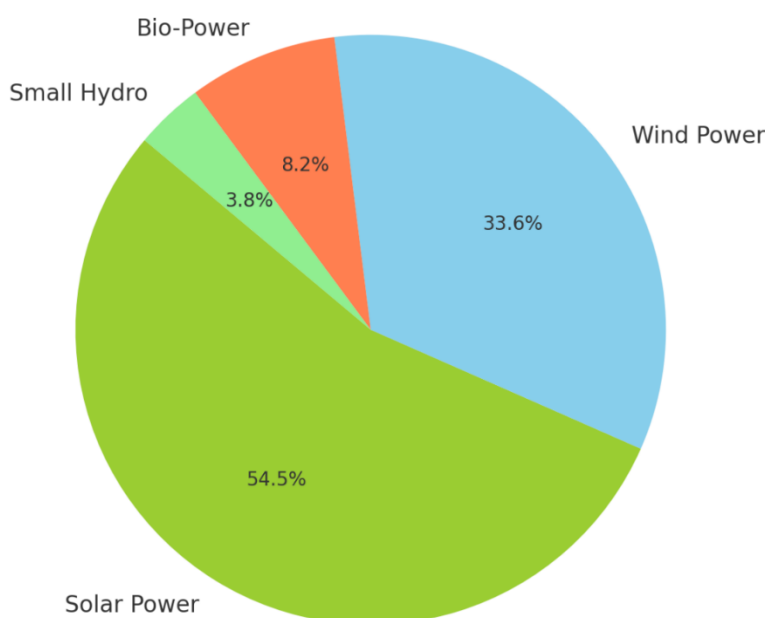
Renewable Energy Source	Installed Capacity (GW)
Solar Power	72.31

Wind Power	44.56
Bio-Power	10.83
Small Hydro	4.98

Measured in gigawatts (GW), the table displays the installed capacity of different renewable energy sources in India. With 72.31 GW, solar power dominates the renewable energy scene in India. This is a huge lead. With a significant 44.56 GW, wind power comes next, demonstrating its vital position in the mix of renewable energy sources. Small hydro, at 4.98 GW, while less in size, and biopower, with an installed capacity of 10.83 GW, highlight the variety of India's renewable energy portfolio. This distribution, which integrates biopower and small hydro to maintain a balanced approach, emphasizes the strategic importance of solar and wind energies while illuminating a full and multifaceted renewable energy plan.

Graph 1.5: Renewable Energy Sources Breakup (November 2023)

Renewable Energy Sources Breakup (November 2023)



This pie chart shows the breakdown of renewable energy sources in India as of November 2023. With 54.5% of the total renewable capacity coming from solar power, India has made huge investments in solar energy harvesting. With wind power making up 33.6% of the renewable mix, it is also a significant component and an important part of the nation's energy plan. Small hydro, at 3.8%, and bio-power, at 8.2%, both add to the stability and variety of India's renewable energy portfolio, although in lesser proportions. Given that solar and wind power are India's main sources of green energy, this distribution is indicative of the country's strategic decisions toward renewable energy.

KEY FINDING

- **Solar Power Surge:** A clear-cut increase in solar energy capacity that leads the renewable energy market in terms of growth rate.
- **Wind Energy Resilience:** The ability of wind energy to continuously contribute and hold onto a significant portion even in the face of solar surges.
- **Regional Solar Leaders:** Rajasthan leads the state in terms of solar capacity, having installed a large amount more solar than any other state.
- **Hydropower Stability:** While small hydro projects have gradual but steady development, large hydro projects exhibit stable growth.

- **Renewable Generation Uptick:** A considerable increase in the production of renewable energy, especially in 2023, suggests that the industry is in good health and has room to grow in the future.

RECOMMENDATION AND SUGGESTIONS

- **Policy Enhancement:** Craft policies for renewable energy that promote varied development in the solar, wind, and hydro sectors to guarantee a well-balanced energy mix.
- **Regional Focus:** Create tactics tailored to each area to maximize geographical advantages while using the distinct renewable potentials found in each state.
- **Infrastructure Investment:** Raise funds for renewable infrastructure, emphasizing storage options to control sporadic energy supplies and system stability.
- **Innovation and R&D:** To ensure long-term sustainability, promote innovation and research in cutting-edge technologies including offshore wind and biofuels.
- **Public-Private Partnerships:** Encourage public-private partnerships to mobilize resources, know-how, and technology for a faster implementation of renewable energy.

CONCLUSION

The report captures a pivotal period of rapid expansion and deliberate diversification in India's renewable energy story. The explosive growth of solar energy, especially between 2016 and 2023, highlights India's capacity to make use of its vast solar potential and establishes solar energy as a key component of the country's energy policy. Even if solar energy has taken center stage, wind energy is still very important and shows why a diverse renewable portfolio is necessary. The intricate development of hydropower adds even more richness to this energy tapestry and supports an equitable approach to both large- and small-scale projects. Variations in solar capacity across regions emphasize the need for customized strategies that take into account specific geographic and infrastructure factors. This finding both validates the dynamic rise of renewable energy in India and provides a path for future initiatives, so reaffirming the study's basic premise. It emphasizes the need for ongoing innovation, policy improvement, and investment to maintain momentum and meet India's challenging targets for renewable energy.

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